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ANALYSIS OF EFFICIENCY OF FREIGHT TRANSPORT ON INLAND WATERWAYS

Anita Abođi
Danijela Pjevčević, Ph.D.
Vladislav Maraš, Ph.D.
Aleksandar Radonjić, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering, Department for Waterborne Transport
Vojvode Stepe 305, 11000 Belgrade, Serbia
a.abodji@sf.bg.ac.rs; danijela@sf.bg.ac.rs; v.maras@sf.bg.ac.rs; a.radonjic@sf.bg.ac.rs

ABSTRACT

A large number of different types of cargo is transported on the Danube River. In accordance with that, this paper analyses the transport of artificial fertilizers between Port of Prahovo and Port of Novi Sad. We developed a simulation model with an aim to follow and evaluate key performance indicators on the analyzed route.
Usual practice implies the transport of artificial fertilizer with a pushed convoy consisting of a pusher and a tow of six barges. The barges are loaded in the port of Prahovo, after which the loaded convoy of barges sails upstream to the port of Novi Sad. In the unloading port, barge convoy is disconnected from the pusher. The pusher is then connected with the new tow of barges to form pushed convoy, which continues to sail downstream to the port of loading.
An analysis of a number of scenarios was performed by changing the input parameters (number of barges in the tow, number of pushed convoys, number of pushers, upstream and downstream speed of pushed convoy). The following key performance indicators were evaluated: the amount of cargo transported, the number of round trips and the average pusher and barge waiting times. In addition, the total annual travel costs were calculated for each of the scenarios. Data Envelopment Analysis (DEA) method was used to analyze the efficiency of scenarios that met the condition of transporting the required amount of artificial fertilizer in a defined period

Keywords: artificial fertilizers transportation, barge transport, key performance indicators, simulation, DEA

1. INTRODUCTION

In all transport systems, management responsible for operation of the vessels faces a complex decision-making environment in which a large number of problems need to be solved. Barge formations a complex task that has a huge impact on transportation costs. According to that, this paper presents the possibilities of using simulation modeling to determine the most favorable scenario of transporting artificial fertilizers on inland waterways, in accordance with the given initial conditions. Data envelopment analysis (DEA) was used for the selection of scenarios that are efficient from the aspect of the required number of round trips, the average pusher waiting time, the average sailing time, and total annual travel costs. Several papers showed that operation research techniques can be successfully used to optimize and enhance efficiencies of bulk transport operations. Pablo Cortés et. al. (2007) focused on the simulation of the freight transport process which begins with the movement through the whole estuary of the river and finishes with the vessels arriving to the port dependencies, where the logistic operations of loading and unloading processes take place. Theirs and Janssens (1998) analyze in detail the modeling of maritime traffic on the river, including navigation logic, tides and lock planning based on current actual measurements and traffic forecasts.

Almaz and Altiok (2012) presented simulation modeling of vessel traffic in Delaware River and Bay with an objective of investigating the impact of deepening the fairway.

When it comes to costs, many authors deal with their minimization, so in line with this, De Puy et al. (2002) developed two mathematical models that support the minimization of barge transport costs.

Pjevcevic et al. (2017) applied the DEA method in order to improve the container transshipment strategy at the automated port container terminal. The application of simulation modeling and the DEA method has shown how the sizing of the Automated Guided Vehicles (AGV) fleet can be useful when planning operations at the port terminal.

Pjevcevic, et al. (2018) presented a decision-making process of selecting the most efficient technology for dry bulk cargo handling at an inland port (DEA models were used to identify the most efficient variant).

Milović et al. (2018) discussed a similar problem of the transport process, where they analyzed the organization of transport of building material from Veliko Gradište on the Danube river, to Žabalj on Tisa river. Simulation modeling was done in the Simio software. The indicators of the operation of transport and handling devices have been defined and monitored through the development of scenarios of a different number of pushers and tows (composition of barges).

The rest of the paper is organized as follows. The simulation model and the selection of possible variants of artificial fertilizer transport will be presented in the Chapter 2. Possible variants depend on the changes of upstream and downstream speeds, and the variance of barge formation in the barge convoy. DEA Method is elaborated in the Chapter 3. The input values for the assessment of the efficiency analysis are the number of round trips and the average pusher waiting time, while the output values are the total annual transport costs and sailing time. The followings section concludes the paper.

2. SIMULATION MODEL OF TRANSPORT OF ARTIFICIAL FERTILIZERS

2.1. Input data and assumptions

In this paper, a simulation model was developed by using Simio software as an objectively oriented approach [10]. The simulation model considers the transport of 400,000 tons of artificial fertilizers from the port of loading (Prahovo) to the port of unloading (Novi Sad).

Assumptions of the simulation model are:

- service frequency from the port of Prahovo – 5 days;
- contractual transporting period – 250 days;
- distance between Prahovo and Novi Sad – 393 km;
- loading rate in the port of Prahovo – 200 t/h;
- unloading rate in the port of Novi Sad – 180 t/h;
- carrying capacity – 1352 tons;
- loading time is described by a normal distribution:

$$N\ (\mu = 6.5\ h;\ \sigma = 1\ h); \qquad (1)$$

- Unloading time is described by a normal distribution:

$$N\ (\mu = 7.5\ h;\ \sigma = 1\ h); \qquad (2)$$

- Upstream sailing time is described by normal distribution as a function of distance and speed of navigation, including technical operations:

$$N\left(\mu = \left(\frac{l}{ut_{\uparrow}} + 0.1 \cdot \frac{l}{ut_{\uparrow}}\right) h;\ \sigma = 1\ h\right) \qquad (3)$$

$ut_{\uparrow}$ – upstream speed of pushed convoy;

- Downstream sailing time is described by normal distribution as a function of distance and speed of navigation, including technical operations:

$$N\left(\mu = \left(\frac{l}{ut_{\downarrow}} + 0.1 \cdot \frac{l}{ut_{\downarrow}}\right) h;\ \sigma = 1\ h\right) \qquad (4)$$

$ut_{\downarrow}$– downstream speed of pushed convoy.

Figure 1 represents the schematic flow of empty and full push convoys from the port of Prahovo to the port of Novi Sad. 1

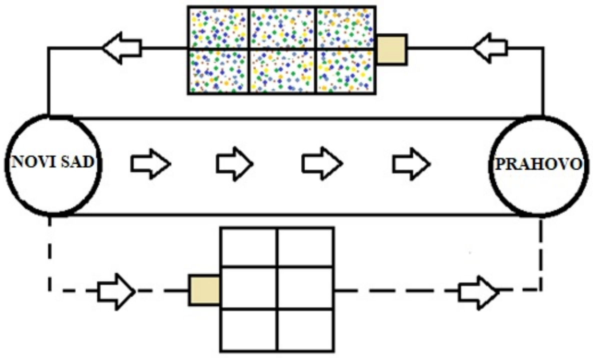


Figure 1: Schematic representation of the flows of empty and full push convoys

Several possible scenarios of artificial fertilizers transportation were defined, depending on the ranges of variable values i.e. pushed convoy upstream and downstream speeds and the barge tow formation:

- number of pushed convoys (1 or 2);
- number of pushers (1 or 2);
- number of barges in the tow (from 4 to 6);
- pushed convoy upstream speed (4.5 km/h, 5.5 km/h, 6.5 km/h);
- pushed convoy downstream speed (12.5 km/h, 14.5 km/h, 16.5 km/h).

Table 1 shows the values of variables used in the simulation model scenarios.

Table 1: Variable values in the simulation model

Scenario	Number of Pushed convoys	Number of pushers	Number of barges in the tow	Pushed convoy upstream speed [km/h]	Pushed convoy downstream speed [km/h]
1	2	1	6	5.5	14.5
2	2	1	6	5.5	16.5
3	2	1	6	6.5	12.5
4	2	1	6	6.5	14.5
5	2	1	6	6.5	16.5
6	2	2	5	4.5	12.5
7	2	2	5	4.5	14.5
8	2	2	5	4.5	16.5
9	2	2	5	5.5	12.5
10	2	2	5	5.5	14.5
11	2	2	5	5.5	16.5
12	2	2	5	6.5	12.5
13	2	2	5	6.5	14.5
14	2	2	5	6.5	16.5
15	2	2	4	4.5	16.5
16	2	2	4	5.5	12.5

Scenario	Number of Pushed convoys	Number of pushers	Number of barges in the tow	Pushed convoy upstream speed [km/h]	Pushed convoy downstream speed [km/h]
17	2	2	4	5.5	14.5
18	2	2	4	5.5	16.5
19	2	2	4	6.5	12.5
20	2	2	4	6.5	14.5
21	2	2	4	6.5	16.5
22	2	2	4	4.5	15.5
23	2	1	5	6.7	17.0
24	2	1	6	5.5	13.5
25	2	2	4	4.5	15.5
26	2	1	5	7.5	16.5

The following indicators were monitored for each of the considered scenarios:

- cargo transported – the amount of cargo that is transported from the port of Prahovo to the port of Novi Sad during the contractual transporting period;
- number of round trips of a pusher– one round trip is defined as the time between the departure of the pusher from the port of loading, until the next departure of the same pusher from the same port;
- average pusher waiting time - represents the average time that the pusher spends waiting for a full or empty barge tow;
- average barges waiting time - represents the average time the barge spends waiting in the port.

The simulation was performed on 45 different scenarios, with 50 replications. Each of the scenarios involved a combination of the different values of pushers, barge tows, barges in a tow and pushed convoy upstream and downstream speeds within defined limits. Out of a total of 45 defined scenarios, 19 scenarios did not meet the requirement of transporting 400,000 tons in 250 days and they were not further considered. In addition, transport of close to 400,000 tons of artificial fertilizers was achieved in five scenarios. Therefore, for these scenarios, it was decided to change the value of the upstream and downstream speed of pushed convoy in order to meet the initial condition. Changing the speed means going beyond the defined limits. The following deviations were adopted in the scenarios for the pushed convoy upstream speed: 6.7 km/h (scenario 23) and 7.5 km/h (scenario 26), and for the pushed convoy downstream speed: 17 km/h (scenario 23).

2.2. Obtained results

Table 2 presents the performance indicators obtained by the simulation, as well as the values of sailing time and total costs for each of the scenarios. The values of total annual costs for all considered scenarios were calculated as the sum of capital costs, maintenance costs, operational costs and fuel costs (Abođi, 2021).

Table 2: Overview of indicators obtained by the simulation and calculated indicators (average sailing time and total annual costs)

Scenario	Number of round trips	Average pusher waiting time [h]	Average barges waiting time [h]	Average sailing time [t_{pl}]	Total annual costs [€]
1	50	0.00	92.14	98.56	2704011
2	50	0.00	88.60	95.27	2635023
3	50	0.00	84.96	91.90	2564230
4	50	0.00	80.29	87.56	2473166
5	50	0.00	76.75	84.28	2404178
6	60	31.42	0.43	118.77	4034633
7	60	31.43	0.43	114.44	3925356
8	60	31.42	0.43	111.15	3842571
9	60	31.42	0.43	102.89	3634503
10	60	31.43	0.43	98.56	3525226
11	60	31.42	0.43	95.27	3442441
12	60	31.42	0.43	91.90	3357490
13	60	31.43	0.43	87.56	3248213
14	60	31.42	0.43	84.28	3165428
15	75	25.3	0.26	111.15	4510357
16	75	25.28	0.26	102.89	4250273
17	75	25.28	0.26	98.56	4113677
18	75	25.30	0.26	95.27	4010195
19	75	25.28	0.26	91.90	3904007
20	75	25.28	0.26	87.56	3767411
21	75	25.30	0.26	84.28	3663929
22	75	25.28	0.26	112.69	4558760
23	60	0.00	77.30	81.77	2662566
24	50	0.00	94.30	100.57	2746170
25	75	25.28	0.26	112.69	4558760
26	60	0.00	71.29	76.22	2522556

As can be seen from Table 2, a large number of scenarios met the set criterion of transporting 400,000 tons of cargo over 250 days. It can also be seen that the values of the indicators vary a lot. The number of round trips ranges from 50 to 75. The average waiting time of the pusher has a value from 0 to 31.42 h; while the average waiting time of the barges varies from 0.26 to 94.30 h.

The total sailing time is the sum of the pushed convoy upstream and downstream navigation time and ranges from 76.22 to 118.77 h. Scenario 5 has the lowest total annual costs of 2,404,178 euros, while scenarios 25 and 22 are responsible for 4,558,760 euros.

It can be concluded that the minimum average sailing time is 76.22 h calculated by scenario number 26. The presented analysis of total annual costs and average sailing time points out to different scenarios and does not give a clear picture of which scenario is to select as the most favorable. For that reason, the DEA method was applied to examine which scenario is efficient from the aspect of inputs and outputs obtained from simulation exercises.

3. DATA ENVELOPMENT ANALYSIS

3.1. Selection of inputs and outputs

The aim of this chapter is to present a methodology for finding an efficient solution of the given problem based on the number of round trips of the pusher, average pusher waiting time, total annual costs, and average pushed convoy (upstream and downstream) sailing time.

DEA model is applied as a non-parametric technique where several criteria are taken into account and the relative efficiency index of the observed decision-making units (DMU) is created [4]. In our paper, each Decision Making Units represents one of the scenarios

This DEA model considers two inputs and two outputs. The number of pusher round trips and the average pusher waiting time are adopted as inputs, while the values of average sailing time and total annual costs for each transport scenario are given as the outputs. Each elaborated DMU can be assessed as:

- relatively efficient (assigned with an efficiency index value equal to 1 (100%)) or
- relatively inefficient (assigned with an efficiency index value less than 1 (<100%)) [4].

The Table 3 shows the inputs and outputs that were used in the DEA software [3].

Table 3: Input and output values of the DEA model

	INPUT		OUTPUT	
DMU / Scenarios	Number of round trips	Average pusher waiting time [h]	Average sailing time [h]	Total annual costs [milion €]
1	50	0.00	0.0101	0.3698
2	50	0.00	0.0105	0.3795
3	50	0.00	0.0109	0.3900
4	50	0.00	0.0114	0.4043
5	50	0.00	0.0119	0.4159
6	60	31.42	0.0084	0.2479
7	60	31.43	0.0087	0.2548
8	60	31.42	0.0090	0.2602
9	60	31.42	0.0097	0.2751
10	60	31.43	0.0101	0.2837
11	60	31.42	0.0105	0.2905
12	60	31.42	0.0109	0.2978
13	60	31.43	0.0114	0.3079
14	60	31.42	0.0119	0.3159
15	75	25.30	0.0090	0.2217
16	75	25.28	0.0097	0.2353
17	75	25.28	0.0101	0.2431
18	75	25.3	0.0105	0.2494
19	75	25.28	0.0109	0.2561
20	75	25.28	0.0114	0.2654
21	75	25.30	0.0119	0.2729
22	75	25.28	0.0089	0.2194
23	60	0.00	0.0122	0.3756
24	50	0.00	0.0099	0.3641
25	75	25.28	0.0089	0.2194
26	60	0.00	0.0131	0.3964

The choice of inputs and outputs is a very important step in the development of the DEA model. After a correlation analysis was performed, the following inputs and outputs were selected: number of round trips and average pusher waiting time as inputs, and average sailing time and total annual costs as outputs. We used an output-oriented DEA model to analyze the efficiency of each scenario. As the costs and pushed convoy sailing time need to be minimized, from the shipowner perspective, reciprocal values of the outputs are taken into account in the DEA model.

3.2. Analysis of the obtained results

After the application of DEA software for analysis of efficiency of 26 different DMUs (Table 3), the final results are obtained and shown in Figure 2. From the Figure 2, it can be concluded that efficiency of only scenario 5 is equal to 1. In this scenario, transport of 400,000 t of artificial fertilizers can be achieved with:

- one pusher;
- two barge tows of six barges;
- pushed convoy downstream speed of 16.5 km/h;
- pushed convoy upstream speed of 6.5 km/h.

For this scenario, the following outcomes could be expected:

- 50 round trips;
- average barge tow waiting time of 76.75 h;
- no pusher waiting;
- pushed convoy upstream sailing time of 60.46 h;
- pushed convoy downstream sailing time of 23.82 h;
- total cost equals to 2,404,178 euros.

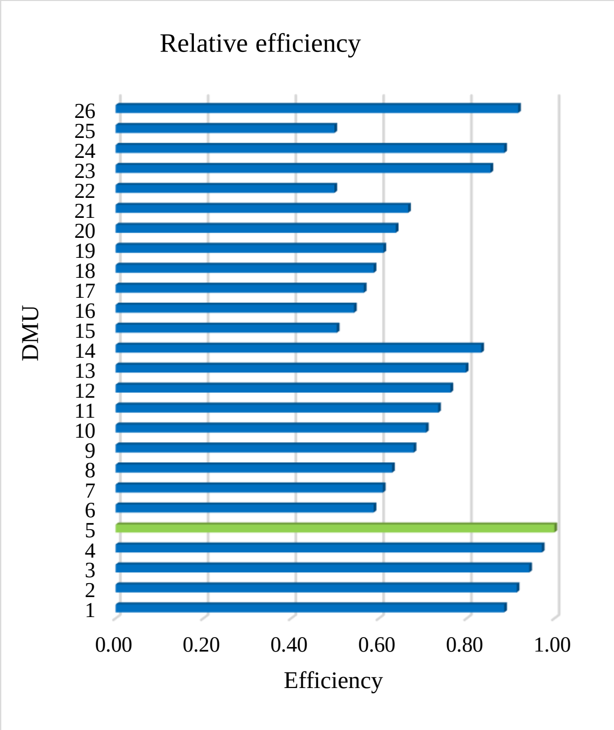


Figure 2: Relative efficiency of the DMUs

4. CONCLUSION

The transport of artificial fertilizers from the port of Prahovo to the port of Novi Sad was elaborated in this paper. We performed an analysis of 45 different in order to find an efficient solution for transporting a given amount of cargo in a contractual transporting period by using DEA methodology.

Out of 45 different scenarios that differed in the number of barge tows, the number of pushers, number of barges in the tow, as well as the pushed convoy speeds of upstream and downstream navigation, only 26 fulfilled the request to transport a given amount of artificial fertilizer on the route Prahovo - Novi Sad in the contractual transporting period. All these scenarios were further analyzed using the DEA method. The efficiency of only one, i.e. scenario 5 is equal to 1.

The application of the DEA method can significantly contribute to the selection of an effective solution and help in the implementation of a particular project, as well as answer questions that cannot be easily reached. In this paper, we proved that DEA methodology can be considered as a very useful tool for solving practical problems in the area of inland waterway transportation.

Further researches can be performed in various ways. Elimination of empty trips certainly represents one of them and a goal that could be particularly welcomed by barge shipowners. Further, development of models that would encompass multiple tasks of cargo transportation, various types of cargoes, as well as different organizational approaches in pusher utilizations could significantly contribute to making this approach more realistic.

REFERENCES

[1] Abođi, A., (2021). Transport of Artificial Fertilizers on Inland Waterways: Efficiency Analysis (in Serbian), Master theses, University of Belgrade, Faculty of Transport and Traffic Engineering

[2] Almaz, O. A., & Altiok, T., (2012). Simulation modeling of the vessel traffic in Delaware River: Impact of deepening on port performance. Simulation modelling practice and Theory, 22, 146-165.

[3] https://onlineoutput,com/tag/dea-solver-software-free-download/

[4] Martinovic, N., (2019). Optimal scheduling of consultants on several projects based on efficiency assessment, doctoral dissertation, (in Serbian) Faculty of Organizational Sciences, University of Belgrade.

[5] Milović, K., Pjevčević, D., Maraš, V., Radonjić, A., (2018) Simulation model of transport of building materials on inland waterways, YU INFO 2018 & ICIST, pp 142-146, ISBN 978-86-85525-21-6, Kopaonik, http://yuinfo.org/.

[6] Pablo Cortés, Jesús Muñuzuri, J. Nicolás Ibáñez, José Guadix, Simulation of freight traffic in the Seville inland port, Simulation Modelling Practice and Theory, Volume 15, Issue 3, 2007, Pages 256-271, ISSN 1569-190X, https://doi.org/10.1016/j.simpat.2006.11.004.

[7] Pjevčević, D., Dimitrijević, B., Biševac Vukićević, I., Vukadinović, K., (2018). Design process of dry bulk cargo handling at an inland port: Case study of Port "Danube" Pancevo. International Journal of Industrial Engineering – Theory, Applications, and Practice, 25 (2), 267-282.

[8] Pjevcevic, D., Nikolic, M., Vidic, N., & Vukadinovic, K. (2017). Data envelopment analysis of AGV fleet sizing at a port container terminal. International Journal of Production Research, 55(14), 4021-4034.

[9] Simio Simulation and Scheduling Software, https://www.simio.com

[10] Thiers, G. F., & Janssens, G. K. (1998). A Port Simulation Model as a Permanent Decision Instrument. SIMULATION, 71(2), 117–125. https://doi.org/10.1177/003754979807100206

SHIPPING AND COVID-19: THE IMPACT WORLDWIDE AND IN GREECE

Aggelos Aggelakakis, M.Sc.
Centre for Research and Technology Hellas/Hellenic Institute of Transport
6 th Charilaou-Thermis, Thessaloniki, Greece
agaggelak@certh.gr

Afroditi Anagnostopoulou, Ph.D.
Centre for Research and Technology Hellas/Hellenic Institute of Transport
Kasimati 1, Piraeus, Greece
a.anagnostopoulou@certh.gr

ABSTRACT

Coronavirus pandemic (COVID-19) adversely impacted the entire shipping industry causing serious operational difficulties and ceasing all normal daily activities. The worst circumstances appeared in these sectors as workforce was shut down for safety reasons in order to avoid the escalation of virus disease. In addition, quarantine periods in different countries caused cargos that transported via sea to remain to the ports in order to avoid possible transferring the virus with them.

This paper aims to present the major challenges and issues in cargo shipping (i.e. a cargo ship that carries cargo, goods, and materials from one port to another) and container shipping (i.e. a cargo ship that carries all of its load in truck-size intermodal containers) during these challenging times analyzing operational restrictions, needs and studying measures that should be adopted to face the new reality. It focuses on the results derived from collected data, publicly available statistics and systematic surveys on ports worldwide, highlighting the traffic variations and impact of crisis during the pandemic period using also data from global supply chain where major delays and disrupted freight flows emerged. Decrease in container vessel calls, significant delays in hinterland operations and collisions in empty container handling are some of the analyzed topics in this paper. A thorough assessment conducted, focusing firstly on variations regarding cargo and container shipping industry as well as the impact of COVID-19 in Greece. Finally, critical areas that should be considered to enhance the business continuity of cargo and container shipping are also presented.

Keywords: Covid-19, container shipping industry, cargo shipping industry, quantity analysis, quality analysis

1. INTRODUCTION

COVID-19 pandemic has had an unexpected and extremely significant impact on normality and daily activities around the world. The health crisis caused by the pandemic escalated to unprecedented levels, with a serious impact on national health systems, people and the global economy. Governments around the world, in order to protect citizens and businesses from the negative effects of the pandemic, have temporarily suspended their economic activity and implemented protection measures against the spread of coronavirus. One of the sectors that was significantly impacted by the pandemic, is the global maritime transport system, with all the shipping activities from passenger ships and container vessels to oil tankers having been affected.

A brief overview of the difficulties of the shipping sector is given by the annual report of the Union of Greek Ship-owners. This report is important because Greek Ship-owners own 20.67% of global tonnage and 54.28% of the EU-controlled tonnage. According to the report, many shipping sectors have been faced with a sudden and steep drop in demand, which in turn has considerably affected freight rates and earnings. For example, in the dry bulk segment, average daily earnings for the period between January and April 2020, were lower by, more than 85% for capesizes, 40% for Panamaxes and 35% for Supramaxes, compared to 2019. At the same time, the operation of companies related to shipping, such as ports, terminals, cargo handlers etc. were affected, putting them under great financial pressure (Union of Greek Ship-owners, 2020).

In addition, the restriction of international trade after the outbreak of the pandemic, significantly affected the ship traffic and therefore the revenue of the shipping industry. According to the European Maritime Safety Agency (EMSA, 2020), during the first 38 weeks of 2019 (until 20th September 2019), there were 658,068 ship calls at EU ports, and in the same period in 2020 there were 562,852 ship calls. The number of calls decreased by 14.5% in comparison with 2019. According to EMSA again, ship traffic from Europe to China (and conversely) reduced in comparison to the same period in 2019 (first 38 weeks). In particular, the analysis of the maritime traffic from China to Europe shows that there is a reduction of 32%, while from Europe to China there is a more significant decrease of 51.1% (European Maritime Safety Agency, 2020). At the same time, more tonnage of container ships was idle around the world than during the global financial crisis, according to Alphaliner (Yeshin, 2020).

Important data also emerge from the report of the United Nations Economic and Social Committee on Asia and the Pacific in relation to the short-term effects on the entire Shipping sector due to COVID-19, which are (Economic and Social Commission for Asia and the Pacific, 2020):

- Decreased maritime trade
- Vulnerability in ports with low trade volume due to fleet adjustment including blank sailing
- Delayed customs and port clearance
- Increased ship waiting time and delaying crew shift
- Relatively high freight rates that could further increase if capacity continues to be constrained and demand/ supply mismatch occurs.
- Slower port development
- Slowdown of port development
- Acceleration of the digital supply chain through automated systems and creation of "smart" ports
- More focus on increasing resilience and robustness of operations to wide-ranging risks, including from pandemics

Overall, the new priorities and operational constraints are analyzed and corresponding measures adopted to deal with the emerging needs at a global level are also presented. Based on collected data, publicly available statistics and available systematic surveys on ports worldwide, this paper aims to assess the impact of the pandemic in the cargo and container shipping. The Greek case is also presented analyzing the effect of COVID-19 in cargo and container shipping during the breakout period (i.e. March – December 2020) and the period after the breakout (i.e. 2021). The remainder of the paper is organized as follows: Section 2 discusses the new challenges and needs setting the basis for servicing cargo and container shipping worldwide. The proper measures and actions followed to measure the pandemic consequences are presented in Section 3. Finally, in Section 4 conclusions are drawn and future actions derived by the COVID-19 in the shipping industry are also described.

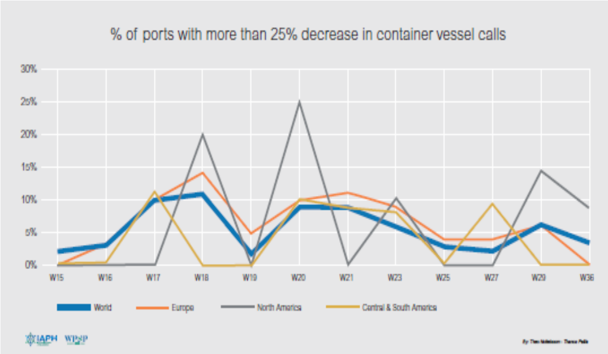
2. NEW CHALLENGES, CONSTRAINTS AND NEEDS IN THE MARITIME TRADE

COVID-19 pandemic has changed the priorities of the port environment. In particular, due to the circumstances, ports give priorities to the “essential port activities” to preserve freight transport and logistics chain and to ensure the delivery of goods (medical cargo, foodstuff, etc.) that were necessary to face the pandemic. The international supply chain as a whole, part of which is the maritime trade, is facing new challenges, with problems and restrictions, due to the pandemic, that create delays and cancellations in itineraries and orders. The above in combination with the reduced demand for specific goods such as transport equipment and fuels, which fell by 50% in April 2020, leads to difficult financial circumstances for all maritime actors involved (Pallis & Sirimanne, 2020).

According to the United Nations, global shipping trade decreased by 5% in the first quarter of 2020 while in the second, during which the effects of the pandemic were more severe, it decreased by 27% compared to the corresponding periods of 2019 (UNCTAD, 2020a). It is worth noting that shipping continued to play a key role in the global supply chain, transporting all goods and this was crucial in the situations where land logistics were not functioning properly due to land border closures and containment and quarantine procedures (Economic and Social Commission for Asia and the Pacific, 2020).

Although global coronavirus cases have peaked more than once in 2020, the effects on shipping were more pronounced between April and June 2020 and vary between regions. This may be due to the lack of readiness of the international shipping industry to react to the outbreak of the crisis in the first phase of its peak (Pallis & Sirimanne, 2020). As far as developing countries are concerned, declines in exports were likely driven by reduced demand in destination markets, declines in imports may indicate not only reduced demand but also exchange rate movements (UNCTAD, 2020b).

Ship arrivals in ports are directly affected by market demand for foodstuff, medical supplies, raw materials, fuels, consumer goods etc., and by measures taken by each country to which a ship arrives or departs. As a result, from the start of the pandemic in November 2019 to February 2021 worldwide, about half of the ports appear to see a decrease in container vessels arrivals in the period between mid-April and October 2020, compared to the corresponding period before the coronavirus (Notteboom & Pallis, 2021). At the same time, it appears that in the ports of North America this decrease was more pronounced and appeared a little later (in late May 2020 and later) compared to the decrease in arrivals in Europe as shown in Figure 1. In particular, 1 in 4 ports in North America in mid-May 2020 presented a significant drop (more than 25%) in container vessels calls (Notteboom and Pallis, 2020).



Source: Notteboom and Pallis, 2020

Figure 1: Percentage of ports with more than 25% decrease in container vessel calls

On the contrary, the reduced arrivals of conventional cargo ships had a big decrease (rate approaching-40%) at the ports of the Least Developed Countries worldwide.

In the case of bulk carriers, the negative effect of the COVID-19 crisis has been severe in Latin America (-21.6%) as well as Australia and Oceania (-18.6%) as these regions are major exporters of dry bulk cargoes (coal and iron ore). In addition, the impact was significant and in Europe (-11.4 per cent) (Pallis & Sirimanne, 2020).

Data released by shipping companies and port authorities on container handling levels and revenue for 2020, demonstrate the magnitude of the new challenges facing the pandemic. Indicatively, the port of Long Beach, San Pedro Bay and Westports Holdings Berhad (Westports) seem to be representative examples, as they are subject to TEUs (Twenty Foot Equivalent Units) reductions of around 5-11%, from year to year for the first quarter of 2020 (PortTechnology, 2020a). These reductions also have a significant impact on the revenues of shipping companies, as was the case with COSCO Shipping Ports (CSP), which reported a 34.9% reduction in its annual gross profit (PortTechnology 2020c).

Furthermore, the crisis had continued to drive down demand for goods and increase blank sailings. Canceled sailings continued to rise at a rapid rate in the second quarter of 2020 as ocean carriers adjusted their voyages to a decline in demand for imports during the national COVID-19 outbreak (PortTechnology, 2020b).

In August 2020, after the attempt to return to normality and the partial opening of economies, maritime trade between Asia and Europe seems to be heading to a typical peak period. However, a different imbalance resulting from container shortages in Asian ports (e.g. Shanghai, Singapore and Kelang Port) appears to be a natural consequence of the difficulties faced by importers in the United States and Europe to return empty containers on China. These shortages in the supply chain cause significant problems in the availability of containers to serve shipping lines (Knowler, 2020).

3. MEASURES AND ACTIONS TO BALANCE THE EFFECT OF THE PANDEMIC

During the pandemic, authorities from all over the world prioritized the successful observance of the health and safety protocols for all the involved bodies in the port area as well as the smooth management of the freight handling including cargo loading / unloading procedures, cargo storage etc. Therefore, precautionary measures were imposed and the necessary adjustments were implemented in order to mitigate the effects of the pandemic and maintain satisfactory operational port services (Pallis & Sirimanne, 2020).

In order to give priority to necessities (food, medicine, etc.), "priority lanes" were defined for respective ships ensuring immediate transport and unloading processes. Similarly, "priority lanes" were also used for trucks receiving the goods at the departure port and for any other relevant procedure making this new measure very efficient.

Measures taken to prevent the spread of the coronavirus also included frequent inspections and disinfections of ships and their respective port workplaces. Another commonly implemented measure was the suspension of in-port services as well as the services of relevant stakeholders. This was mostly adopted as a precautionary measure by several ports worldwide and did not caused extra delays since the cargo to be managed was reduced for this period (April to November 2020).

A 14-day forced quarantine for ships arriving was another measure used in ports at a worldwide level. In some cases, this quarantine period combined with the necessary submission of appropriate medical certificates by the crew caused increased truck congestion and severe delays in managing the cargo. More specifically, when the distance traveled by the ship from the origin to its destination was less than 14 days and the origin country was of high epidemiological burden, the quarantine period exceeded the trip duration (Economic and Social Commission for Asia and the Pacific, 2020).

In supply chains, significant delays were noticed due to the different measures among countries, the prevention of entering countries of high epidemiological burden as well as the quarantine periods of drivers moving from one country to another (Doumbia-Henry, 2020). This improved significantly from mid-May 2020 when the vast majority of ports (92%) managed to return their operations to pre-pandemic conditions.

Shift work, teleworking and keeping social distance by avoiding face-to-face encounters and wearing protective masks were the most common measures implemented for the staff working in port areas. Regarding the greatest staff shortages, the ports of Central and South America were on the top of the list. In addition, the lack of dock workers and truck drivers were noticed in 20-25% of the ports from May to July 2020 based on the research of Notteboom & Pallis (2020). Finally, the severe problems and the inefficiencies of the itineraries, the arrivals and the deliveries/receipts resulted in idle times for workers in ports and ships.

Overall, the aforementioned measures and actions caused serious financial impacts on the revenues of the port authorities, shipping companies and port-related businesses even from the first days of the pandemic. Therefore, the implemented measures and actions attempted to address these impacts are presented as follows: 1. New types of goods attracted in ports to compensate the lost quantities and the corresponding profits due to COVID-19; 2. Studies for evaluating the COVID-19 effects and reductions of profits; 3. Fully privatized ports (such as ports in United Kingdom) used bank lending, without success in many cases due to the general economic instability; 4. Simplified payment processes used in other port authorities (such as

Valencia) for their suppliers in order to provide the necessary liquidity to them (Pallis & Sirimanne, 2020).

4. THE CASE OF GREECE

The effects of the COVID-19 pandemic were also evident in Greece, where shipping is a very important sector of the economy, and the country's GDP has fallen to 168.5 billion euros in 2020 from the 183.6 billion euros in 2019 (Alexopoulou, 2021). Immediate measures to mitigate the spread of virus have severely affected the number of ships approached the country's ports having 17.7% decrease in 2020 (Tsamopoulos, 2021). More specifically, piers II and III of the Piraeus port reported the highest decrease (i.e. 15.4% in March 2020) in terms of container handling. It is worth to mention that the total decrease for the port of Piraeus was only 2.6% from January to April in 2020 due to the significant increase (during the first two months) before the outbreak of the pandemic in Greece (Fotinos, 2020). Respectively, a decrease of 11% in the handling of containers and of 2.5% in the handling of conventional cargo appeared for the port of Thessaloniki during the month of March (ThPA S.A., 2020).

Overall, the results about freight transport for the year 2020 were really encouraging as they overturned the forecasts that showed significant reductions in the revenues of the two major ports of the country (Piraeus port and Thessaloniki port). In particular, the port of Piraeus (PPA S.A.) recorded an increase of 1.1% in the revenues for the year 2020 from the concession of the container station - COSCO (PPA S.A., 2021). The Piraeus Container Terminal (PCT S.A.) managed to achieve a smooth continuation after the breakout during 2020 and maintained the first place in the Mediterranean region with a decrease of only 5.5% TEUs. Similarly, the port of Thessaloniki (ThPA S.A.) managed to achieve an 11.3% increase of revenues in 2020 compared to 2019 (ThPA S.A., 2020), which is mainly due to the increased traffic of the container terminal. According to the Management of the ThPA S.A., this achieved due to (i) the higher quality of services in managing the containers, (ii) the improved customer service and (iii) the new pricing policy (ThPA S.A., 2020).

In 2021, the course of container traffic in the port of Piraeus was declining and the container handling reached 305,400 TEUs on December 2021 which was a reduction of 25.4% compared to December 2020 (COSCO SHIPPING Ports Limited, 2022). However, this decline in traffic is attributed to the general disorder in the supply chain due to COVID-19 as well as to the strikes in the port of Piraeus that forced ships to bypassed it and use other ports in the Mediterranean area. At European level, the Piraeus Container Terminal felt to 5th place from 4th handled 5.3 million TEUs as the Spanish port of Valencia handled 5.6 million TEUs (Global Trade, 2022). On the other hand, the pier I of PPA S.A. recorded an increase of 16.6% in total traffic (from 399,285 TEUs to 465,584 TEUs) in the first 9 months of 2021 (Metaforespress.gr, 2022). This resulted in significant increase in turnover, marking the highest profitability ever achieved. The reason of this achievement is the continuous investments for the modernization and upgrading and the coordinated business operation. In particular, the turnover amounted to € 154.2 million, profit before taxes amounted to € 49.2 million and profit after taxes to € 36.8 million (Pireas Piraeus, 2022).

Regarding the port of Thessaloniki, container handling at the container station increased by a total of 2.2%, from 461 thousand TEUs in 2020 to 471 thousand TEUs in 2021. During the same period, the volume of conventional cargo handling increased significantly, namely by 13.3%, from 3,714 thousand tons to 4,236 thousand tons respectively, mainly due to an increase in the volume of nickel and carbon. Ship approaches increased overall by 7.1%, from 1,286 in 2020 to 1,377 in 2021, including container, conventional cargo and passenger ships (Port Technology, 2022). In addition, a total revenue increase of 8.5% was recorded, from € 52.7 million in the nine months of 2020 to € 57.1 million in the same period of 2021 (Naftemporiki, 2022). Overall, the pandemic had a limited impact on the port's revenue, about 3%, and the turnover (increased by 7.2%) amounted to € 76.9 million and net profit after taxes (increased by 5%) amounted to € 21.1 million (Athens News Agency - Macedonian Press Agency, 2022).

5. CONCLUSIONS

The COVID-19 pandemic caused many problems in the shipping market overturning forecasts, expected revenues and TEU volumes at a global level. Overall, the main challenges could be summarized as follows: i) isolation of port terminals and ports during quarantine periods imposed at a national level; ii) reductions in the freight movements among countries to mitigate the virus spread; (iii) disputes between landlords and charterers about the period of time charged; and (iv) bankruptcies of small shipping companies. Both ports and shipping companies focused more on practices to reduce the immediate negative effects following the special circumstances arisen since the evolution of the new conditions could not be predicted. In addition, the maritime transport of food, energy and medical supplies at a worldwide level constitutes a key precondition for tackling the pandemic and thus, appropriate response plans and effective measures and policies should have been developed.

At an operational level, the balance between the effective freight operations and the safety of the workforce is the key issue. It is important to ensure that all stakeholders (employees, suppliers, customers, etc.) are fully informed and follow common practices adapted to the new conditions and are in line with the current legislation and regulations. At a strategic level, state aid is expected to be intensified in Third World countries where the maintenance of sea routes is considered of strategic importance, while in the countries of the European Union liquidations of assets are expected to cover the direct obligations.

Finally, investments driven by digital transformation are imperative due to the particular conditions of the pandemic and the "social distance" applied. Hence, the evolution of online services, electronic platforms as well as smart devices and Internet of Things (IoT) is imperative to support the business activity and viability of shipping industry.

REFERENCES

[1] Doumbia-Henry, C. (2020). Shipping and COVID-19: protecting seafarers as frontline workers. WMU Journal Of Maritime Affairs, 19(3), 279-293. https://doi.org/10.1007/s13437-020-00217-9

[2] Economic and Social Commission for Asia and the Pacific. (2020). Covid-19 and its impact on shipping and port sector in Asia and the Pacific. Transport and trade connectivity in the age of pandemics. UN solutions for contactless, seamless and collaborative transport and trade. Technical Note, September. Retrieved from: https://www.unescap.org/sites/default/d8files/knowledge-products/ShippingPoliyBrief-16Oct2020-FINAL.pdf

[3] European Maritime Safety Agency. (2020). COVID-19-impact on shipping. Retrieved from: http://www.emsa.europa.eu/newsroom/covid19-impact/item/4038-september-2020-covid-19-impact-on-shipping-report.html

[4] Knowler, G. (2020). Demand surge intensifies container shortages in Asia. JOC Magazine. Retrieved from: https://www.joc.com/maritime-news/demand-surge-intensifies-container-shortages-asia_20200915.html

[5] Notteboom, T., & Pallis, T. (2020) International Association of Ports and Harbours (IAPH)- World Ports Sustainability Program (WPSP) Port Economic Impact Barometer Half Year Report: A Survey-Based Analysis Of The Impact Of COVID-19 on World Ports In The Period April To September 2020. Retrieved from: https://sustainableworldports.org/wp-content/uploads/2020-09-16-COVID19-Barometer-Report.pdf

[6] Notteboom, T., & Pallis, T. (2021). International Association of Ports and Harbours (IAPH)- World Ports Sustainability Program (WPSP) Port Economic Impact Barometer. Retrieved from: https://sustainableworldports.org/wp-content/uploads/2021-02-19-COVID19-Barometer-Report.pdf

[7] Pallis, A., & Sirimanne, S. (2020). COVID-19 and maritime transport: Impact and responses. UNCTAD. Retrieved from: https://unctad.org/system/files/official-document/dtltlbinf2020d1_en.pdf

[8] PortTechnology. (2020a). CMPort suffers first quarter crash as COVID-19 and tariffs take toll. Retrieved from: https://www.porttechnology.org/news/cmport-suffers-first-quarter-crash-as-covid-19-and-tariffs-take-toll/

[9] PortTechnology. (2020b). Major US port suffers as COVID-19 causes another TEU drop. Retrieved from: https://www.porttechnology.org/news/long-beach-continues-to-suffer-as-covid-19-causes-another-teu-drop/

[10] PortTechnology. (2020c). Westports predicts fall in TEU as COVID-19 bites. Retrieved from: https://www.porttechnology.org/news/westports-predicts-fall-in-teu-as-covid-19-bites/

[11] UNCTAD. (2020a). Global Trade Update-June 2020. Retrieved from: https://unctad.org/system/files/official-document/ditcmisc2020d2_en.pdf

[12] UNCTAD. (2020b). Global trade continues nosedive, UNCTAD forecasts 20% drop in 2020. Retrieved from: https://unctad.org/news/global-trade-continues-nosedive-unctad-forecasts-20-drop-2020

[13] Union of Greek Ship-owners (2020). Annual Report 2019-2020. Retrieved from: https://www.ugs.gr/media/13667/ugs_ar_gr-web.pdf

[14] Yeshin, M. (2020). COVID-19: The Impact on the Cargo Industry. Retrieved from: https://www.marsh.com/gr/en/insights/risk-in-context/covid-19-impact-on-cargo-industry.html#cargo1

[15] Alexopoulou, R. (2021). ELSTAT: 8.2% the recession in 2020 (in greek). Retrieved from: από: https://www.naftemporiki.gr/finance/story/1699525/elstat-sto-82-i-ufesi-to-2020

[16] Tsamopoulos, M. (2021). Research: The effects of the pandemic on Greek ports (in greek). Retrieved from: https://www.newmoney.gr/roh/palmos-oikonomias/nautilia/erevna-i-epiptosis-tis-pandimias-sta-ellinika-limania/

[17] Foteinos, F. (2020). The coronavirus affected the performance of Piraeus in the containers (in greek). Retrieved from: https://www.metaforespress.gr/naftilia/%CE%BC%CE%B5%CF%84%CF%81%CE%B9%CE%AC%CE%B6%CE%B5%CF%84%CE%B1%CE%B9-%CE%B7-%CF%80%CF%84%CF%8E%CF%83%CE%B7-%CF%84%CF%89%CE%BD-%CE%B5%CE%BC%CF%80%CE%BF%CF%81%CE%B5%CF%85%CE%BC%CE%B1%CF%84%CE%BF%CE%BA/

[18] ThPA S.A. (2020). The effect of COVID-19 on the traffic of the Port of Thessaloniki (in greek). Retrieved from: https://www.thpa.gr/index.php/el/2014-05-27-22-23-29/2323-et_210420_gr

[19] PPA S.A. (2021). Financial results 2020 of PPA SA. (in greek) Retrieved from: https://www.olp.gr/el/plirofories-ependyton/etairikes-anakoinoseis/item/6935-oikonomika-apotelesmata-2020-tis-olp-ae

[20] COSCO SHIPPING Ports Limited. (2022). Container Throughput 2021. Retrieved from: https://ports.coscoshipping.com/en/Businesses/MonthlyThroughput/pdf/2021.pdf

[21] Global Trade. (2022). Top 5 Ports in Europe 2021. Retrieved from: https://www.globaltrademag.com/top-5-ports-in-europe-2021/

[22] Metaforespress.gr. (2022). The performance of pier I of the PPA (in greek). Retrieved from: https://www.metaforespress.gr/naftilia/%CE%BC%CE%B5-%CF%80%CF%84%CF%8E%CF%83%CE%B7-41-%CE%AD%CE%BA%CE%BB%CE%B5%CE%B9%CF%83%CE%B5-%CE%B7-%CE%B4%CE%B9%CE%B1%CE%BA%CE%AF%CE%BD%CE%B7%CF%83%CE%B7-%CE%B5%CE%BC%CF%80%CE%BF%CF%81%CE%B5%CF%85/

[23] Pireas Piraeus. (2022) The annual update of PPA S.A. took place to the Institutional Investors Association (in greek). Retrieved from: https://www.pireaspiraeus.com/%CF%80%CF%81%CE%B1%CE%B3%CE%BC%CE%B1%CF%84%CE%BF%CF%80%CE%BF%CE%B9%CE%AE%CE%B8%CE%B7%CE%BA%CE%B5-%CE%B7-%CE%B5%CF%84%CE%AE%CF%83%CE%B9%CE%B1-%CE%B5%CE%BD%CE%B7%CE%BC%CE%AD%CF%81%CF%89%CF%83%CE%B7-2/

[24] Port Technology. (2022) Thessaloniki moves over 470,000 TEU in 2021. Retrieved from: https://www.porttechnology.org/news/thessaloniki-moves-over-470000-teu-in-2021/

[25] Naftemporiki. (2022). The port of Thessaloniki aims to retrieve its historic role (in greek). Retrieved from: https://www.naftemporiki.gr/finance/story/1844528/to-limani-thessalonikis-bazei-plori-gia-anaktisi-tou-istorikou-tou-rolou

[26] Athens News Agency - Macedonian Press Agency. (2022). The port of Thessaloniki: Investments up to 200 million euros (in greek). Retrieved from: https://www.metrosport.gr/limani-thessalonikis-ependyseis-eos-200-ekat-eyro-566208

TRANSPORT DEMAND MODEL ON THE EFFECTS OF ESTABLISHING VERTICAL FARMS IN URBAN AREAS

György Ágoston, Ph.D.
University of Dunaújváros, Institute of Informatics, Department of Software Development and Applications
Táncsics M. u. 1/A., H-2400 Dunaújváros, Hungary
agoston@uniduna.hu

Ferenc Pongrácz, Ph.D.
Tungsram Operations Kft.
Váci út 77. H-1044 Budapest, Hungary
Ferenc.Pongracz@tungsram.com

Bálint Csonka, Ph.D.
Budapest University of Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Department of Transport Technology and Economics
Műegyetem rkp. 3., H-1111 Budapest, Hungary
csonka.balint@kjk.bme.hu

ABSTRACT

Due to population growth and climate change, securing food supply became one of the critical challenges of our everyday lifes. Growing urban areas may be in a particularly vulnerable position. One possible solution is to use different indoor farming technologies, such as vertical farms. This paper analyzes the transport effects of setting up vertical farms. The aim of the paper is to determine the characteristics and impacts of vertical farm generated traffic between farms and consumers. Since the location and capacity of the vertical farm have significant impact on the transport of goods, in this paper a transport demand model will be elaborated to optimize the location and characteristics of vertical farms in urban areas. The model is demonstrated within a case study to present the efficiency of the optimization, and a sensitivity analysis is also been performed. The main result is a vertical farm model that supports reducing the transport related externalities and production costs in urban areas. The research was mostly conducted at Tungsram's R&D vertical farm in Budapest, Hungary.

Keywords: Smart city, transport externalities, location optimization, vertical farm, food supply

1. INTRODUCTION

The use of indoor farming has been booming worldwide in recent years. Producing large quantities of healthy food with a predictable schedule is an important goal worldwide. One possible solution is setting up vertical farms (VFs), where plants are grown under artificial conditions inside a building, or even underground, without sunlight and soil, in a special multi-level design. The research location was a 150m^2 hydroponic R&D farm inaguruated by Tungsram, in Budapest (Figure 1).

Source: Tungsram Operations Kft., Hungary

Figure 1: Hydroponic R&D vertical farm at Tungsram HQ, Budapest, Hungary

The installation and operation of VFs can be analyzed along various factors (e.g., energy supply, IT security). In this paper, we analyze the impact of VF production and location on total cost by constructing a mathematical model.

2. TRANSPORTATION NEEDS OF VERTICAL FARMS

The logistics of VFs are analyzed by Husti [1]. The main similarities and differences between conventional crop production and vertical farming are the following (list with additions):

Input factors required in conventional crop production are required (seeds, fertilizers, chemicals), however there are additional necessities in vertical farming e.g., the seedbed. It is also necessary to keep additional equipment in stock at all times, for example, consumables for harvesting – packaging materials – and consumables for the operation of the farm, e.g., hair net, footbag. The use of bees for pollination and fish or crustaceans for aquaponics creates additional input material requirements.

The energy demand of VFs is significant. Therefore, installation and operation may not be cost-effective in some locations. Providing constant high energy supply is essential (primarily electricity and gas for heating). Water is also needed, but its quantity is relatively low due to the high recycling efficiency.

If the plants are produced for human consumption (when certain food safety standards are obtained and applied which allows the product to be packaged without washing and can be consumed immediately by the purchaser later, as a 'ready-to-eat' product), it is necessary to ensure that the fresh product is delivered to consumers as soon as possible to maximalize the products' shelf life.

The main advantages of VFs are their programmability and modularity, which are also important features when organizing transportation. Namely, the plants are made at a predetermined rate which supports the certainty of supply and transport demand. If logistics (delivery of products) are delayed for any reason, it is possible to postpone the harvest for 2-3 days by modifying the light recipes accordingly. The light recipe is a predefined computer program, optimized for the proper growth of a given plant, which includes a schedule for turning on and off certain LEDs that emit light of different appropriate wavelengths. Everything is controlled by sensors and a computer. Besides, VFs only require a 2-3 days of pre-planned shoutdown per year due to maintanence.

Generated green waste management is also necessary. In the case of a standalone VF, there may be a need to remove or compost the plant waste. In the case of chain-linked VFs, the generated plant waste may also be used locally.

The novelty of the manuscript is the system approach that was used to model the relationship among various cost elements, supply and demand related attributes. Best of our knowledge, a similar vertical farm total cost model was not elaborated yet.

3. LITERATURE REVIEW

After several initial attempts, the first vertical farms equipped with high-tech technology appeared in the 2000s (e.g., AeroFarms, U.S.A.). The main reasons of the 'rediscovery' of VF idea/model were population growth, urbanization, food supply problems (caused partly by global climate change), and radical advances in technology (the use of LEDs and new internet techniques) [2]. Comprehensive studies of the new technology have also been issued by business parties [3-4]. The experience of different agricultural companies and scientific research focused on technical implementation, business calculations and product characteristics (vitamin and nutrient content, human consumption, production optimization). The secret kept by the companies is the so-called 'light recipe', which can give the company a competitive advantage over the competition.

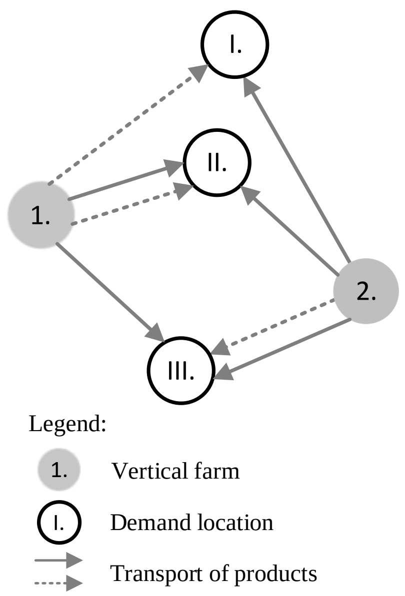
New research investigated the effects of external factors. The COVID-19 pandemic highlighted the vulnerability of cities and supply chains, and access to food was hampered by new problems [5-6]. War also generates difficult situation [7]. The installation of several units in different locations was also examined, and mathematical models were also developed [8-11].

4. METHODOLOGY

The VF modelling was divided into physical and mathematical models. The physical model summarizes the relationship among the elements. Then, the relationships are formulated into a mixed-integer linear programming (MILP) model.

4.1. Physical model

The relationship among VFs and demand locations are summarized in Figure 2.

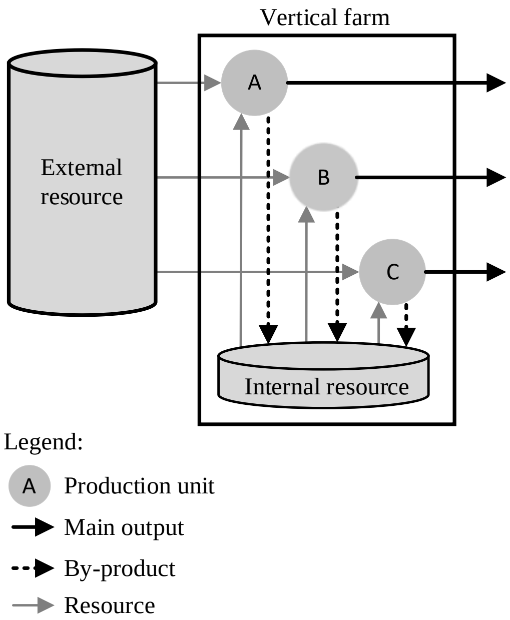


Source: Authors' own edition

Figure 2: Relationship among vertical farms and demand locations

A VF may meet demand at various locations and vice versa. The transport of various product types may be managed separately.

The VF may have various production units which are responsible for various products. The production requires resources. We don't distinguish between resources based on their characteristics, such as fertilizer and water, which is a limitation of the model. However, resources were categorized based on their source. Thus, external and internal resources may be defined. External resources are coming from outside of the VF. Internal resources are the by-products of the production units. Thus, the synergies among the production units may be considered. Namely, the by-product of a unit may be a resource for another unit. Furthermore, assuming a lower internal resource cost, production balancing may save cost. The structure of the VF is summarized in Figure 3.



Source: Authors' own edition

Figure 3: Vertical farm structure

4.2. Mathematical model

The VF supply and demand optimization problem is formulated into a mixed integer linear programming (MILP). The following indexes are used in the model:

i vertical farm,
j demand location,
k production type,
m number of VFs,
n number of demand locations,
o number of production types.

Therefore, variables and parameters may be location (VF and demand), and product type dependent.

The following variables were identified:

x_i binary deployment variable of VF i,
$y_{i,j}^k$ the volume of transported product k between VF i and demand location j,
z_i^k external resource of product k production at VF i,
$v_i^{k,k'}$ by-product of product k production used as a resource for product k' production. Thus, the by-product is the internal resource. The by-product may provide a resource for each product.

We have modelled the following cost elements:

c^α production quantity independent VF deployment cost,
c^β production quantity dependent VF deployment cost,
c^γ external resource cost,
c^δ location, quantity, and product type dependent transport cost.

The cost elements are calculated according to (1)-(4).

$$c^\alpha = \sum_i^m (\alpha_i x_i) \quad (1)$$

$$c^\beta = \sum_i^m \sum_k^o \left(\beta_i^k \sum_j^n y_{i,j}^k\right) \quad (2)$$

$$c^\gamma = \sum_i^m \sum_k^o \left(\gamma_i^k z_i^k\right) \quad (3)$$

$$c^\delta = \sum_i^m \sum_j^n \sum_k^o \left(\delta_{i,j}^k y_{i,j}^k\right) \quad (4)$$

Where:

α_i^k production quantity independent VF deployment cost parameter,
β_i^k production quantity dependent VF deployment cost parameter,
γ_i^k external resource cost parameter,
$\delta_{i,j}^k$ transport cost parameter.

The objective function is to minimize the total cost (5).

$$min\left(c^\alpha + c^\beta + c^\gamma + c^\delta\right) \quad (5)$$

The solution of the optimization problem must fulfil the following constraints:

- binary constraint on variable x (6),
- non-negative constraints: variable y, z and v are equal to or greater than zero (7), (8) and (9), respectively,
- land-use constraint: the land-use of the VF is limited at each location (10),
- resource constraint: the resource must meet the production's demand (11),
- by-product constraint: the sum of used by-product is equal to or lower than the sum of by-product (12),
- demand constraint: the supply must meet the demand at each location (13),
- production constraint: producing farms are deployed, namely x=1 (14).

$$x_i \ binary \quad (6)$$

$$y_{i,j}^k \geq 0 \quad (7)$$

$$z_i^k \geq 0 \quad (8)$$

$$v_i^{k,k'} \geq 0 \quad (9)$$

$$\sum_k^o \left(a_i^k \sum_j^k y_{i,j}^k\right) \leq A_i \quad (10)$$

$$b^{k'} \left(v_i^{k,k'} + z_i^{k'}\right) \geq \sum_j^n y_{i,j}^{k'} \quad (11)$$

$$\sum_{k'}^o v_i^{k,k'} \leq B^k \sum_j^n y_{i,j}^k \quad (12)$$

$$\sum_i^m y_{i,j}^k \geq d_j^k \quad (13)$$

$$\sum_j^n \sum_k^o y_{i,j}^k \leq x_i \sum_j^n \sum_k^o d_j^k \quad (14)$$

Where:

- a_i^k land-use intensity parameter,
- A_i land-use limitation,
- $b^{k'}$ the rate of production volume and resource volume. E.g., $b^{k'}$ is 20, if 5 units of resource needed to produce 100 units,
- B^k the rate of production and by-product. E.g., B^k is 0.05, if 5 units of by-product can be achieved per 100 units of production,
- d_j^k the product demand.

However, various resource types are not distinguished, the characteristics of by-product types may be considered through further constraints. E.g., $v_i^{A,B} = 0$, if the by-product of product A cannot be a resource for product B. The number of variables in the model may be calculated based on (15).

$$N = m + m \cdot n \cdot o + 2m \cdot o \quad (15)$$

Where N is the number of variables. The three components in the addition are the number of x, y and resource variables (z and v), respectively. Consequently, the number of VFs causes the most significant increase in the number of variables and the number of demand points has the lowest impact.

4.3. Case study

We have elaborated a case study to present the applicability of the model. 3 possible VF locations, 5 demand locations and 2 product types were considered. We modelled a theoretical demand location to consider overproduction because of by-products. The demand and the transport cost of products between VFs and theoretical demand location were zero. Accordingly, the greater production may decrease the cost of external resources. Thus, 6 demand locations were modelled. The parameters are summarized in Table 1. The intlinprog function of Matlab was used for optimization.

Various scenarios were determined based on the share of costs. The focus was put on the rate of c^β and c^δ (production dependent and transport cost). Accordingly, each result may be valid for these scenarios. To extend the applicability of the results, further analysis is necessary. The question was how the rate of these cost elements influences the production volume at VFs. The results are summarized in Table 1. The Σy columns represent the total production volume per vertical farm location and scenario. Namely, the production volume was the same at each location in case of scenario A and B, and scenario C shows a more distributed case.

Table 1: Case study results

	c^α	c^β	c^γ	c^δ	Σy_1	Σy_2	Σy_3
Scenario A	9%	66 %	4 %	21 %	765	0	1300
Scenario B	14 %	44 %	7 %	35 %	765	0	1300
Scenario C	16 %	33 %	5 %	45 %	650	700	715

Source: Authors' own calculation and edition

The results indicate, that if the production dependent cost is higher than the transport cost, centralized production is more beneficial than decentralized.

5. CONCLUSIONS

As vertical farms become more prevalent in everyday life, generating new freight demand, they will have an impact on transport systems. This effect depends on the location and exact function of each external location. When creating a new vertical farm, it is advisable to optimize it based on traffic as well. The major contribution of this research is the deterministic VF cost model considering production volume, relationships among productions, land use, location, and transport cost. Our model supports the optimization of VF operation in urban areas. The elaboration of the VF cost model was the first step in our research. We plan to give a more detailed description of the relationships to improve reliability, run VF location and production optimization using real-life data about supply chains and vertical farms and consider the inherently stochastic nature of factors affecting production (e.g., transport) to examine the resilience of VFs. In that case if a node fails, what connections can be used to continue production.

APPENDIX – COST PARAMETERS

Table 2-9 shows the cost parameters.

Table 2: α parameters

	α_i	
i	1	500
	2	750
	3	1000

Source: Authors' own calculation and edition

Table 3: β parameters – Scenario A

β_i^k		K	
		1	2
i	1	5	6
	2	5.5	6.5
	3	5	6.5

Source: Authors' own calculation and edition

Table 4: β parameters – Scenario B and C

β_i^k		K	
		1	2
i	1	2	2.4
	2	2.2	2.6
	3	2	2.6

Source: Authors' own calculation and edition

Table 5: γ parameters

γ_i^k		K	
		1	2
i	1	10	10
	2	11	11
	3	11	11

Source: Authors' own calculation and edition

Table 6: δ parameters – Scenario A and B, k=1

δ_i^k		J					
		1	2	3	4	5	6
i	1	1	2	4	4	6	0
	2	1.5	1.5	4	1.5	4	0
	3	2	2	1	2	2	0

Source: Authors' own calculation and edition

Table 7: δ parameters – Scenario A and B, k=2

δ_i^k		J					
		1	2	3	4	5	6
i	1	1.2	2.4	4.8	4.8	7.2	0
	2	1.8	1.8	4.8	1.8	4.8	0
	3	2.4	2.4	1.2	2.4	2.4	0

Source: Authors' own calculation and edition

Table 8: δ parameters – Scenario C, k=1

δ_i^k		J					
		1	2	3	4	5	6
I	1	2	4	8	8	12	0
	2	3	3	8	3	8	0
	3	4	4	2	4	4	0

Source: Authors' own calculation and edition

Table 9: δ parameters – Scenario C, k=2

δ_i^k		J					
		1	2	3	4	5	6
i	1	2.4	4.8	9.6	9.6	14.4	0
	2	3.6	3.6	9.6	3.6	9.6	0
	3	4.8	4.8	2.4	4.8	4.8	0

Source: Authors' own calculation and edition

Constraint parameters (Table 10-13):

Table 10: Land use parameters

A_1	1000
A_2	700
A_3	1300

Source: Authors' own calculation and edition

Table 11: Land use intensity parameters

a_i^k		k	
		1	2
i	1	1	1
	2	1	1
	3	1	1

Source: Authors' own calculation and edition

Table 12: Production parameters

b^1	18
b^2	25
B^1	0.02
B^2	0.01

Source: Authors' own calculation and edition

Table 13: Demand parameters

d_j^k		k	
		1	2
j	1	200	300
	2	150	100
	3	170	170
	4	300	350
	5	300	25
	6	0	0

Source: Authors' own calculation and edition

REFERENCES

[1] Husti, I. (2022). A beltéri vertikális termesztés néhány jellemzője és logisztikai összefüggése. In Sz. Duleba (Ed.), Logisztikai Évkönyv 2022 (pp. 300-319). Budapest, Hungary: Magyar Logisztikai Egyesület. https://doi.org/10.23717/LOGEVK.2022.27 (accessed 15/02/2022)

[2] Choubchilangroudi, A., & Zarei, A. (2022). Investigation the effectiveness of light reflectors in transmitting sunlight into the vertical farm depth to reduce electricity consumption. Cleaner Engineering and Technology (Vol. 7). https://www.sciencedirect.com/science/article/pii/S266679082200026X?via%3Dihub (accessed 20/03/2022)

[3] Dent, M. (2020). Vertical Farming: 2020-2030. Technologies, markets and forecasts in indoor vertical growing. Research report. IDTechEx. https://www.idtechex.com/en/research-report/vertical-farming-2020-2030/719 (accessed 15/03/2022)

[4] Indoor Soilless Farming: Phase I: Examining the industry and impacts of controlled environment agriculture. The Markets Institute at WWF. Innovation Analysis (2020). https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/84omrzpdge_WWW_SoilessAg_Phase1_Final_Report_Full_051320.pdf (accessed 13/03/2022)

[5] Cohen, N. (2022). Food Crisis as a Tool for Social Change: Lessons from New York City's COVID-19 Response. Urban Governance. https://www.sciencedirect.com/science/article/pii/S2664328622000031 (accessed 20/03/2022)

[6] Capodistrias, P., Szulecka, J., Corciolani, M., & Strøm-Andersen, N. (2021). European food banks and COVID-19: Resilience and innovation in times of crisis. Socio-Economic Planning Sciences. https://www.sciencedirect.com/science/article/pii/S0038012121001798 (accessed 20/03/2022)

[7] Muhialdin, B. J., Filimonau, V., Qasem, J. M., & Algboory, H. (2021). Traditional foodstuffs and household food security in a time of crisis. Appetite (Vol. 165). https://www.sciencedirect.com/science/article/abs/pii/S0195666321002051?via%3Dihub (accessed 20/03/2022)

[8] Racedo-Gutiérrez, J., & Torres-Delgado, F. (2020). Piecewise Linearization for Solving Models to Locate Urban Logistics Facilities. IFAC-PapersOnLine. Vol. 53(2), pp. 11181-11186. https://www.sciencedirect.com/science/article/pii/S2405896320305814 (accessed 15/03/2022)

[9] Sheu, J-B. (2003). Locating manufacturing and distribution centers: An integrated supply chain-based spatial interaction approach. Transportation Research Part E: Logistics and Transportation Review. Vol. 39(5), pp. 381-397. https://www.sciencedirect.com/science/article/abs/pii/S1366554503000188?via%3Dihub (accessed 15/03/2022)

[10] Chen, C-L., Yuan, T-W., & Lee, W-C. (2007). Multi-criteria fuzzy optimization for locating warehouses and distribution centers in a supply chain network. Journal of the Chinese Institute of Chemical Engineers. Vol. 38(5–6), pp. 393-407. https://www.sciencedirect.com/science/article/abs/pii/S036816530700086X?via%3Dihub (accessed 15/03/2022)

[11] Serrano, A., Faulin, J., Astiz, P., Sánchez, M., & Belloso, J. (2015). Locating and Designing a Biorefinery Supply Chain under Uncertainty in Navarre: A Stochastic Facility Location Problem Case. Transportation Research Procedia. Vol. 10. pp. 704-713. https://www.sciencedirect.com/science/article/pii/S2352146515002112?via%3Dihub (accessed 15/03/2022)

ENERGY EFFICIENCY AND CLIMATE CHANGE MITIGATION FOR FISHING VESSELS

Ivica Ančić
Lidija Runko Luttenberger
University of Rijeka
Sveučilišna avenija 4, Croatia
ivica.ancic@uniri.hr, lidija.luttenberger@uniri.hr

ABSTRACT

Continuous efforts in the marine industry are directed towards improving energy efficiency and reducing the environmental impact of ships. The strategic document in Croatia focusing on that topic is the Operational Programme for Maritime Affairs and Fisheries of the Republic of Croatia. Based on this Programme different measures are funded from the European Maritime and Fisheries Fund (EMFF). In this paper a special focus is put on measure I.20 Energy Efficiency and Climate Change Mitigation. Through this measure the installation of new diesel engines in fishing vessels is co-financed from the EMFF. The main requirement is that the power output of the new engine is lower than that of the replaced one. This paper discusses pros and cons of such approach, provides an insight in the technical characteristics of the current fishing fleet, and proposes improvements regarding the environmental policies in the marine sector.

Keywords: energy efficiency, environmental impact, fishing vessels, EMFF

1. INTRODUCTION

Continuous efforts in the marine industry are directed towards improving energy efficiency and reducing the environmental impact of ships. These efforts are not limited only to ocean-going vessels, but include also vessels engaged in the short-sea shipping (SSS). SSS denotes transport of goods over shorter distances by sea. In the context of the EU it is defined as the transport by sea between ports in the EU, as well as ports in the Mediterranean Sea [1].

SSS offers many advantages over land-based transport as it is generally more energy efficient and has lower impact on the environment [2]. However, it has to be noted that this impact is not negligible and should be further reduced through different measures. These can include for example energy storage devices. Dedes et al. [3] investigated whether energy storage devices can be a feasible solution on-board bulk carriers. They identified that Power Take-Off/Power Take-In (PTO/PTI) system has potential when combined with batteries to increase energy efficiency, especially for Panamax and Handysize bulk carriers. In addition, for sufficiently high fuel price (520 USD/t), this solution can even be economically feasible. The cost effectiveness of an air lubrication system was discussed by Mäkiharju et al. [4], while Butterworth et al. [5] conducted experiments on a container ship model with air cavity concept. Both technologies proved to be similarly effective at lower speed, but their influence is reduced at higher speeds. Carbon dioxide Reduction Technologies (CRT) have been analysed by Calleya et al. [6]. They found that CRT have the potential to reduce CO_2 emissions, although at a relatively high cost. The technologies are implemented during voyage, but other technologies, such as cold ironing also have potential to reduce the environmental impact of ships [7].

Most of the research on the ship's energy efficiency is focused on ocean-going vessels, which sail in relatively similar conditions. But ships engaged in SSS, especially fishing vessels, sail in continuously changing conditions. The main problem for fishing vessels is to define which of these measures is the most appropriate in different situations. This is usually left to the ship-owners to decide individually. However, a better way is to aggregate these measures into strategies (national and international) which can provide a framework with clear goals and plans. The strategic document in Croatia focusing on that topic is the Operational Programme for support from the European Maritime and Fisheries Fund [8]. It introduces a set of measures oriented towards fishing vessels and fish farms. Some of these measures, specifically I.21, are focused on improving energy efficiency of fishing vessels, and reducing their environmental impact. The aim of this paper is to analyze this measure, evaluate its effect in reducing the environmental impact of fishing vessels in Croatia, and to provide some recommendations for improvement.

In next chapter a brief description of the measure is provided. Since the measure is based on the engine power output, an analysis of the engine power in the fishing vessels in Croatia is performed in subsequent chapter. The results of the analysis and its relation with the current regulation are discussed afterwards with some concluding remarks at the end of the paper.

2. OPERATIONAL PROGRAMME FOR MARITIME AFFAIRS AND FISHERIES OF THE REPUBLIC OF CROATIA

Based on aforementioned Programme, different measures are funded from the European Maritime and Fisheries Fund (EMFF). In this paper a special focus is put on measure I.21 Energy Efficiency and Climate Change Mitigation. Through this measure the installation of new diesel engines in fishing vessels is co-financed from the EMFF. The co-financing rate is set at 30% and up to 50,000.00 EUR maximum. The measure also provides a set of rules which every project proposal has to comply with in order for the financing to be approved.

The main requirement stipulated in this measure concerns the maximum continuous rating (MCR) of the new engine. For vessels having length below 12 m, the power output of the new engine must not exceed the output of the old one. For vessels between 12 and 18 m in length, the new engine has to have MCR that is at least 20% lower, and for longer ships, the new engine has to have MCR that is at least 30% lower compared to that of the replaced engine. If the reduction in output exceeds the minimum stipulated, extra points are credited in the evaluation process. Additional points are also credited for engines older than 15 years.

Proclaimed goal of the measure I.21 is to reduce the ships' impact on climate change and to improve their energy efficiency. Therefore the reasoning behind such measure is clear: Croatian government believes that new engines having lower MCR will be more energy efficient, consume less fuel and hence reduce the emissions of harmful substances as well as reduce the impact on the environment. The power of the engine is indeed one of characteristics which affects the engine environmental impact, but hardly the only one. Fishers would like to receive co-financing for the installation of a new engine, but are reluctant to install engines with lower MCR, primarily due to safety concerns, especially in harsh weather conditions. Thus an analysis of the engine power should be performed in order to identify which ships are suitable candidates for an engine replacement.

3. THE ANALYSIS OF THE ENGINE POWER OF FISHING VESSELS IN CROATIA

The analysis of the engine power is performed for fishing vessels registered in Croatia and which have a license to perform fishing operations in the Adriatic Sea. The aim of this analysis is to establish a correlation between the engine power and some other ship technical characteristic. Based on such correlation, a group of potential candidates for measure I.21 could be identified.

3.1. Source of data

The data used for the analysis can be obtained from the Registry of the fishing fleet of the Republic of Croatia, which is available online. The data is publicly available free of charge, but is not appropriate for statistical analyses. Hence, data collected by the European Commission, aggregated into an Excel file, and available online [9] is used for this analysis. It includes various technical data, such as ship's length, gross tonnage (GT), hull material, power of the main engine, year of construction, as well as various administrative data.

3.2. Analyzed parameters

As mentioned in the previous chapter, the ship's environmental impact is determined not only by its engine power, but depends also on a number of different parameters, such as the fuel used and the engine's specific fuel oil consumption, which depends on the engine speed and load, which again depends on the sailing speed, ship draft, weather conditions, propeller condition etc. The database used includes only a limited number of ship characteristics, meaning that this analysis cannot take into account each parameter that determines ship's environmental impact, Fig. 1. In order to identify potential candidates for the measure I.21, a simple correlation is convenient. Since the current regulation for fishing vessels is mostly based on the ship size measured in GT (and since gross tonnage is a parameter easily recognized by fishers), it is interesting to compare how these two characteristics correlate.

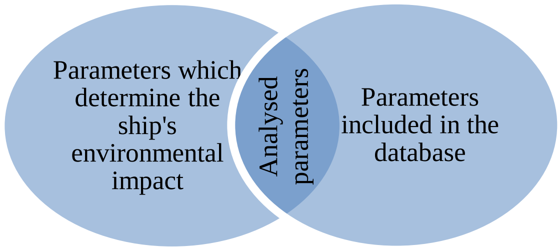


Figure 1: Analyzed parameters in this paper

3.3. Methodology

The analysis is performed based on the regression analysis and the least square method using Microsoft Excel. With in-built function a trendline can be plotted and the coefficient of determination R^2 can be determined. Based on this a correlation between the set of data and the trendline can be established. If the value of the R^2 is higher than 0,6, then there is some correlation of the trendline and the observed data set. Values of R^2 over 0,85 indicated good correlation. Values of R^2 close to 1 indicate mathematical correlation.

3.4. Results

Results of the performed analysis observing the engine power (more precisely, the main engine maximum continuous rating) and the ship's GT are presented in Fig. 2.

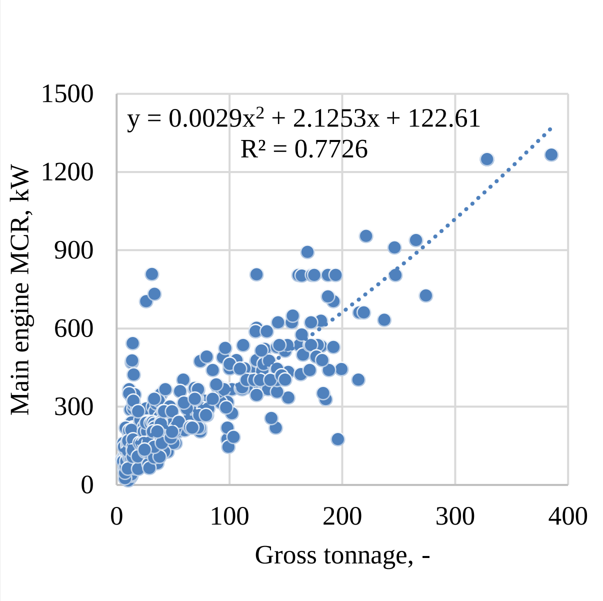


Figure 2: The correlation of the main engine MCR and the GT of fishing vessels in Croatia

Since the value of R^2 was relatively low, another analysis taking into account only purse seiners was performed. Its results are presented in Fig. 3. As expected, the correlation has improved notably.

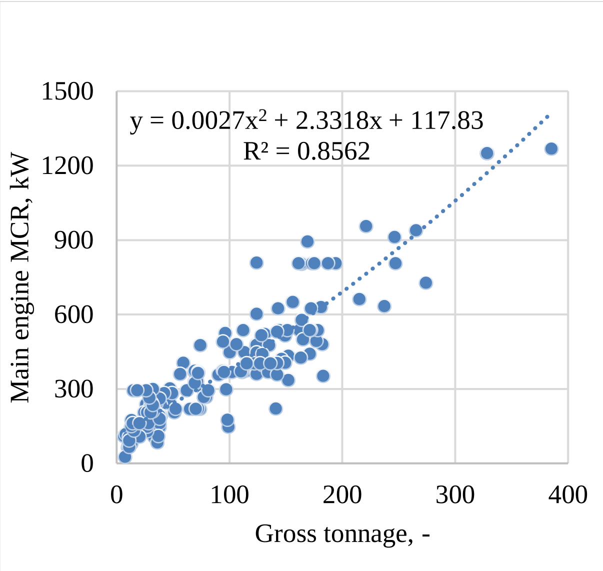


Figure 3: The correlation of the main engine MCR and the GT of purse seiners in Croatia

4. DISCUSSION

Based on the results from the previous chapter, several remarks can be given. First of all, limitations of these analyses should be highlighted. As indicated in chapter 3.2, ship's environmental impact depends on many different parameters, while the analysis is performed only for two of them: engine power and ship's GT. This is primarily due to the fact that the database used does not include any data on the ship's speed, propeller characteristics, gear used or even the engine used.

Furthermore, the environmental impact of a ship is determined by the emission of harmful substances, and not by its MCR. These emissions are produced throughout the ship's lifecycle, but mostly during ship operation. Some emissions, like CO_2 and SO_X emissions, are determined by fuel composition and consumption, while NO_X emission depends on the fuel combustion parameters. The fuel consumption and the combustion parameters depend on the engine load and speed. These two values define the engine operational point. As mentioned in the introduction, ocean-going vessels sail the majority of time near the optimal engine operating point (with the lowest specific fuel oil consumption), but ships engaged in SSS can have operational points anywhere within the engine operational map. Thus, CO_2 emission in operation can be calculated based on the engine power at a given operating point (defined by the current engine load and speed and usually lower than the MCR), specific fuel oil consumption at that point and the carbon conversion factor. The NO_X emission can be determined based on the engine power and the specific NO_X emission determined from an engine map depending on the engine load and speed. These emissions can then be normalized and aggregated into one value, such as the Index of Energy Efficiency and Environmental Eligibility (I4E) which can be used to compare different ships' environmental impact [10]. The observed measure I.21 has simplified this procedure greatly, making it much easier to use, but with questionable environmental effect.

Since it is not expected for the current measure I.21 to be amended in a way that would implement a physically valid procedure (e.g. as described in [10]), the idea behind this paper is to provide at least some guidance for fishers as to which ships could be considered for an application involving engine replacement. Based on Fig. 4, an average MCR of a purse seiner can be determined. For instance, a purse seiner of GT=150 has an average MCR of 528 kW. Thus, if a particular purse seiner is powered by an engine having significantly higher MCR, then this purse seiner should be evaluated further in order to determine if its engine should be replaced by a new one. This however requires a more detailed analysis.

But even limited analysis can provide some insight. When comparing Fig. 2 and Fig. 3, a noticeably higher correlation for purse seiners can be observed, than the one for the entire fleet. If the composition of the rest of the fleet is analyzed, it can be noted that it mostly consists of trawlers, Fig. 4. Therefore, the inclusion of trawlers actually reduces the correlation between the engine power and GT. This indicates that for trawlers engine power is less dependent on the GT. Even more, fishers often point put that the engine power is not crucial parameter when it comes to trawlers. For them the gear ratio and the propeller speed are much more important since they can generate higher bollard pull force, which is crucial while trawling. Since the database used does not include any data on these parameters, they should first be collected so a further analysis can be performed.

Figure 4: A trawler in the Adriatic Sea

On the other hand, for purse seiners, Fig. 5, the engine power can be considered as an important parameter, since it is a prerequisite to achieve the required sailing speed. Fishers also find engine power to be the crucial parameter for ensuring safety when sailing in rough weather conditions. Further actions should be directed towards fishers, precisely in educating them about the ship power system improvements and the benefits of installing new engines, especially the benefits of hybrid and integrated power systems. The trendline shown in Fig. 3 can be used as a tool for quick evaluation of their propulsion system power and as an indicator that engine power could be reduced. This could encourage fishers to install new engines and even consider alternative configurations which could not only reduce the environmental impact, but also reduce their costs.

Figure 5: A purse seiner in the Adriatic Sea

5. CONCLUSION

In this paper the measure I.21 aiming to increase the energy efficiency and to reduce the environmental impact of fishing vessels is discussed. The measure considers only the engine power and requires its reduction for new engines. Fishers are reluctant to reduce the power of their engine primarily due to safety concerns, so the effect of the measure is limited. Since it is not feasible to change the measure, this paper presents a method to roughly estimate the average engine power of a purse seiner based on the GT. This can be used to determine if the observed fishing vessel has higher power than average. This could then indicate that the ship is a potential candidate for the installation of an engine having lower power output and encourage the fishers to at least consider its replacement.

REFERENCES

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Short_sea_shipping_(SSS) (accessed on 24.3.2022.)

[2] Runko Luttenberger, L., Ančić, I., Šestan, A., & Vladimir, N. (2013). Integrated power systems in small passenger ships (pp. 1-7). Nice, France: World Electric & Hybrid Boat Summit - PlugBoat 2013

[3] Dedes, E.K., Hudson, D.A., & Turnock, S.R. (2012). Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping. Energy Policy 40, 204-218.

[4] Mäkiharju, S.A., Perlin, M., & Ceccio, S.L. (2012). On the energy economics of air lubrication drag reduction. Int. J. Nav. Archit. Ocean. Eng. 4 (4), 414-422.

[5] Butterworth, J., Atlar, M., & Shi, W., (2015). Experimental analysis of an air cavity concept applied on a ship hull to improve the hull resistance. Ocean. Engineering, 110, 2–10.

[6] Calleya, A., Pawling, R., & Greig, A. (2015). Ship impact model for technical assessment and selection of Carbon dioxide Reducing Technologies (CRTs). Ocean. Engineering. 97, 82–89.

[7] Goodman, R., & Barnes, M. (2010). Short Sea Shipping: A Compatibility Model, Technical Analysis. www.foe.org

[8] Operational Programme for support from the European Maritime and Fisheries Fund in Croatia. https://ec.europa.eu/oceans-and-fisheries/document/download/9af07f9d-f33b-4e45-ab4b-faa5c42a7555_en?filename=op-croatia-summary_en.pdf

[9] https://webgate.ec.europa.eu/fleet-europa/search_en

[10] Ančić, I., Vladimir, N., & Cho, D. S. (2018). Determining environmental pollution from ships using Index of Energy Efficiency and Environmental Eligibility (I4E). Marine policy, 95 (2018), 1-7 doi:10.1016/j.marpol.2018.06.019

BUOY MOORING MANAGEMENT MODEL

Andrej Androjna, Ph.D.
Lina Kaldana, M.Sc.
Marko Perkovič, Ph.D.
Peter Vidmar, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4,6320 Portorož, Slovenia

Andrej.Androjna@fpp.uni-lj.si, Lina.Kaldana@fpp.uni-lj.si, Marko.Perkovic@fpp.uni-lj.si, Peter.Vidmar@fpp.uni-lj.si

ABSTRACT

This paper presents a management model for online booking of temporarily available mooring buoys at sea in the Debeli Rtič Nature Park. For this purpose, a thorough analysis was conducted, including a proposal for the selection of a manager, an overview of legislation, different buoy rentals, time intervals, methods of implementing the selected model using the buoy booking and payment application, control methods and other components that could influence the design of the management model and the planning of related activities. The proposed application for booking and using mooring buoys at the anchorage is the Porthop application, which is adapted to the Debeli rtič Nature Park. As for the management model of the anchorage, the optimal variant is to lease the anchorage to a concessionaire in the form of a daily 12-hour buoy rental in combination with the rental of partial seasonal moorings on buoys. The results support the implementation of coastal fisheries management measures, the effectiveness of protected area management and the reduction of negative impacts of visits to the marine part of the Debeli Rtič Nature Park.

Keywords: buoy rental, on-line booking, mooring management

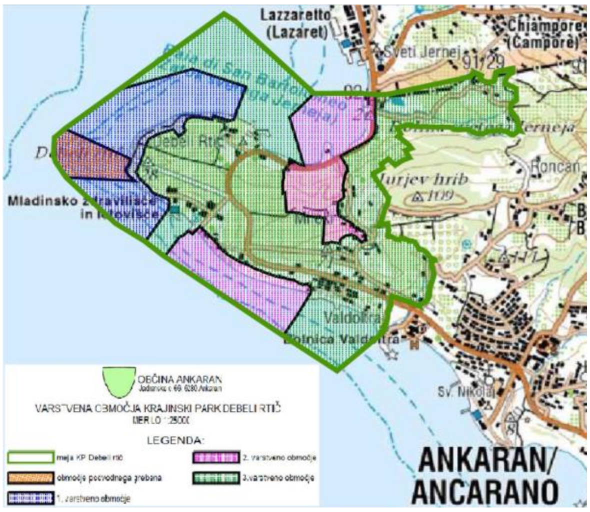
1. INTRODUCTION

Strunjan Nature Park, as a partner of the MPA NETWORKS Interreg Mediterranean project, is leading the networking activity: direct experience transfer and promotion of actions between related protected areas (WP 4.4 - Networking activities: peer-to-peer experience sharing & boosting). The role of Strunjan Nature Park is to transfer management experience to the newly established Debeli rtič Nature Park, which will participate as a pilot area in the implementation of the activities in this work package. The Strunjan Nature Park will thus accelerate the implementation of the priority measures for the management of the Debeli Rtič Nature Park. It will support the introduction of coastal fisheries management measures, the effectiveness of protected area management and the reduction of negative impacts of visits to the marine part of the Debeli Rtič Nature Park.

In order to create a management model for the allocation of temporary moorings at sea in the Debeli Rtič Nature Park and the corresponding planning of related activities, a study (hereinafter) was prepared for the management of moorings at sea, including the methods for renting buoys, time intervals, methods for implementing the selected model using the application for reservation and payment of moorings, control methods and other components that could influence the design of the management model and the planning of related activities.

2. REGULATORY BASIS

The area covered by the mooring management study includes the marine part of the protected area of the Debeli rtič Nature Park (Figure 1) [1].



Source: [1]

Figure 1: The marine part of the protected area of the Debeli rtič Nature Park

The study is based on all official documents officially adopted and valid in the Debeli rtič Nature Park and takes into account the technical bases already elaborated and purposefully acquired:

a) Decree on the Debeli rtič Nature Park, Uradni list RS, No. 48/2018 of 13 July 2018 [1].
b) Monitoring of the state of tourist visits in Debeli rtič, Report, Project MedPAN North, Component 5, Local Activity 5. 2. 3. 3, Popić A., R. Turk, 2013 [2].
c) Project documentation for construction and implementation (PZI) No. 05-2020 - Anchor buoys for temporary mooring of vessels in Debeli rtič Nature Park, ERTA d. o. o, 2020 [3].
d) Management guide for Marine, Protected Areas of the Mediterranean Sea, Permanent Ecological Moorings, University of Nice-Sophia Antipolis & National Park of Port-Cros, Francour P., Magréau JF, Mannoni PA, Cottalorda JM, Gratiot J., 2006 [4].
e) Legal provisions for the protection of cultural heritage (eVRD), Ministry of Culture [5].
f) Project conditions for Debeli rtič Nature Park anchor buoys, Maritime Administration of the Republic of Slovenia, No. 3730-53 / 2020/7 of 18 January 2021 [6].

3. METHODOLOGY

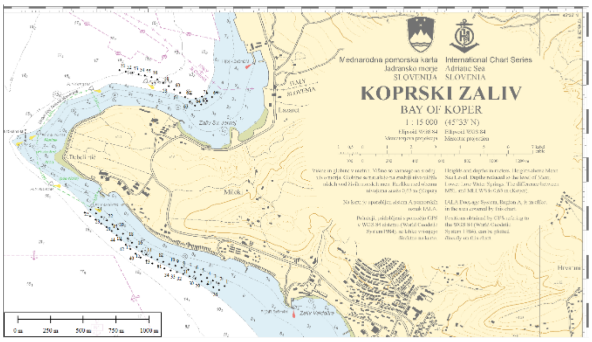
The methodology of the study for the management of berths in the Debeli Rtič Nature Park is based on previously studied professional bases, officially adopted documents on the safety of navigation and legal regulation of ports / anchorages in the Slovenian sea and also applies to the Debeli Rtič Nature Park [1, 7-8], contractors' project documentation [3] and the opinion of the Slovenian Maritime Administration on the project conditions of berths with screw anchors in the Debeli rtič Nature Park [6].

The study for the management of moorings in the Debeli rtič Nature Park includes an expert opinion and calculations for six different proposed methods of renting moorings, a review of the required normative acts and a proposal for the selection of a manager.

4. PROVISIONAL TEMPORARY MOORINGS AT SEA

It is expected that the installation of anchorages or temporary moorings at sea will be in accordance with the Project Documentation for Construction and Implementation (PZI) No. 05-2020 - Anchor buoys for Temporary Mooring of Vessels in the Debeli rtič Nature Park [3] and will not endanger seabed communities.

Prior to the installation of mooring buoys at the anchorage (Figures 2), it is also planned to regulate the status of the port in accordance with the draft Maritime Spatial Plan of the Republic of Slovenia [8], i.e., with the adoption of the Port Ordinance of the Municipality of Ankaran.

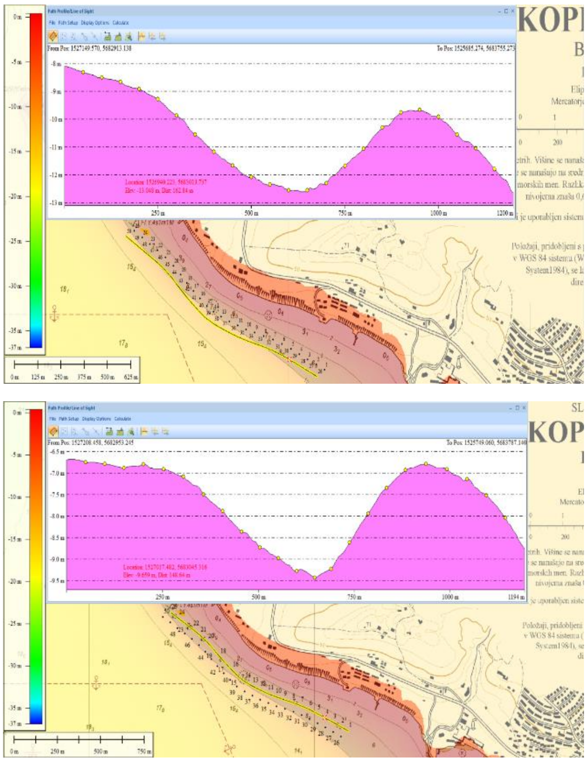


Source: Authors

Figure 2: Location of anchor buoys (nautical chart) in the area of the Debeli rtič Nature Park

Two areas are designated for the installation of 72 anchor buoys, as shown in Figures 3 and 4:

1. The area between the Youth Health Resort and the Debeli rtič Resort and Swimming Pool "Na študentu", where two rows of 25 anchor buoys can be installed at a distance of about 150 m and 200 m from the shore, making a total of 50 anchor buoys (Figure 3). The first figure shows the depth profile and the connecting distance of 1,094 metres between buoys 1 and 25. The second part shows the depths of the mooring buoys in the second row (mooring buoys from no. 26 to no. 50), where the connecting distance is 1,200 metres.

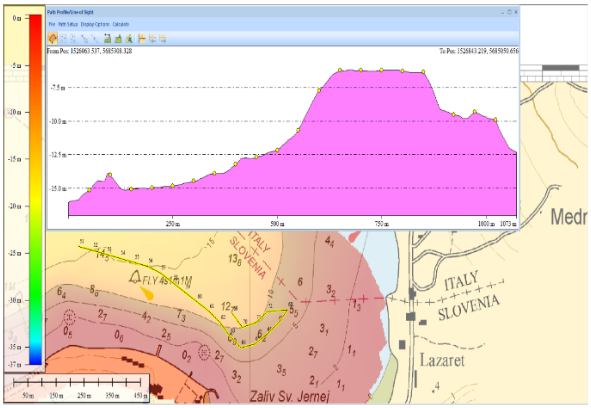


Source: Authors

Figure 3: Location of anchor buoys between Youth Health Resort, the Debeli rtič Resort and Swimming Pool "Na študentu"

2. The area of Jernej Bay, where the mooring buoys are mostly located at a distance of more than 150 metres from the shore, a total of 22 mooring buoys (Figure

4). The picture also shows the depths (buoys from no. 26 to no. 50) and the length of the connecting stretch (1,073 metres).



Source: Authors

Figure 4: Location and depths in the area of Jernej Bay

The mooring buoys are used only for mooring vessels up to 12 metres in length, while larger vessels have the possibility to anchor freely in the third protected area at a distance of more than 200 metres from the shore, as stipulated in the Decree on the Debeli rtič Nature Park [1].

Figure 5 shows the density of vessel traffic at a distance of 2 NM from Debeli rtič and in the vicinity of the planned anchor buoys.

Source: AIS data

Figure 5: The density of vessel traffic at a distance of 2 NM from Debeli rtič

The data is taken from the vessel monitoring system AIS. All vessels and fishing vessels over 15 metres in length are required to report their position, direction of speed and other static data.

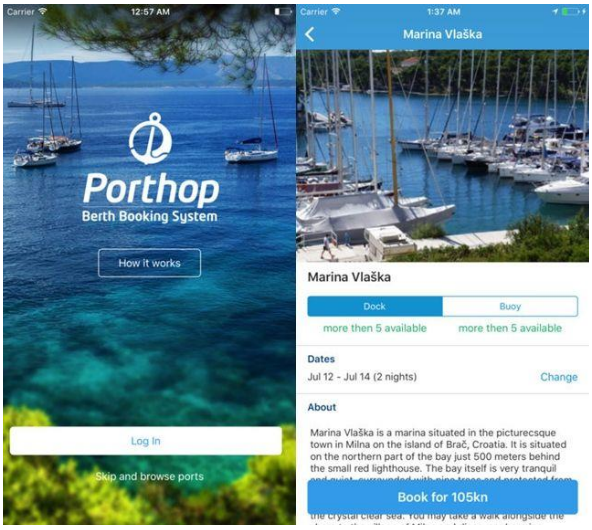
5. MOORING MANAGEMENT - AN EXAMPLE OF GOOD PRACTICE

The aim of the study is to find the optimal solution for the development of a management model for berths at sea in the Debeli rtič Nature Park. The project requirements were related to the selection of a model and an application that would enable online booking and payment of moorings at the anchorage. Today, we know of many areas around the world where such an online business functions quite simply often with the help of various applications. Online booking and payment of moorings at anchor is therefore possible in many countries with developed nautical tourism, e.g., in the Mediterranean (Greece, Turkey, France, Spain, Croatia the Balearic Islands, etc.), the United States, Canada, New Zealand, Australia, the Virgin Islands, etc. [9-15]. After a detailed analysis of existing web applications that allow booking and paying for a berth at an anchorage, we concluded that the Croatian web application Porthop would be the most suitable on the Slovenian coast and that there is no need for a completely separate development of a new, similar application [14]. The inclusion of the Slovenian coastal area could only complement or increase the usefulness of the Porthop application.

The project "PortHop - an online system for booking nautical berths" - was co-financed by the European Regional Development Fund in 2017. The aim of the project was to create the conditions for sustainable growth and development of the innovative company Porthop d. o. o. on domestic and foreign markets and to ensure successful marketing of the innovative product. The total value of the project was 176,000 euros, of which the EU financed 139,000 euros and the Republic of Croatia contributed 37,000 euros, or 21%.

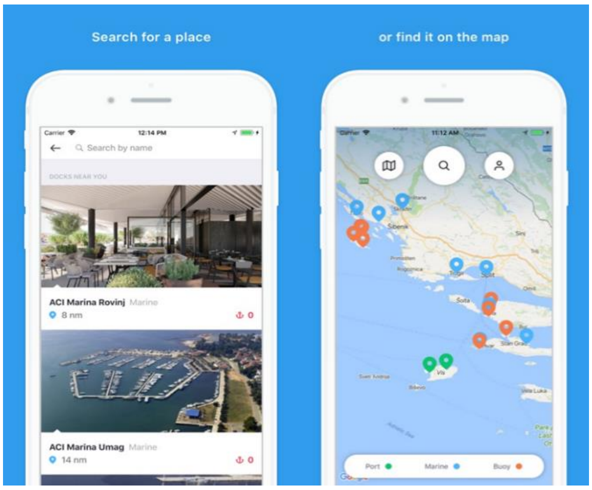
PortHop is an online system for booking and paying for berths in marinas or at buoys in Croatia. It also provides users with additional information on nautical tourist points and services (petrol stations, health centres, post offices, etc.) in the ports. The additional Berth & Approach tab also provides information on how to get there, sheltered wind conditions and other important information. Finding a berth is very easy and searching for the desired marina requires only one step to complete the reservation. In most marinas, payment for the berth can be made via the app and the reservation (arrival and departure) usually has to be made by noon.

The booking process is shown in figures 6 to 9.



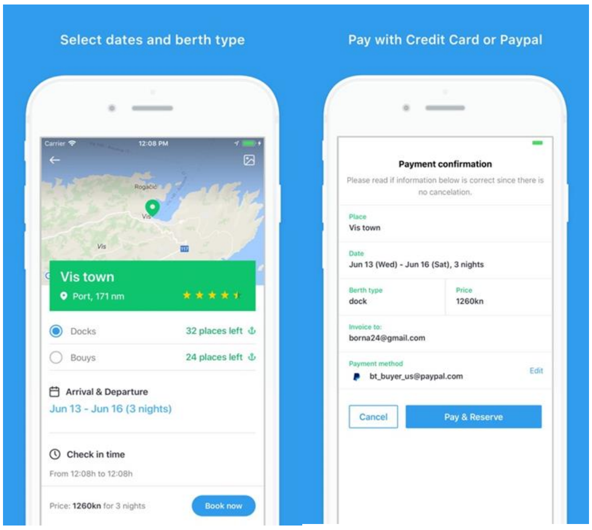
Source: [14]

Figure 6: The process of finding the desired location



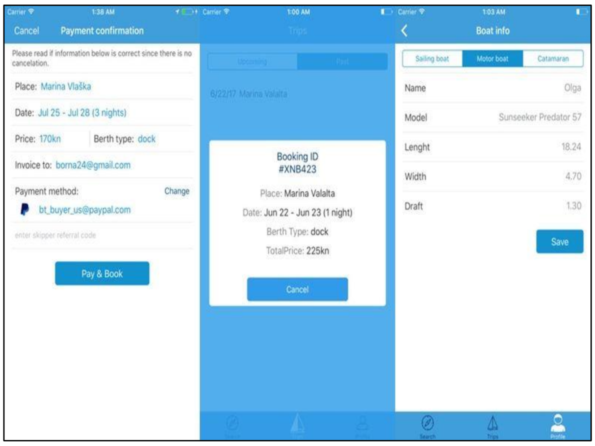
Source: [14]

Figure 7: The process of finding the desired location



Source: [14]

Figure 8: Selection of the desired location and method of payment for the berth



Source: [14]

Figure 9: Confirmation of the reservation/payment of the berth

6. DEFINITION OF MOORING METHODS, TIME INTERVALS, SELECTION OF MANAGER

6.1. Definition of the methods for renting moorings at anchor buoys and presentation of the time intervals

With the relevant normative regulation, in accordance with the Project Documentation for Construction and Implementation (PZI) No. 05-2020 - Anchor buoys for Temporary Mooring of Vessels in the Debeli rtič Nature Park [3] - 72 mooring buoys can be rented in the area between the Youth Health Resort and the Debeli Rtič Resort and the bathing area "Na študentu", as well as in the area of Jernej Bay. According to the project documents, the moorings are only for vessels up to 12 m in length and only during the summer tourist season (from 1 June to 15 September) from sunrise to sunset.

At the Faculty of Maritime Studies and Transport of the University of Ljubljana, we studied six options for managing/renting mooring buoys in order to find the optimal and economically acceptable solution, namely:

1. rental of mooring buoys for 12 hours only.
2. rental of a combination of 12-hour and 24-hour moorings.
3. rental of seasonal moorings only.
4. rental of a combination of 12-hour and seasonal moorings.
5. concessionaire and 12-hour and seasonal berths.
6. concessionaire (with a fixed concession fee) and rental of 12-hour berths.

All the above management methods at different time intervals are economically evaluated. To book the use of berths, we recommend the web application Porthop or a similar application, for which we offer two options:

1. as the application has already been developed with European funding from the Regional Development Fund, the first option, and probably the easiest, would be to acquire a licence for the needs of the Debeli Rtič Nature Park, which also covers the possibility of using other moorings on the Slovenian coast (e.g., Strunjan).

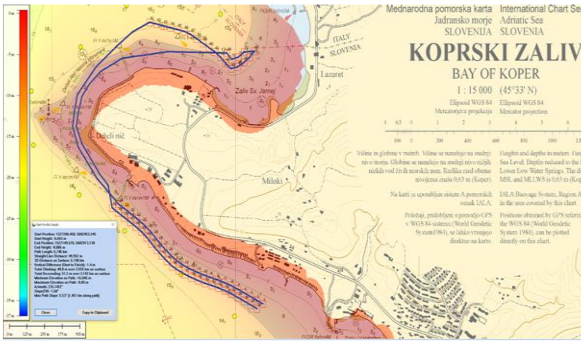
2. the contracting authority decides to take a similar step as Porthop d. o. o. [14] with the help of the European Regional Development Fund and develop a stand-alone application for the needs of the Republic of Slovenia. In this case, the financial contribution of the own contribution would be between 20 and 25% of the total value of the project.

6.2. Selection of the Anchor Manager

In order to verify the reservation for the use of mooring buoys and the suitability of the mooring vessels, an anchor manager should be appointed to check the condition of the mooring twice a day for a 12-hour hire or three times for a possible 24-hour hire, as suggested in Figure 10. In order to collect the cost of the berth, it should also be equipped with a POS terminal.

In the case of a 12-hour berth, this would be supervised by a person with a small inflatable boat with an outboard motor, the purchase price of which should not exceed 20,000 euros. In the case of a 24-hour berth control, users should also be offered a means to remove waste from the berth. According to the national regulations for boats and floating equipment [16], this task and the simultaneous control would require a boatman and his assistant as well as a suitable vessel. The price for such a working vessel is in principle between 60,000 and 100,000 euros.

The client has the option of performing the function of berth manager independently or through a concession, in which case the activity would be carried out by the concessionaire. The latter option would probably be more customer-friendly, as in this case there are no start-up costs for the purchase and maintenance of the vessel. According to our information, the estimated amount for which the concessionaire would be willing to provide the service is between 200 and 300 euros/day. Of course, there is also the possibility for the contracting authority to award a concession if it sets a fixed concession fee for the concessionaire.



Source: Authors

Figure 10: Anchorage observation plan

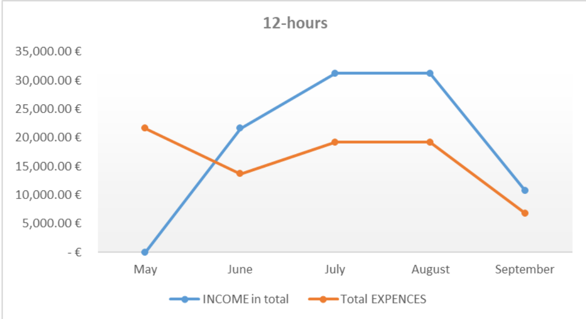
7. ANALYSIS OF DIFFERENT METHODS OF RENTING MOORINGS - FINANCIAL STRUCTURE

We have made a calculation for all six mooring options mentioned in Chapter 6.1.

7.1. Rental of mooring buoys for 12 hours only

The calculation of costs takes into account the initial cost of setting up and removing the mooring buoys, and the final calculation of return on investment (ROI) also takes into account the investment of 40,000 euros, which includes the purchase of a boat and the application, as presented in Figure 11.

The ROI shows us that this option would pay for itself in less than three years. The remaining costs are lower compared to the following options, as there are fewer rounds of 12-hour moorings.



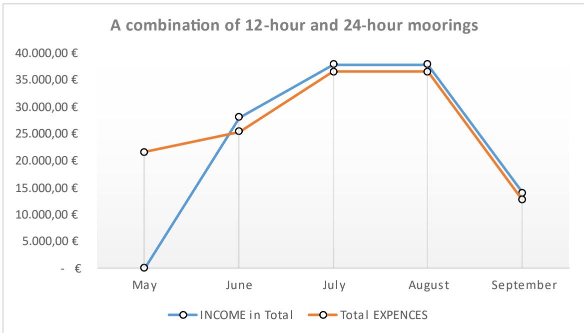
Source: Authors

Figure 11: Rental of mooring buoys for 12 hours only

Overall occupancy is expected to be 70% in June, 95% in July and August and 70% in September, with priority given to smaller vessels (5% and 10% respectively).

7.2. Rental of a combination of 12-hour and 24-hour moorings

The cost calculation takes into account the initial cost of placing and removing mooring buoys and in the final calculation of ROI the investment of €40,000, which includes the purchase of the boat and the app. The remaining costs are significantly higher compared to the previous option, as there are more patrols for 24-hour moorings. It should also be noted that the additional option reduces the revenue from the first option, as there are only 72 berths. The monthly profit, as presented in Figure 12, is positive, but the revenue does not cover the initial costs of setting up and removing moorings.



Source: Authors

Figure 12: Rental of a combination of 12-hour and 24-hour moorings

This combination also considered an overall occupancy rate of 70% in June, 95% in July and August and 70% in September, favouring smaller vessels and a 12-hour berth option.

7.3. Rental of seasonal moorings only

The calculation of costs takes into account the initial costs of installing and removing mooring buoys and does not anticipate the remaining investment, therefore no ROI is calculated for this option either. If all berths were let seasonally, no berth patrols would be required, which would significantly reduce costs. As depicted in Figure 13, this option therefore has the highest profit, which still amounts to 41,328 euros.

This option has taken into account an occupancy rate of 85% in June, 95% in July, August and September, as we assume that the berths will be fully occupied due to the otherwise high prices for berths on the Slovenian coast and the high demand in June, perhaps also due to the weather - and then the berths would be almost fully occupied, and as it is a seasonal purchase, the occupancy rate would remain unchanged until the end of the season.

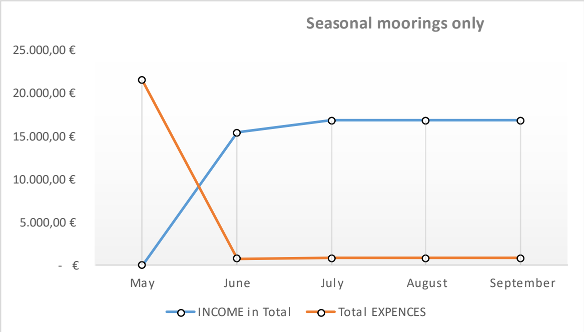


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Figure 13: Rental of seasonal moorings only

7.4. Rental of a combination of 12-hour and seasonal moorings

The cost calculation takes into account the initial cost of installing and removing mooring buoys and in the final calculation of ROI the investment of €40,000, which includes the purchase of the boat and the app. The remaining costs are significantly lower compared to the previous options (with the exception of the option to rent seasonal moorings only), as there are significantly fewer patrols due to the occupancy of the seasonal moorings, as presented in Figure 14.

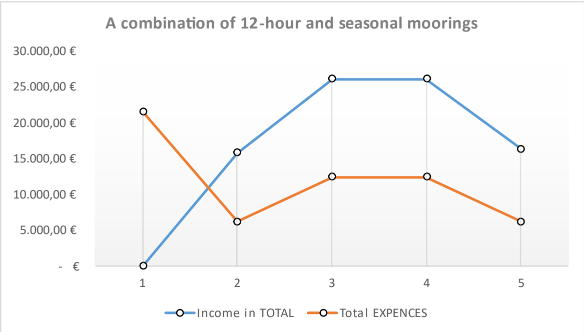

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Figure 14: Rental of a combination of 12-hour and seasonal moorings

The ROI is 64.04%, which means that the initial investment pays for itself in less than 2 years. This option also has the second highest business result, which amounts to EUR 25,615.80.

In this combination, we have taken into account the 70% total occupancy in June, 100% in July, August and September, the preference for smaller vessels and the 12-hour berth option.

7.5. Concessionaire and 12-hour and seasonal berths

The cost calculation includes the initial cost of setting and removing the buoys. The final calculation of ROI takes into account an investment of €20,000, which includes the applications, and the purchase of a boat is deducted from the investment. The remaining costs are significantly lower compared to the previous options (with the exception of the option to rent seasonal moorings only), as only the concessionaire's fixed costs of €200 per day are taken into account. The ROI is 207.82%, which means that the initial investment (which is half less than the other options requiring investment) is recovered in less than half a year. As depicted in Figure 15, this option also has the highest return of 41,564 euros.

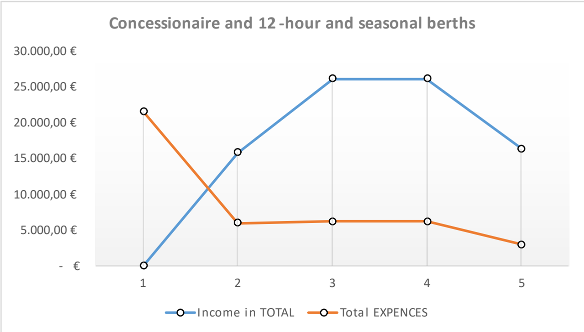

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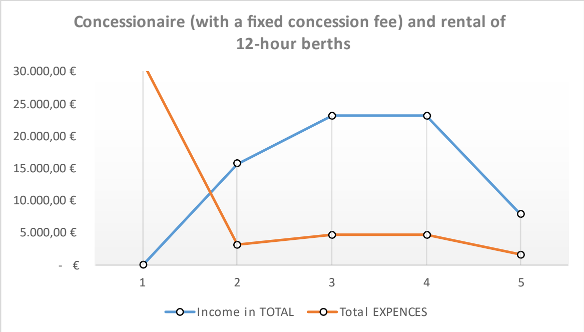
Figure 15: Concessionaire and 12-hour and seasonal berths

In this combination, we have taken into account the 70% total occupancy in June, 100% in July, August and September, the preference for smaller vessels and the 12-hour mooring option.

7.6. Concessionaire (with a fixed concession fee) and rental of 12-hour berths

The calculation of costs includes the initial costs of placing and removing the mooring buoys and the concession fee paid by the concessionaire to the municipality. The final calculation of ROI takes into account an investment of €20,000, which includes the purchase of the application. The concessionaire uses his/her own boat. The installation and removal of the buoys and the concession fee are considered as costs, as they are payable annually. It is also assumed that the concessionaire uses 20% of the revenue to cover other costs. In this case, the calculation is made for the concessionaire who works on his/her own account and the municipality receives the concession fee. The ROI is 122.31%, which means that the initial investment is returned to the concessionaire in less than one year, as shown in Figure 16. This option also has a high business return of €24,462.08, i.e., more for the concessionaire than the previous option and a return of €10,000 for the municipality, without any obligations regarding implementing or maintaining weather conditions in season, part, etc.



Source: Authors

Figure 16: Concessionaire (with a fixed concession fee) and rental of 12-hour berths

In this combination we have taken into account the overall occupancy rate of 70% in June, 95% in July and August and 70% in September, with a preference for smaller vessels.

8. ANALYSIS OF THE MANAGEMENT METHODS

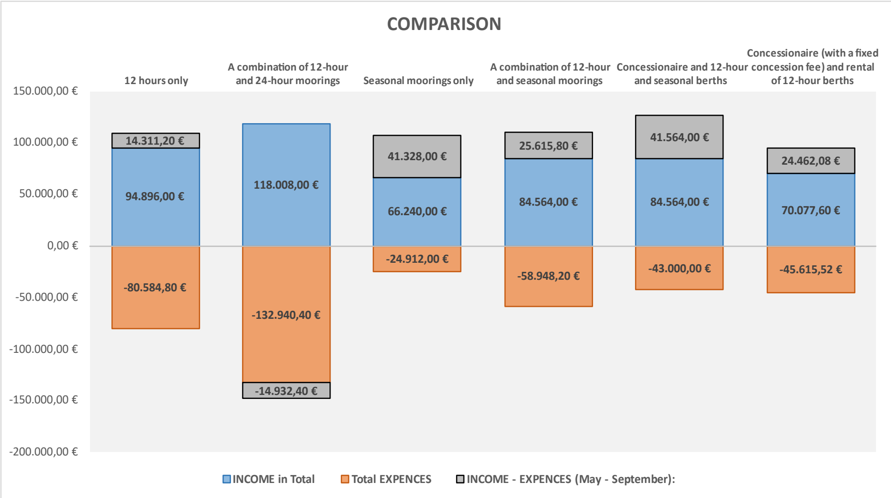
Given the remaining assumptions about the price of the moorings themselves, the investment for the application and purchase of the boat, and the estimated labour costs, a combination of a 12-hour and a 24-hour mooring is an absolutely inadvisable option, as it would not offset the higher costs due to more frequent patrols (it would pay off if only 24-hour moorings were sold). The most financially advisable option would be a combination of seasonal moorings and 12-hour moorings managed by a concessionaire who would receive a fixed amount of 200 euros per day, as presented in Figure 17.

The issue here is the reliability and diligence of the concessionaire with fixed payment. It is also recommended to have only daily moorings managed by the concessionaire but paying a fixed concession fee to the municipality at its own expense, as this option is more financially advantageous for the concessionaire and provides the municipality with a fixed income without having to worry about seasonal weather, occupancy, performance, etc. This is followed by the option of offering only seasonal moorings, which means almost the same profit and much less risk. However, we should not ignore the fact that renting out day moorings can have a positive impact on other tourism activities in the community. Therefore, we would recommend a combination of daily, 12-hour and seasonal berths, as this can also reduce doubts about the actual occupancy of the berths during the season (if they are booked in advance). Especially in the first year of operation, when all calculations are based on assumptions, we would recommend berths managed by the concessionaire due to the lower costs. The contract needs to be worded to include penalties for negligent work, or the municipality has the option to simply leave the entire implementation to the concessionaire, adding €10,000 (or another price) to the municipal coffers.

Everything written can change if the price of a single berth option changes or if occupancy changes. Cost is also extremely important because the cost of any combination that requires detours is very high (e.g., the time of the detours or the price of the workers and/or the boat).

9. CONCLUSION

The Faculty of Maritime Studies and Transport at the University of Ljubljana has prepared a study for the client Strunjan Nature Park on the management of moorings in the Debeli rtič Nature Park, which includes expert opinions and calculations for various proposed mooring methods. The proposed application for booking and using moorings at the anchorage is the Porthop application, which is adapted to the Debeli rtič Nature Park. It was determined that the most economical way for the client to manage the anchorage with the help of a concessionaire would be to rent daily 12-hour berths in combination with renting berths for seasonal mooring of smaller vessels.



Source: Authors

Figure 17: Analysis of the management methods

REFERENCES

[1] Decree on the Debeli rtič Nature Park, The Official Gazette of the Republic of Slovenia, No. 48/2018 of 13 July 2018.

[2] Monitoring of the state of tourist visits in Debeli rtič, Report, Project MedPAN North, Component 5, Local Activity 5. 2. 3. 3, Popić A., R. Turk, 2013.

[3] Project documentation for construction and implementation (PZI) No. 05-2020 - Anchor buoys for temporary mooring of vessels in Debeli rtič Nature Park, ERTA d. o. o, 2020.

[4] Management guide for Marine, Protected Areas of the Mediterranean Sea, Permanent Ecological Moorings, University of Nice-Sophia Antipolis & National Park of Port-Cros, rancour P., Magréau JF, Mannoni PA, Cottalorda JM, Gratiot J., 2006.

[5] Legal provisions for the protection of cultural heritage (eVRD), Ministry of Culture, 2018. https://podatki.gov.si/dataset/ varstveni-rezimi-kulturne-dediscine-evrd, accessed Dec 11, 2021.

[6] Project conditions for Debeli rtič Nature Park anchor buoys, Maritime Administration of the Republic of Slovenia, No. 3730-53 / 2020/7 of 18 January 2021.

[7] Maritime Code, The Official Gazette of the Republic of Slovenia No. 62/16, 41/17, 21/18, 31/18, 18/21 in 21/21, Ljubljana, 2001.

[8] The draft Maritime Spatial Plan of the Republic of Slovenia, The Official Gazette of the Republic of Slovenia numb. 116/21 of 15 July 2021.

[9] Book a mooring in the Balearies - CBBASea, Centre Balear de Biologia Aplicada, http://www.cbbasea.com/landing/index-en.html#book, accessed Dec 11, 2021.

[10] BoatyBall is Your Moor Secure Way to Pay, Stay, and Play, https://boatyball.com/tags/boater_app.html, accessed Dec 11, 2021.

[11] Reservation & Moorage Booking in Great Victoria Harbour, https://gvha.ca/marinas-facilities/reservations/, accessed Dec 11, 2021.

[12] Book your berth in marinas, buoy fields, and at (restaurant-) jetties at the best available price, https://my-sea.com/en, accessed Dec 11, 2021.

[13] Mooringo, https://mooringo.com/boaters/, accessed Dec 11, 2021.

[14] Porthop, https://www.getporthop.com/, accessed Dec 11, 2021.

[15] mySea, https://apps.apple.com/us/app/mysea/id802375798 , accessed Dec 11, 2021

[16] The national regulations for boats and floating equipment, The Official Gazette of the Republic of Slovenia, No. 25/08, 3/10 and 6/18, Ljubljana, 2018.

URBAN ROAD SAFETY – LITERATURE REVIEW

Boris Antić, Ph.D.
University of Belgrade, Faculty of Transport and Engineering
Vojvode Stepe Street 305, Belgrade, Serbia
b.antic@sf.bg.ac.rs

Filip Živković, M.s.
Road Traffic Safety Agency
Mihajlo Pupin Blvd. 2, Belgrade, Serbia
filip.zivkovic@abs.gov.rs

Jelica Davidović, Ph.D.
Dalibor Pešić, Ph.D.
University of Belgrade, Faculty of Transport and Engineering
Vojvode Stepe Street 305, Belgrade, Serbia
jelicadavidovic@sf.bg.ac.rs, d.pesic@sf.bg.ac.rs

ABSTRACT

The development of the society has led to a significant development of road traffic, but also to a clear perception of the negative effects that road traffic has on society. In order to show how traffic affects life in cities and human health, a literary review was conducted. The conducted literary review included 31 papers (2010 to 2021), where not only papers in the field of traffic were analyzed, but also papers in the field of environmental protection, medicine and urbanism. The result shows that the built environment affects the citizen's mobility, which leads to increased use of private automobiles, while sustainable patters of building the environment contribute to increasing the mobility of vulnerable road users. Increased use of automobiles leads to significant environmental pollution, through pollutants, noise and surface occupancy, which affects the ecological image of the city, but also the health of citizens (where the development of physical and mental diseases stand out). Urban road safety favors sustainable transport modes, such as active transport modes, but a major limitation is the lack or poor maintenance of infrastructure that would lead to increased use of these transport modes, but also to an overall increase in road safety levels. Creating sustainable cities, by applying urban road safety measures, should not only reduce the number of motor vehicles and leave public spaces to citizens, but will thus improve the overall image of the city, increase accessibility to objects of attraction, and it will also reduce environmental pollution.

Keywords: Urban road safety; Urban sustainability; Sustainable cities; Public health; Environmental pollution; Active transport modes

1. INTRODUCTION

Living in 21st century has become unthinkable without road traffic and all its benefits. Also, it is not possible to achieve further development of society without road traffic as an existential function of living space. The advantages of road traffic were recognized even with appearance of the first automobiles moving at speeds less than 20km/h, when time savings were achieved when crossing longer distances.

However, as road traffic developed more and more, so did the negative effects and consequences that road traffic has on the social, health, environmental and economic aspects of human life. Some of the most significant negative effects are: road traffic accidents (property damage, number of injuries and fatalities), resource depletion, environmental pollution with exhaust gases, noise, stress caused by participation in road traffic, social pollution (interpersonal relationship pollution) and the like.

According to the World Health Organization (WHO, 2018), 1.35 million people died in road traffic accidents worldwide in 2016, which is an increased compared to previous years (with the mortality rate of 18.2 fatalities per hundred thousand inhabitants). However, the same data show that the number of motor vehicles reached 2 billion in 2016, and the mortality rate per one hundred thousand registered vehicles is falling (64 during 2016). All of the above has led to the fact that injuries from road traffic accidents are the 8th cause of death in all age groups (but the leading cause when it comes to mortality in children and youth (5-29 years)).

Based on Integrated Database of the Road Traffic Safety Agency (http://195.222.99.60/ibbsPublic/ visited on 04/23/2021). 459 road traffic accident with fatalities and 11,829 with injuries occurred in Serbian during 2020.

According to the same database, 87 road traffic accidents with fatalities and 3,592 with injuries occurred in Belgrade during 2020. Annual report on the number of registered vehicles of the Statistical Office of the Republic of Serbia (2021) reported that 2,164,818 passenger automobiles were registered in Serbia, and 594,063 passenger automobile were registered in Belgrade during 2020.

However, road traffic accidents, although easily measurable, are not the only negative consequences of road traffic. Some of the consequences that cannot be easily measured and proven numerically are diseases of the cardiovascular and respiratory organs and diabetes; air pollution by exhaust gases and noise caused by traffic; reduced physical activity that leads to various other forms of physical and mental illness and effects the environment; impact on population mobility and public space occupancy.

According to an initiative by the International Transport Forum, called “Safer City Streets”, the streets were seen as very dangerous for vulnerable road users. In this regard, the concept of Urban Road Safety has been established, which together with sustainable mobility, aims to reduce motorization in the city center, and all in order to increase citizens’ mobility and reduce congestion, protect their health from harmful effect of polluting emissions of exhaust gases and noise, and above all to protect their lives.

Although the ITF initiative uses the term Urban Road Safety, this term still does not have an exact definition in the field of road safety. In this regard, it is necessary to give a proposal for a definition, which will be used in the continuation of this paper: “Urban road safety is a part of the road safety as a scientific discipline, which studies the impact of negative effects of road traffic on society, and which, on the other hand, develops the improvement of the environment and psycho-physical health in cities that are socially and economically suitable for life.”

According to the develop definition of urban road safety, it is not equally important in all countries, as the problem of safety, pollution, public health and other harmful consequences of road traffic is not equally expressed in all countries of the world. However, as the world approaches the entry into the sixth phase of road safety, it is necessary to work intensively on the development and change measures that will significantly reduce the consequences of road traffic. Since it is not possible to talk about one unified solution, it is necessary to work on the list of proposed measures that need to be considered. Precisely for that reason, a literary review of papers published so far dealing with the topics of urban road safety was conducted. This literary review will give the overview of the achievements of science in this filed, and on the basis of which further directions of work in the field of urban road safety should be defined, so that in the next ten years there will be no significant expansion of road traffic problems in urban areas. The aim of this literary review is to better understand urban road safety, as a new branch of road safety as a scientific discipline.

2. METHODOLOGY

The results presented in this paper are the result of searching the literature related to the problems of urban road safety, and their solutions.

Step 1 – In the first step, a search of the electronic database of scientific papers (ScienceDirect) was performed, according to predefined keywords. The defined keywords, according to which the search was performed, are the following: urban road safety, sustainable mobility, traffic related noise and air pollution, physical and mental health, public health, traffic congestion, public space, walking and cycling, air quality. Combinations of all keywords were also included. During the literary review, key words were selected that authoritatively describe the modern concept of road traffic safety and life in urban areas. The search was performed in all journals of the mentioned database. It is important to note that the search is limited to the period from 2010 to 2020, due to the fact that urban road safety is a topic that has begun to be considered in recent years. In this way, a large number of papers dealing with this area were collected (99 papers). The largest number of papers was published in the journals Accident Analysis and Prevention (14), Transport Research Procedia (9) and Journal of Transport and Health (6). Of the total number of collected papers, the largest number was published during 2019 (32), followed by published during 2020 (20). In addition to the electronic database of scientific papers, websites and technical reports were searched, which provided data on the number of road traffic accidents, the number of fatalities and injuries, as well as the number of registered vehicles.

Step 2 – After collecting the papers, an analysis was performed based on the title, keyword and abstract, during which the elimination of some papers was performed. During this analysis, the authors excluded papers that are not closely related to the road traffic safety and urban mobility (urban road safety) in city areas. In this way, the number of papers to be analyzed was reduced (31 papers). The largest number of papers was published in the Journal of Transport and Health (5). Most selected papers were published in 2019 (10).

Step 3 – The papers left after the first two steps are analyzed in detail and presented in the paper. The paper also present the results of papers that are not primarily in the field of transport, but medicine, urbanism and ecology, and which deal with road traffic impact on people and the environment.

The results are systematized into papers dealing with Urban sustainability (12 papers), Environmental pollution (4 papers), Public health (8 papers) and Active transport modes (7 papers).

3. RESULTS

In this section, the results of reviewed papers are systematized in four groups:

- Urban sustainability – this group of results gives an overview how the built environment of cities affects the level of road safety and citizens' mobility. This leads to a review and effect of measures implemented to increase accessibility to vulnerable road users.
- Environmental pollution – this group of results shows the traffic impact in cities through indicators that are not easily measurable as traffic accidents, i.e. air and noise pollution.
- Public health –the results of the review of how traffic, through all the negative effects, affects the physical and mental health of citizens.
- Active transport modes – walking and cycling can contribute a lot to the development of healthy habits of citizens and the improvement of mobility in cities; however, this is a process that requires a change of awareness and the development of the necessary infrastructure.

3.1. Urban sustainability

Cities around the world face with the problems related to unequal mobility and accessibility, pollution caused by motor vehicles, traffic accidents and street crime (Mohan et al. 2017). In their paper, Mohan et al. stated that street layout and road width can have a major impact on the number of fatalities in road traffic accidents in cities (in addition to vehicle safety, road design and police enforcement). In addition, they find that the denser traffic network, with an increased number of intersections per area, has a significant lower number of road traffic accidents. In other words, a higher number of intersections along the road is significantly associated with a lower number of road traffic accidents and pedestrian mortality rate.

Feng Wei and Lovegrove 2012 for solving the problem of "traffic safety epidemic" (consequences of road traffic accidents), as a good practice, recognize the preparation of more sustainable patterns of community development. This is an urge for more sustainable land use and transportation, as a key to improve global road traffic safety, because the built environment directly affects automobile dependence, as well as socio-economic status. Their opinion is that a more sustainable form of built environment (which are suitable for walking, cycling, in other words, neighborhood for activity) can lead to a reduction of automobile use, which, on the other hand, leads to a reduction in road traffic accidents. For example, this will lead to greater use of bicycles, where the number of bicycle accidents is growing much slower than automobile accidents.

Schreuer et al. (2019) conducted a study in which they analyzed daily activities outside the home of people with and people without disabilities, where the built and nature environment were identified as potential barriers for people with disabilities. The authors recognize that there are several ways to measure the impact of the environment: accessibility to buildings or characteristics of the condition of the street. They recognize that poor street connectivity and large slopes require greater distances and citizens' efforts (especially people with disabilities). However, on the other hand, they state that the higher density of constructed facilities represents a better connection in terms of public transport and accessibility, which is a great benefit for people who use various forms of aids. Concluding, they state that a smaller number of slopes leads to increased activities of persons with disabilities, and the use of non-residential land for cultural and leisure activities has the same effect.

Weng et al. (2019) recognized the construction of a neighborhood that will have a good fifteen-minute connection as a good solution for improving physical activity, in order to provide citizens with the opportunity to walk more. With spatial regression, they showed that adults in China walk much more, while regression is negative associated with children (due to limited access to public areas, greenery, shops, etc.). They also state that adults choose communities that are suitable for mutual contacts for walking. However, low housing density and poor street connectivity may reduce residents' motivation to be physically active. Four aspects for building walkable and healthy communities have been identified: providing full service provision, building pedestrian streets, forming a compact landscape, and developing housing affordability.

In order to reduce number of automobiles in cities, the most commonly applied measure is the introduction of prohibition on automobile traffic and parking. However, this is not only something that affects the users of private automobiles, but also the owners of shops located in the zone where the prohibition was implemented (usually in the city center) (Szarata et al. 2017). Szarata et al. indicate that an increased number of visitors have been observed at locations that are closed to road traffic. When it comes to the shop owners in the areas where the change was made, they generally did not notice significant changes in terms of revenue (19% of them declared a decrease in revenue, while 7% stated that they made a higher profit). On the other hand, the authors state that the prohibition on access to automobiles has a positive effect on active transport modes, especially walking, as the mode that most visitors choose to access the zone. Also, there was an increase in the use of bicycle as transport mode (from 4% to 9.3%). However, such a policy can also lead to related problems, such as longer trips, congestion, lack of parking spots, poorly developed cycling infrastructure and the like. Szarata et al. state that citizens must give their contribution in the choice of locations where such a policy will be implemented, due to the fact that it is redesign of the space that is primarily intended for people, where will be an absence of road traffic and will be landscaping.

Istanbul faces problems caused by increased urban mobility, such as congestion, increased motorization, public transport congestion, air pollution and noise. In this regard, Canitez et al. (2020) conducted a qualitative analysis of Istanbul's public transport policies and strategies based on Master Plan and Strategic Plans. The authors state that the focus on large infrastructure projects cannot reduce the mentioned problems of urban mobility, because they are not aimed at changing citizens' transport modes, i.e. towards changing transport modes from automobiles to more sustainable modes, such as public transport, cycling and walking. On the other hand, Kraidi and Evdorides (2020) state that the number of bus stops, parking spots, pedestrian crossings, speeding and the number of intersections have a significant impact on the risk of road traffic accidents with pedestrians. In this regard, the authors emphasize that when designing surfaces, special emphasis should be placed on this vulnerable group of road users, in order to improve their safety.

In European cities, cycling and walking are becoming more common transport modes, which can replace automobile travel, especially in cities where there are a large number of short trips. In their study, Gösling et al. (2019) state that cycling and walking have benefits that can be measured as 0.18€/pkm and 0.37€/pkm, respectively, and the biggest are the health benefits. The cost of cycling per person is significantly lower than when driving a passenger automobile, and is primarily related to saving travel time. However, cyclist are more exposed to polluted air due to nature of their movement and therefore tend to choose longer routes in order to avoid pollution. Gösling et al. state that the total cost of automobiles is estimated at 500 billion euros at the Europe level, while cycling and walking bring benefits in the form of 24 billion and 66 billion euros annually, respectively. The authors also state that the automobile system is supported in the form of various subventions, but that for health reason it is necessary to support active transport modes. According to the calculation they carried out, they state that replacing an automobile with a bicycle represent a benefit of 0.30€/pkm, while switching from an automobile to walking brings a benefit of 0.48 €/pkm.

Pisoni et al. (2019) focused on the concept of the "Sustainable Urban Mobility Plan", as a solution to the problem of air pollution, and which aims to support local authorities in the search for new urban strategies. Namely, in their review, they defined SUMP as a goal for improving accessibility to urban areas, which ensure high quality and sustainability of mobility and transport in that area. As a SUMP is a political measure, it must consider many challenges: Health (how to create a healthier environment for citizens); Congestion (how to create an economically viable and convenient city); Safety and security (how to ensure a safe urban environment and mobility); Participants (how to involve citizens); Strategic planning (how to achieve policy goals while meeting society's mobility needs); Climate change (how to reduce climate change caused by emissions resulting from urban public transport). The SUMP should consider each measure and assess it as: Avoid – avoiding unsustainable practices; Shift – shifting from unsustainable to sustainable transport mods; Improve – improving current behavior in transportation activities. The authors conclude that the Sustainable Urban Mobility Plan is an important policy instrument that improves mobility and quality of life in cities.

The concept of Complete Streets, i.e. a system oriented towards the design of streets that are sufficiently safe for all road users, i.e. for all transport modes, is used all over the world. Mofolasayo (2020) states that this concept has great advantages for vulnerable road users in terms of sharing streets with vehicles that can achieve high speeds. However, the author states that the speed of vehicles and the separation of transport modes have a significant impact on pedestrians and cyclist. This emphasizes the need for infrastructure to be sufficiently safe for active transport modes.

In his paper, Wu (2014) recognized that no city can be sustainable without external ecosystem services, however, an urban landscape can be sustainable if properly designed, planned and managed.

3.2. Environmental pollution

Automobile use is the free choice of each person, however, automobile use has a very widespread impact on both individual and the local and global level (Douglas et al. 2011). Douglas et al. recognize road traffic as one of the important factors of air pollution, namely, in their research the estimated that road traffic caused approximately 30% of $PM_{2.5}$ and 50% of PM_{10}, as well as 22% of total CO_2 emission. In addition, the use of automobile is a kind of noise pollutant that can caused sleep and blood pressure diseases and the like. This show that automobiles, although the choice of the individual, are actually a problem of the whole society. In their paper, Douglas et al. state that the solution to this problem lies in the development of sustainable transport, and, above all, in active transport modes and road safety, better land use and the promotion of health habits.

Urbanization and increased use of road traffic have led to increasing exposure to air pollution and noise. Andersson et al. (2020) conducted research on how exposure affects the human health in Sweden, on a sample of 6,304 men. The results show that there is no significant increase in the risk of cardiovascular diseases due to exposure to noise that is a product of road traffic (level higher than 60dB). The observed ratios were: 1.08 for cardiovascular disease mortality, 1.14 for heart disease, and 1.07 for insulin use. Dealing with the research of noise that is a consequence of traffic in Sfax (Tunisia), Bouzid et al. (2020) conducted a survey questionnaire (1,271 respondents) and field noise measurements (633 measurements at 211 locations). The authors noted the highest noise levels from 60 to 65dB and state that the impact of traffic noise on human health depends on variables such as the individual and the situation.

A study conducted by Neves and Brand in 2018, in Wales (United Kingdom), involved 50 respondents whose movements were recorded via GPS systems and their travel diaries (two seven-day periods in 2011 and 2012). As a result of this study, it is known that out of the total number of realized trips (2,664 trips), approximately half of them were shorter than 3 miles. The reason for those short trips are the daily citizens' needs, going to work, to the store, driving children to school, and even the lack of a better solution. In addition to a large number of short trips, Neves and Brand state that every respondent on average caused an emission of 28.6kgCO_2 on a weekly base, with only participation in road traffic accounting for 90% of CO_2 emission. However, they also state that if the trips that the respondents made by bicycle or on foot were done by automobile, the emission per person would be higher by 4.9%. As the conclusion of the work, they recognized that it is possible to change the transport mode from a passenger automobile to a more active mode in the case of 41% of realized trips, which would reduce CO_2 emission by approximately 4.5%.

3.3. Public health

Másliková (2017) states that death in a road traffic accident is the most severe consequence of the same. In addition, the impact of injuries is also very significant. However, accidents also affect the mental state of an individual. This consequence often remains long-lasting, or at least in the following period after physical recovery. Referring to the consequences of road traffic accidents, Másliková recognizes the importance of social support, in order for an individual to cope with emerging difficulties. In this regard, she states that accident can have health and social consequences. When it comes to the health consequences of road traffic accidents (where pedestrians are recognized as the most vulnerable group) they can be divided into temporary and permanent disability. The social consequences of road traffic accidents include loss of productivity, legal and medical costs, changes in the social, family and professional life of an individual.

Nadrian et al. (2020) conducted a study based on the assessment of the impact of traffic congestion on the health of the citizens of Sanandaj, Iran. The authors conducted a case study and a mixed method to collect data for analysis (documentation, interviews and focus groups, field recording and survey). The results of the study show an increase in the number of registered deaths and hospitalized people due to diseases related to air pollution. The authors recognize that traffic congestion have a great impact on the physical and mental health of citizens, which citizens showed through a survey. Namely, the citizens of Sanandaj believe that the increasing traffic congestion in the city reduce the level of air quality, limit the mobility, reduce the quality of public services and encourage the use of cigarettes. In their paper, Nadrian et al. in particular state that the big problem lies in the lack of streets, underground and overground crossings, parking spots in the areas with the largest volume of road traffic and in poor traffic education.

Douglas et al. (2011) recognized that automobiles have an impact on air pollution, but also on amplified ambient noise. Every year, more than a million people prematurely die due to air pollution, which causes cardiovascular diseases and the development of cancer cells, especially in vulnerable groups. Road traffic contributes to this by emitting polluting particles $PM_{2.5}$ and PM_{10} (with 30% and 50%, respectively). In addition, road traffic accounts for 22% of total CO_2 emission, contributing to climate change, which has claimed more than 150,000 lives since 2000. In their paper, Douglas et al. state that the noise emitted by road traffic affects the development of sleep disorders, hypertension and increased blood pressure in people who are exposed to increased exposure.

To examine the impact of air pollution on cyclist, Krecl et al. (2020) operated a bicycle on the streets of Curitiba (Brazil), passing through several zones with different traffic management strategies (bus lines, bicycle lines, slow traffic zones, traffic lights). The authors state that the air pollution was very high during the morning peak hour, following by the afternoon peak hour. The concentration of pollutants is very high at bus stops and signalized intersections, while the lowest level of pollution was observed in streets with less traffic, where is a particularly small number of heavy vehicles. However, the authors state that the impact of slow traffic zones on the level of air pollution, that cyclists are exposed, is still unclear and that additional research is needed.

In order to exam the impact of road traffic noise on sleep quality and mental health, Sygna et al. (2014.) used a survey on self-reported sleep quality. The results of their study show that there is a slight increase in psychological anxiety with increasing levels to road traffic noise. However, this has only been noted in people who have reported poor sleep quality. They also recognized the existence of the link between road traffic noise exposure and possible mental disorders. In this way, it has been shown that there is a statistical relationship between noise and sleep, which indicates that sleep quality is a mediator between noise and mental health.

Evidence that noise greatly affects human health is a study conducted in 2016 by Recio et al., which examined the impact of noise on cardiovascular, respiratory and metabolic health. Most of the European population is exposed to daytime noise level higher than 65dB (night level – 55dB), which can caused cardiovascular and respiratory diseases, type 2 diabetes or problems during childbirth. During 2020, ambient sounds levels were measured at 19 locations in the city of Belgrade (Republic of Serbia), where the author divided locations into four zones (residential zone, high-traffic zone, central city zone and recreational zone), and the measurement was performed during the winter and summer months (Zivkovic, 2020). The results of the conducted measurement show that the level of ambient sounds exceeded the allowed limits at most measurement locations, in the range from 0.5dB to 20.3dB.

Air pollution and the environment can also affect mental health (Klompmaker et al. 2019). Using data from a national health survey, Klompmaker et al. concluded that air pollution was positively associated with poor mental health. While road traffic noise is associated only with the medical prescribing of anxiolytics, noise caused by rail traffic is associated with psychological disorders. The environment is associated with poor mental health of the elderly.

In a review of the safety of vulnerable road users, Olszewski et al. (2019) state that the number of pedestrians, cyclists and motorcyclist fatalities in the countries of the European Union is not declining at the same rate as in the case of other road users. Risk factors for the vulnerable road users include the location where the accident occurred, the type of intersection and control, as well as lighting conditions. Olszewski et al. conclude that the risk of fatality is always higher in areas classified as rural (in relation to urban conditions), and in night conditions (as opposed to day conditions). However, they also state that there are different shares in different countries. A possible reason for this lies in different population densities, different climates or different defined speed limits.

3.4. Active transport modes

Buehler et al. (2020) used a national household survey (2001-2017) in order to estimate the frequency, duration and traveled distance by walking and cycling per person in the United States. The results show that in the period from 2001 to 2017, an increase in the rate of walking was observed, while the rate of cycling remained the same. The authors found that respondents with the higher level of education, lower automobile ownership rates, and living in more density population areas were more likely to choose walking and cycling as a transport mode. The analysis showed that male respondents ride a bicycle three times more than female respondents, while the choice of walking is equal among the gender. On the other hand, the use of bicycles and walking decrease among children aged 5 to 15 in the observed period, while it increased for the age group of 16 to 44. Buehler et al. conclude that the improvement of infrastructure, programs and policies towards active transport modes can increase the share if this group in the overall distribution.

Walking as an active transport mode can provide a number of benefits, such as independence, flexibility, reliability, exercise and accessibility. It is these advantages that make walking a favorite among other transport modes. However, Lyons (2020) states that walking is not a transport mode that is often chosen because of its limitations, such as uncertainty of how long the journey will take and determining the way to navigate to the destination. In his paper, the author starts from the assumption that walking as a service represents the future of mobility. Walking as a service is based on the applications on smartphones that provide information on distance and travel time, which has proven to be a good practice, as the average number of walking increased from 2015 to 2018 in London.

Cycling is considered as much as ten times more dangerous than driving an automobile, but the results show that the cities with a high share of bicycle traffic are safer not only for cyclist, but also for all road users (Marshall et al. 2019). In their paper, Marshall et al. state that a larger number of cyclists on the road is not as important as the infrastructure that is being built for them. Namely, the improvement of cycling infrastructure with cycling surfaces that are safer (more protected) is largely related to the lower number of fatalities in road traffic accident and better road safety outcomes for all road users. As a result for increased safety for all road users, the authors state the application of various measures, such as traffic calming measures and defining safer speeds. If the cycling area increases from 2,500 linear feet to 5,000 linear feet, the mortality rate per 100,000 inhabitants will decrease from 9.7 to 7.9 per year, while the injury rate will decrease from 53.4 to 41.5 (there is a decrease of 18% and 22%, respectively). If additional measures are taken to increase the safety of cycling infrastructure, the mortality rate can be expected to decrease by 44% and the injury rate by 50%.

Physical inactivity of children and adolescents is a significant health problem of modern era. However, active travel offers currently health benefits and forms future sustainability and healthier habits (Kaplan et al. 2016). Young people who have grown up in flats do not have a habit of using active modes as a transport mode, while those who have grown up in the house are more likely to choose walking or cycling. Kaplan et al. also state that young people will choose to walk or cycle to school only if it is a very short distance. High road traffic density is negatively related to the probability that young people will choose to walk, while higher density of automobiles, trucks and traffic accidents is negatively related to the probability that young people will choose to ride a bicycle. The increased number of intersections leads to a smaller number of bicycle choices as a transport mode.

In their paper, Nawrath et al. (2019) considered how people of different social-cultural backgrounds value different levels of greening of the urban landscape in relation to cycling and whether they prefer green bike paths (even if it is connected to longer bike paths). Research shows that respondents are more inclined to choose green bike paths (at least with minimum vegetation). The presence of trees along the trail significantly increases the attractiveness of the street (trail) for activities such as cycling. This attractiveness also applies to walking as a transport mode. The authors argue that higher levels of education lead to better knowledge of the environment. In conclusion, Nawrath et al. state that the increase of green elements in urban landscape supports cycling as a sustainable transport mode within the city, which also have a positive impact on human health and convenience for living in the urban environment.

In their review, Weiss et al. (2015) state that the introduction of electric bicycles in the city system can greatly reduce carbon dioxide emissions and noise levels in the city. In addition, they state that such a solution is very suitable for overcoming the infrastructural and geographical problems that the city may face. However, before cities decide on such a measure, it is first necessary to adapt transport and charging infrastructure (introduction of special traffic lines/paths).

Electric scooter without excessive emissions and noise, and with acceptable dimensions, can help European cities alleviate growing problems with road traffic, emissions and parking (Hardt and Bogenberger 2019). In a study conducted by Hardt and Bogenberger, a group of respondents rode electric scooters for up to 56 days (with an average of 520.6km per vehicle). The results show that these vehicles are mostly used for local leisure travel, but there are also users who have used them for transportation to work. The conclusion of the test that was conducted is that there is a growing awareness of the benefits of electric scooters, and that the problem of charging infrastructure can be easily solved. Respondents cited ease of parking as the biggest advantage of this mode of transport, but also identified some disadvantages, such as weather dependence, the problem of carrying luggage and a subjective sense of safety.

4. DISCUSSION

The first group of analyzed papers is a group related to Urban sustainability (Table 1 in Appendix). In this group, 12 papers were analyzed, which were published in the period from 2012 to 2020. Among the applied methods are the most frequent analyzes of implemented strategies, followed by literature review and field questionnaires. The main conclusion is the need for more sustainable patterns of building an environment that is suitable for all groups of residents, which will lead to reduced use of private automobiles, but also to increased levels of road safety; on the other hand, this will lead to increase in the mobility of vulnerable road users.

As a second group, this paper analyzes papers related to Environmental pollution (Table 2 in Appendix). Four papers were analyzed, which were published in the period from 2011 to 2020. The method that has been singled out in these papers as the most suitable for giving results of environmental pollution is the measurement of exposure to air and noise pollution. Environmental pollution is here divided into air pollution and noise pollution, however, the basic conclusion shows that the ecology of cities is significantly disrupted by motor road traffic.

The third group of papers consists of papers related to Public health (Table 3 in Appendix). In this group, 8 papers were analyzed, which were published in the period from 2014 to 2020. Of the applied methods, the questionnaires related to the health of citizens stand out, but the contribution to this group of papers is significantly given by the measurement of exposure in the field. The conclusion of this group of papers shows that air pollution and noise as a consequence of road traffic contribute to the development of physical and mental diseases in humans.

Active transport modes are the fourth group of papers analyzed in this review (Table 4 in Appendix). A total of 7 papers were analyzed, which were published in the period from 2015 to 2020. Most of the papers used questionnaires as a source of data, but the advantage of using modern GIS tools is also noticeable. Although active transport modes significantly contribute to the citizens' health, and the surfaces intended for this group contributes to the general increase in road safety, a significant percentage of motor traffic and lack of surfaces intended for this group leads to slow development of this transport mode.

5. CONCLUSIONS

Over the last decade, the connection between road traffic and the environment has become increasingly recognizable. Namely, the development of road traffic contributes to environmental pollution, both by exhaust gases and the construction of road infrastructure, parking spaces and the like. In addition, road traffic has great negative effects on human health, contributes to the development of cardiovascular and respiratory diseases, physical inactivity and obesity (especially in young people). Noise is also a negative consequence of road traffic that affects the quality of human sleep and the development of mental illness. Of course, road traffic accidents, fatalities and injured in those accidents, remain the leading negative effect against which the fight should continue (with 1.35 million dead worldwide).

Precisely for that reason, the professional public is increasingly engaged in improving road safety as a scientific discipline, trying to bring it closer to the requirements of the developed world. This has led to adoption of the term Urban Road Safety, where the goal is no longer just to protect people from road traffic accidents (by measures for their prevention), but to protect people from all negative consequences of road traffic, creating an environment in which they have a greater sense of safety, which would increase the use of active transport modes. In other words, it strives to form cities that are more livable, accessible, cleaner and safer for all citizens – it strives for sustainable cities.

The aim of this paper is to better understand the concept of Urban Road Safety. All analyzed papers were published in the last years, when the professional public began to express interest in this area. A very small number of papers are based on survey questionnaires and citizens' attitudes, while several authors decided to de certain field tests (checking the implementation of the measure, measuring air pollution, measuring ambient sound levels, and experimental analysis), analysis of human and environmental impacts and by reviewing possible solutions.

In order to improve urban mobility, a large number of authors recognize the benefits of changing public spaces purpose. Namely, the prohibition on access to all or certain categories of vehicles and the prohibition of parking will lead to increase in the number of citizens who are ready to use a bicycle or walk as a transport mode. This is a measure that will have positive effects on the use of public transport as a more economical mode. In addition, surface redesign can encourage people with disabilities to participate more in activities that are not in their immediate environment. The construction of cycling infrastructure that is physically separated from motor traffic and enriched with green elements is a very suitable measure supported by a large number of citizens.

Following the EU Strategy for the period from 2021-2030, where the goal is to achieve the vision zero (i.e. the number of zero fatalities and severely injured in road traffic accidents) by 2050, one can see the connection with urban road safety, where the aim is to reduce the number of fatalities and severely injured in urban areas. In addition, a significant part of urban road safety is based on land use change, where access to safe system can help through design and speed limits. Just as one of the goals of urban road safety is the promotion of active transport modes, so one of the goals of the EU Strategy is to create a safer and more attractive environment for walking and cycling. As this goal of Strategy can lead to an increased risk of vulnerable road users, special emphasis should be placed on their needs, especially in relation to different groups of users (age, gender, and people with disabilities).

The creation of sustainable cities should not only reduce the number of motor vehicles and leave public spaces to citizens, but will thus improve the overall image of the city, increase accessibility to attractions, but will also reduce environmental pollution. A large number of trips realized by passenger automobiles can be replaced by some of the active transport modes, which will improve the air quality in the city, reduce ambient noise level, lead to greater physical activity and improve the overall citizens' health.

A significant number of authors recognized the development of the "Sustainable Urban Mobility Plan" as an important measure to achieve not only the goals of sustainable development of the UN, but also to increase the convenience of living in cities. In that way, additional importance is given to fundamental human rights, i.e. the right to life, freedom and safety. Importantly, the problem of safety, pollution and public health is not equally expressed in all countries of the world, for that reason it is not possible to talk about one unified solution, but only about the list of proposals that need to be considered.

The advantage of this paper in relation to previous papers in this field is that the results of the reviewed papers are systematized in four groups that indicate future activities and scientific research:

- Urban sustainability,
- Environmental pollution,
- Public health,
- Active transport modes.

Therefore, it is possible to define the directions of future research and activities on the issue of urban road safety based on the results of this review, all with the aim of reducing traffic fatalities, but also improving the quality of life of people.

Research in the field of Urban sustainability should answer the questions: how the change of land use affects the citizens' habits, especially the use of active transport modes; and how urban road safety measures (such as prohibiting access to all or certain categories of vehicles) can affect road traffic in town.

Environmental pollution research should answer questions about how road traffic affects city life, how much it contributes to air and noise pollution, and how surface occupancy affects vulnerable road users.

Public health is an area within which it should work on researching into how the harmful effects of road traffic in cities affect human health, and above all exhaust gases, noise, physical inactivity, but also the development on mental illness.

Active transport modes are the basic focus of urban road safety, where it is necessary to give an overview of their advantages on life in cities, especially in relation to traffic congestions.

It is important to keep in mind that all four groups of analyzed papers are interconnected in the whole of urban road safety, and that future work in this field requires simultaneous analysis of all aspects, with the aim of creating sustainable and urban safe cities.

During this literature review, the authors used general keywords for initial review, but future work must include more specific keywords, like last-mile delivery, bike sharing system, e-cargo bike-sharing systems, etc., that might bring to understand of new issues.

REFERENCES

[1] Road Traffic Safety Agency http://195.222.99.60/ibbsPublic/ visited on 04/23/2020

[2] Andersson E.M., Ögren M., Molnár P., Segersson D., Rosengren A., Stockfelt L. (2020.), Road traffic noise, air pollution and cardiovascular events in a Swedish cohort, Environmental Research 185, 109446, https://doi.org/10.1016/j.envres.2020.109446

[3] Badland H., Pearce J. (2019.), Liveable for whom? Prospects of urban liveability to address health inequities, Social Science & Medicine 232, 94-105.

[4] Bouzid I., Derbel A., Elleuch B. (2020.), Factors responsible for road traffic noise annoyance in the city of Sfax, Tunisia, Applied Acoustics 168, 107412, https://doi.org/10.1016/j.apacoust.2020.107412

[5] Buehler R., Pucher J., Bauman A. (2020.), Physical activity from walking and cycling for daily travel in the United States, 2001-2017: Demographic, socioeconomic, and geographic variation, Journal of Transport & Health 16, 100811, https://doi.org/10.1016/j.jth.2019.100811

[6] Canitez F., Alpkokin P., Kiremitci S.T. (2020.), Sustainable urban mobility in Istanbul: Challenges and prospects, Case Studies on Transport Policy 8, 1148-1157, https://doi.org/10.1016/j.cstp.2020.07.005

[7] Douglas M.J., Watkins S.J., Gorman D.R., Higgins M. (2011.), Are cars the new tobacco?, Journal of Public Health 33, 160-169, https://doi.org/10.1093/pubmed/fdr032

[8] European Commission, Annex I, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions, Europe on the Move, Sustainable Mobility from Europe: safe, connected and clean, Brussels, 17.05.2018

[9] Feng Wei V., Lovegrove G. (2012.), Sustainable road safety: A new (?) neighbourhood road pattern that saves VRU lives, Accident Analysis and Prevention 44, 140-148, https://doi.org/10.1016/j.aap.2010.12.005

[10] Gössling S., Choi A., Dekker K., Metzler D. (2019.), The social cost of automobility, cycling and walking in the European Union, Ecological Economics 158, 65-74, https://doi.org/10.1016/j.ecolecon.2018.12.016

[11] Hardt C., Bogenberger K. (2019.), Usage of e-scooters in urban environments, Transport Research Procedia 37, 155-162, https://doi.org/10.1016/j.trpro.2018.12.178

[12] https://www.itf-oecd.org/safer-city-streets visited on 04/23/2020

[13] Kaplan S., Alexander Sick Nielsen T., Giacomo Prato C. (2016.), Walking, cycling and the urban form: A Heckman selection model of active travel mode and distance by young adolescents, Transport Research Part D 44, 55-65, https://doi.org/10.1016/j.trd.2016.02.011

[14] Klompmaker J.O., Hoek G., Bloemsma L.D., Wijga A.H., van den Brink C., Brunekreef B., Lebret E., Gehring U., Janssen N.A.H. (2019.), Associations of combined exposures to surrounding green, air pollution and traffic noise on mental health, Environmental Research 129, 525-537. https://doi.org/10.1016/j.envint.2019.05.040

[15] Kraidi R., Evdorides H. (2020.), Pedestrian safety models for urban environments with high roadside activities, Safety Science 130, 104847, https://doi.org/10.1016/j.ssci.2020.104847

[16] Krecl P., Cipoli Y.A., Targino A.C., Castro L.B., Gidhagen L., Malucelli F., Wolf A. (2020.), Cyclist' exposure to air pollution under different traffic management strategies, Science of the Total Environment 723, 138043, https://doi.org/10.1016/j.scitotenv.2020.138043

[17] Lyons G. (2020.), Walking as a service – Does it have legs?, Transportation Research Part A: Policy and Practice 137, 271-284, https://doi.org/10.1016/j.tra.2020.05.015

[18] Marshall W.E., Ferenchak N.N. (2019.), Why cities with high bicycling rates are safer for all road users, Journal of Transport & Health 13, 285-301, https://doi.org/10.1016/j.jth.2019.03.004

[19] Másilková M. (2017.), Health and social consequences of road traffic accidents, Journal of Nursing and Social Sciences Related to Health and Illness 19, 43-47, DOI: 10.1016/j.kontakt.2017.01.007

[20] Mohan D., Bandgiwala S.I., Villaveces A. (2017.), Urban street structure and traffic safety, Journal of Safety Research 62, 63-71, https://doi.org/10.1016/j.jsr.2017.06.003

[21] Mofolasayo A, (2020.), Complete Street Concept, and Ensuring Safety of Vulnerable Road Users, transport Research Procedia 48, 1142-1165, https://doi.org/10.1016/j.trpro.2020.08.139

[22] Nadrian H., Mahmoodi H., Taghdidi M.H., Aghemiri M., Babazadeh T., Ansari B., Fathipour A. (2020.), Public health impacts of urban traffic jam in Sanandaj, Iran: A case study with mixed/method design, Journal of Transport & Health 19, 100923, https://doi.org/10.1016/j.jth.2020.100923

[23] Nawrath M., Kowarik I., Fischer L.K. (2019.), The influence of green streets on cycling behavior in European cities, Landscape and Urban Planning 190, art. 103598, https://doi.org/10.1016/j.landurbplan.2019.103598

[24] Neves A., Brand C. (2018.), Assessing the potential for carbon emissions savings from replacing short car trips with walking and cycling using a mixed GPS-travel diary approach, Transport Research Part A 123, 130-146, https://doi.org/10.1016/j.tra.2018.08.022

[25] Olszewski P., Szagała P., Rabczenko D., Zielińska A. (2019.), Investigating safety of vulnerable road users in selected EU countries, Journal of Safety Research 68, 49-57, https://doi.org/10.1016/j.jsr.2018.12.001

[26] Pisoni E., Christidis P., Thunis P., Trombetti M. (2019.), Evaluating the impact of "Sustainable urban Mobility Plans" on urban background and quality, Journal of Environmental Management 231, 249-255, https://doi.org/10.1016/j.jenvman.2018.10.039

[27] Recio A., Linares C., Banegas J.R., Díaz J. (2016.), Road traffic noise effects on cardiovascular, respiratory, and metabolic health: An integrative model of biological mechanisms, Environmental Research 146, 359-370, https://doi.org/10.1016/j.envres.2015.12.036

[28] Statistical Office of the Republic of Serbia, Census 2011, https://www.stat.gov.rs/en-US/oblasti/popis/popis-2011, visited on 04/23/2020

[29] Statistical Office of the Republic of Serbia, Registered road motor vehicles and trailers and road traffic accidents, 2020, Number 072, 03/12/2021

[30] Schreuer N., Plaut P., Lihi G., Dalia S. (2019.), The relations between walkable neighbourhoods and active participation in daily activities of people with disabilities, Journal of Transport & Health 15, art. 100630, https://doi.org/10.1016/j.jth.2019.100630

[31] Sygna K., Marit Aasvang G., Aamodt G., Oftedal B., Hjertager Krog N. (2014.), Road traffic noise, sleep and mental health, Environmental Research 131, 17-24, https://doi.org/10.1016/j.envres.2014.02.010

[32] Szarata A., Nosal K., Duda-Wiertel U., Franek L. (2017.), The impact of the car restrictions implemented in the city center on the public space quality, Transport Research Procedia 27, 752-759, https://doi.org/10.1016/j.trpro.2017.12.018

[33] Weiss M., Dekker P., Moro A., Scholz H., Patel M.K. (2015.), On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers, Transport Research Part D 41, 348-366, https://doi.org/10.1016/j.trd.2015.09.007

[34] Weng M., Ding N., Li J., Jin X., Xiao H., He Z., Su S. (2019.), The 15-minute walkable neighborhoods: Measurement, social inequalities and implications for building healthy communities in urban China, Journal of Transport & Health 13, 259-273, https://doi.org/10.1016/j.jth.2019.05.005World Health Organization (2018.), Global status report on road safety 2018.

[35] Wu J. (2014.), Urban ecology and sustainability: The state-of-the-science and future directions, Landscape and Urban Planning 125, 209-221, https://doi.org/10.1016/j.landurbplan.2014.01.018

[36] Zivkovic, F. (2020). The level of ambient sounds as an indicator of urban road safety. Put I Saobraćaj, 66(4), 11-18. https://doi.org/10.31075/PIS.66.04.02

APPENDIX

Table 1: A review of research findings related to Urban Sustainability

Author/Authors	Name of the journal	Year of publication	Method	Conclusion
Mohan et al.	Journal of Safety Research	2017	Analysis of fatalities	Cities with wider streets and larger blocks will have an increased number of fatalities in road traffic accidents.
Feng Wei and Lovegrove	Accident Analysis and Prevention	2012	Transport plan analysis	The transit to more sustainable land use and traffic patterns can lead to a significant improvement u road safety.
Schreuer et al.	Journal of Transport and Health	2019	Self-reported behavior survey	Higher land use percentage, housing density and slope are important characteristics of the city that are important for activities of people with disabilities.
Weng et al.	Journal of Transport and Health	2019	Measurement of 15-minut patency	Communities suitable for walking are mostly inhabited by the elderly population, while a low percentage of children in the total share of walking were observed.
Badland and Pearce	Social Science and Medicine	2019	Literature review	An increasing number of endangered neighborhoods need additional design to protect the environment.
Szarata et al.	Transport Research Procedia	2017	Field survey (owners and visitors)	The prohibition on access to automobiles in certain parts of the city brings benefits to visitors, while it has a very small effect on the revenue of the owners of the premises in the immediate vicinity.
Canitez et al.	Case Studies on Transport Policy	2020	Analysis of strategic documents	Focuses on large infrastructure projects cannot reduce the problems of urban mobility, because they are not aimed at changing transport modes of citizens.
Kraidi and Evdorides	Safety Science	2020	Road traffic accident model	The number of bus stops, parking spaces, pedestrian crossings, speeding and the number of intersections has a significant impact on the risk of road traffic accident for pedestrians.
Gössling et al.	Ecological Economics	2019	Cost-benefit analysis	Changing the transport mode would bring benefits of 24 million euros for switch to bicycle traffic or 66 million euros for switch to walking annually (at the European level).
Pisoni et al.	Journal of Environmental Management	2019	Literature review	SUMP as a concept contributes to the reduction of air pollution (2% - PM2.5 and 4% NO2), but also the improvement of the overall image of the city.

Mofolasayo	Transport Research Procedia	2020	Project analysis	The Complete streets concept has great advantages for vulnerable road users in terms of sharing streets with vehicles. However, speed of vehicles and the separation of transport modes have a significant impact on pedestrians and cyclists.
Wu	Landscape and Urban Planning	2014	Literature review	No city can be sustainable without work on ecosystem development.

Table 2: A review of research findings related to Environmental Pollution

Author/Authors	Name of the journal	Year of publication	Method	Conclusion
Douglas et al.	Journal of Public Health	2011	Analysis of collected data	Automobile dependence is a problem that significantly affects the ecology of the city.
Andersson et al.	Environmental Research	2020	Exposure research	There is no significant increase in the risk of cardiovascular disease due to exposure to road traffic noise.
Bouzid et al.	Applied Acoustics	2020	Questionnaire survey, noise measurement	The impact of road traffic noise on human health depends on variables such as the individual and the situation.
Neves and Brand	Transport Research Part A	2018	Case study using GPS devices and travel logs	Half of all trips, which were realized by automobile, are less than 3 miles. It is possible to replace 41% of travel with cycling or walking, which would 5% CO2 per trip.

Table 3: A review of research findings related to Public Health

Author/Authors	Name of the journal	Year of publication	Method	Conclusion
Másaliková	Journal of Nursing and Social Sciences Related to Health and Illness	2017	Literature review	The consequences of road traffic accidents are divided into health (injuries related to road traffic accident) and social (changes in the quality of life of an individual).
Nadrian et al.	Journal of Transport and Health	2020	Case study	An increase in the number of registered deaths of people due to diseases related to air pollution has been observed. It has been recognized that road traffic has a great impact on a person's physical and mental health.
Kreci et al.	Science of the Total Environment	2020	Field measurement	Air pollution is very high during the morning peak hour. The concentration of polluting particles is very high at bus stops.
Sygna et al.	Environmental Research	2014	Cross-sectional study using a questionnaire	Noise resulting from road traffic can be associated with poorer mental health which is associated with poor sleep quality.
Recio et al.	Environmental Research	2016	Literature review	A comprehensive, integrative model of stress with all known connections between bodily systems, conditions and processes at the physiological and psychological level, enables the establishment of various biological pathways that link exposure to environmental noise with health outcomes.
Zivkovic	Journal of Road and Traffic Engineering	2020	Field measurement	The level of ambient sounds exceeded the allowed limits at most locations in Belgrade.
Klompmaker et al.	Environmental International	2019	Cross-sectional study using a health survey	Road traffic noise is positively associated with prescribing anxiolytics. Noise effects affect different age groups differently.
Olszewski et al.	Journal of Safety Research	2019	Comparison of road safety indicators between countries	The risk of fatalities in road traffic accidents is significantly higher in rural areas at night.

Table 4: A review of research findings related to Active Transport Modes

Author/Authors	Name of the journal	Year of publication	Method	Conclusion
Buehler et al.	Journal of Transport and Health	2020	National survey	In the period from 2001 to 2017, an increase in the rate of walking was observed, while the rate of cycling remained the same. Respondents with a higher level of education are more likely to choose walking and cycling as a transport mode.
Lyons	Transport Research Part A	2020	Application of modern tools	Walking as a service is based on the use of applications on smartphones that provide information about distance and travel time.
Marshall and Ferenchak	Journal of Transport and Health	2019	Analysis of collected data	Greater road safety is associated with a large number of cyclist areas (especially those that are separate from motor traffic). There is a strong correlation between the density of intersection and the reduction in the number of road traffic accidents.
Kaplan et al.	Transport Research Part D	2016	Questionnaire survey and application of GIS analysis	By reducing the number of automobiles and the movement of heavy good vehicles, as well as the points of conflict, it leads to an increase in the number of active trips.
Nawrath et al.	Landscape and Urban Planning	2019	Questionnaire survey	Citizens are inclined to choose bicycle routes that have more green elements.
Weiss et al.	Transport Research Part D	2015	Literature review	Support for electric vehicles can help in reduce air pollution and noise resulting from urban road traffic.
Hardt and Bogenberger	Transport Research Procedia	2019	Experimental study	Many days trips are suitable for the use of electric scooters, however, the main obstacles are subjective feelings of safety, lack of luggage space and weather conditions.

ON ADJUSTMENT OF STOWAGE PLAN WITH MINIMUM RESOURCES

Alexandru Stefan Bacioiu, M.Sc., Ph.D. student
Ionela Goia, Eng., M.Sc., Ph.D. student
Transport Faculty, University Politehnica of Bucharest, Bucharest, Romania
alexandru.bacioiu@yahoo.com, ionela_goia483@yahoo.com

ABSTRACT

Stowage plan is the heart of ship planning. In this paper we consider the optimization of handling the cargo units from a shipping line point of view to minimize the total time of operations in a port of call, including handling movements and maximizing the ship's capacity utilization. Constraints to be satisfied mainly result from the stability of the ship; therefore, how the cargo is handled and arranged in the ship's holds should be in such a way to ensure the stability of the ship for both sea and port conditions to avoid any accidents. Due to unforeseen factors, there are cases when cargo units in a port of call may be different from the contract of carriage. Thus, a deviation from the stowage plan is needed. Thereby, we propose a method of minimizing cargo handling and capacity reserve for the adjustment of stowage plan.

Keywords: stowage plan, capacity reserve, cargo handling

1. INTRODUCTION

The aim of the paper is to contribute to a topic of particular importance in the maritime industry and not limited to this, because the application of stacking and stowage planning can be extended also to other industries which requires storage or warehousing.

The research on containership stowage planning has demonstrated that in the present state of knowledge in this area as well as in the impact on the environment can provide a new approach which will be constructed in this paper. The subject was developed from the desire of efficiency arising from the shipping line point of view to minimize the total time of operations in a port of call having in mind the stability of the ship with all its factors.

The solution to the problems discussed is reflected in this research, through the original approach which includes a method of minimizing cargo handling.

2. LITERATURE REVIEW

The stowage plan of containers is also known as the Master Bay Problem and can be described as an assignment problem in which a number of containers with a specific destination must be assigned to slots in a ship with the aim of reducing the cost of transportation.

Container handlings in port are going on due to several reasons such as the vessel stability should be guaranteed, the over stacking must be reduced or simply the containers arrived in the destination port. About stowage planning and minimizing cargo handling and capacity reserve for the adjustment of stowage plan several works are published and authors, however the following are considered major works studying these problems:

- Ambrosino, D., A. Sciomachen, & E. Tanfani (2004). Stowing a Containership: The Master Bay Plan Problem. Transportation Research Part A: Policy and Practice 38 (2), 81–99.
- Ambrosino, D., Paolucci, M., & Sciomachen, A.. (2013). Experimental Evaluation of Mixed Integer Programming Models for the Multi-Port Master Bay Plan Problem. Flexible Services and Manufacturing Journal 27 (2–3): 263–284.
- Ambrosino, D., Paolucci, M., and Sciomachen, A.. (2017). Computational Evaluation of a MIP Model for Multi-port Stowage Planning Problems. Soft Computing 21 (7): 1753–1763
- Avriel, M., Michal, P., Naomi, S., & Smadar, W. (1998). Stowage Planning for Container Ships to Reduce the Number of Shifts. Annals of Operations Research 76, 55–71.
- Delgado, A., Jensen, R. M., Janstrup, K., Rose, T. H., & Andersen, K. H. (2012). A Constraint Programming Model for Fast Optimal Stowage of Container Vessel Bays. European Journal of Operational Research 220 (1), 251–261.
- Ding, D., & Chou, M. C. (2015). Stowage Planning for Container Ships: A Heuristic Algorithm to Reduce the Number of Shifts. European Journal of Operational Research 246 (1), 242–249.
- Kang, J.-G., & Kim, Y.-D. (2002). Stowage Planning in Maritime Container Transportation. Journal of the Operational Research Society 53 (4), 415–426.
- Moura, A., Oliveira, J., & Pimentel, C. (2013). A Mathematical Model for the Container Stowage and Ship Routing Problem. Journal of Mathematical Modelling and Algorithms in Operations Research 12 (3), 217–231.

Kang and Kim (2002) also studied a stowage planning problem for arranging containers on a vessel that minimizes the time required for shifts and quay cranes (QC) operations on a vessel tour by maintaining ship stability.

Delgado et al. (2012) proposed an integer programming model (MIP) which refers to the problem of slot planning, while Moura, Oliveira and Pimentel (2013) developed a model for a containership which optimizes the stowage of containers and minimize the total cost of routing and shiftings. Their MIP model took into account a vessel with no fixed route and reduced the transportation time and delivery cost.

Ambrosino, Paolucci and Schiomachen (2013) took the original model of optimization proposed by Ambrosino, Schiomachen and Tanfani (2004) and extended it to the multi-port. In order to minimize the number of unloaded and re-handled containers they incorporated two exact MIP models. Ambrosino et al. (2017) continued the work and proposed a new fast MIP model which had the aim to solve the real size of the problem.

Wei-Ying, Yan and Zhuo-Shang (2005) took the containership stowage plan problem, decomposed it into two sub-problems and in order to minimize the overstacking and the number of bays they incorporated two objective functions.

Various other researchers solved the stowage planning problem using conventional solution approaches and stowage planning model with multiple ports, however the present paper addresses a problem which is not extensively studied.

In the next part of the paper, the authors described and solved in an original way the problem of stowage planning.

3. PROBLEM DESCRIPTION

Stowage planning is the core of ship planning. Planning a ship's stowage is a two-step process. The first step is executed by the shipping line. The shipping line's stowage plan has to be designed for all ports of a vessel's rotation [7].

The positions for all containers and all ports of a rotation have to be selected within the ship. Stowage planning of a shipping line usually does not act with specific containers identified by numbers, but on categories of containers. These categories or attributes are: the length or type of a container, the discharge port and the weight or weight-class of containers. Containers of these attributes are assigned to specific positions within the ship.

The objective of optimization from the shipping line's point of view is to minimize the number of shiftings during port operation (ship to ship or ship to shore shifts) and to maximize the ship's utilization. Constraints to be satisfied mainly result from the stability of the ship. In the second step of stowage planning the ship is adjusting the cargo operations plan due to the need to satisfy the constraints coming from the stability of the ship.

Shifting is a term used in container shipping which refers to over stowage and is in simple terms the relocation of containers.

For example, when a container which should be unloaded in a specific port, is stowed below other container, a specific number of movements should be made in order to reach that container [4]. Those shifts can be made onboard or using the shore for temporary storage [6].

The stowage plan is made including the shifts for each port and this is unavoidably because each port of call is considering the optimal way to receive its containers and rarely thinking also for the next ports. Here are stepping up the ship coordinators with clear instructions regarding availability of the bay onboard ship, destination of containers and special containers which require additional regulations to be followed.

From the containership point of view, onboard there are cells, stacks and bays and each stack is limited by height and weight for respecting the stability criteria of the vessel [1]. This is a constraint which is considered critical in the code for safety of voyage, all because it can cause sinking, listing and also damage to containers and cargo.

A problem of stowage planning is considered in the system of maritime transportation. The containers, as is already known at this stage, can be accessed only from the upper part of the stack, therefore exists the need for unloading for a temporary time and reloading the containers.

The aim of a stowage plan is to reduce the time needed for shifting, while in the same time the stability of the ship is maintained at all times.

All these should take into consideration the stability of the ship. It is important onboard a ship to recognize the stability problems which are not always present but they can be an issue which should be addressed.

4. STOWAGE PLANNING

Stowage plans highly affects the ship utilization and port efficiency.

Due to the fact that more than half of the time, a container ship is in port, a large amount of time and cost can be saved by using an efficient and effective cargo operations plan at the ports of call [5].

The main objective of the present maritime system of transport is to minimize the time used for transportation, however also to increase the carrying capacity of the ship as globalization and supply chain management is playing a role higher and higher in the global economy [18].

4.1. Theoretical proposal

We consider the following assumptions:

- Full containers are having the same size and weight

- Empty containers are having same size and weight;
- Full containers and empty containers have different weight, but same size;

A specific container which is either full or empty and will be loaded or unloaded in a port is written as c_{pkso} and the time for this operation is T_{pkso}.

Table 1: Indices of the model

Index	Domain	Description
p	1, ..., 4	Ports i = 1 (DMM) DMM i = 2 (SOH) SOH i = 3 (HMD) HMD i = 4 (SIN) SIN
k	1, ..., m	Number of containers
s	0, 1	Container status s = 0 full DMM SOH HMD SIN s = 1 empty
o	0, 1	Operation o = 0 to be loaded o = 1 to be unloaded

Source: Authors

Time used for handling containers is different depending on the port, number of containers, status of the containers and the operation being made, therefore we have 4 indices.

The adjustment of the stowage plan should be made in such a way that in the end the sum (1) with indices presented in table 1will be minimized.

The proposal is to find a method of minimizing cargo handling and capacity reserve for the adjustment of stowage plan. It is important at this stage to mention that, although it is important to reduce the handling time, the safety and stability will always have priority.

$$min \sum_{p=1}^{4} \sum_{k=1}^{m} \sum_{s=0}^{1} \sum_{o=0}^{1} T_{pkso} c_{pkso} \quad (1)$$

where:

- T_{pkso} is the time used for shifting a container either full or empty between ship and shore;
- c_{pkso} is the container which is handled;
- p represents the port of call;
- k represents the number of containers;
- s represents the status of the container: full or empty;
- o represents the operation of container handling, loading from shore to ship or unloading ofrom ship to shore.

In addition to the accessibility constraints mentioned previously, many other constraints have impact on the stowage planning, such as horizontal and cross stability of the container ship, weight of containers when they are stacked on top of each other and on the decks, when different sizes of containers are stacked together, electricity supply of temperature controlled containers, space constraints of containers for hazardous cargo, and so on.

More constraints need to be satisfied for the stability of the ship, however three of most influencing are: heel, trim and metacentric height, also named GM [10].

The heel is the inclination of a ship to either port or starboard.

The difference between the draft in the forward and aft of a ship is called trim. Depending on the performance indicators of the ship this should be close to zero or within a margin clearly defined for every vessel as this is affecting the stability and manoeuvrability of the ship. Nowadays several tests are done to see which are the optimal voyage conditions for a specific draft or speed.

The GM is the distance from the metacentre M and the centre of gravity G. There are specific IMO criteria for the stability of the ships where is mentioned the minimum GM to be maintained in order to maintain an intact stability of the ship and can be found in the Intact Stability Code which have the purpose of recommend stability criteria and other measures for ensuring the safe operation of all ships to minimize the risk to such ships, to the personnel on board and the environment. Initial GM or metacentric height should not be less than 0.15 m.

In simple terms, to increase the stability of a ship the containers which are heavier should be placed at a lower position in order to increase the GM [10].

Here it comes a point where if between two consecutive ports, heavy containers should be loaded and unloaded, it should be avoided to place most of them on top of the stack, due to the danger of decreasing severely the stability of the ship.

Several constraints need to be satisfied regarding stability of the ship. The distribution of containers in the longitudinal, transverse and vertical plan should meet a point where the ship is not affected in port or at sea.

The equation (2) together with table 2 are used to calculate the position of G by measuring the distance KG – keel to center of gravity.

A strong emphasis is placed on the methods of minimizing cargo handling and therefore the number of movements in a container terminal.

$$\overline{KG} = \frac{KG_{es}\Delta_{es} + \sum_{i=1}^{n} m_i z_i}{\Delta_{es} + \sum_{i=1}^{n} m_i} \qquad (2)$$

Table 2: Calculation of center of gravity

Quantities	Notation	Value	S.I. Unit
Empty ship hull center elevation	KG_{es}	Empty ship hull center elevation (value)	m
Elevation of cargoes onboard	z_i	zi	m
Displacement of empty ship	Δ_{es}	Displacement of empty ship (value)	t
Weight of cargoes onboard	m_i	mi	t

Source: Authors

4.2. Experimental proposal

The main problems which are analyzed in this work relate to the cases where a container ship has to change its stowage plan while at sea, anchorage or berth due to unforeseen factors. The necessity and importance of this proposal is primarily due to the need of minimizing cargo handling at the terminal or onboard the ship.

The sea going condition should be checked while in port, because there are cases where in the port the ship is not affected by the unbalanced distribution of cargo, however at sea due to various factors, the stability of the ship will be affected.

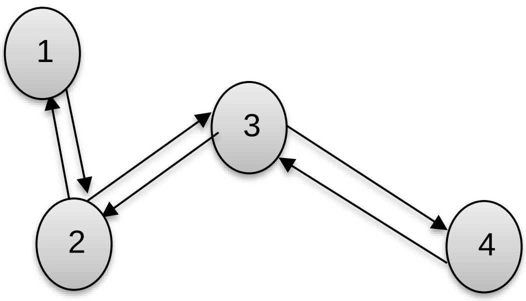


Figure 1: Route planning for container ports (1-4)

An usual route for a container ship is presented in figure 1, as most of container ships are loading and unloading to and from a terminal carrying containers from port p to port p+n.

It is important to understand that a ship should be ready to sail at any time while being in port, therefore at any stage of loading or unloading the stability of the ship should not be affected. Because of this constraint, the stowage plan is often split into parts or stages, and at the end of each of them the ship should meet the planned criteria.

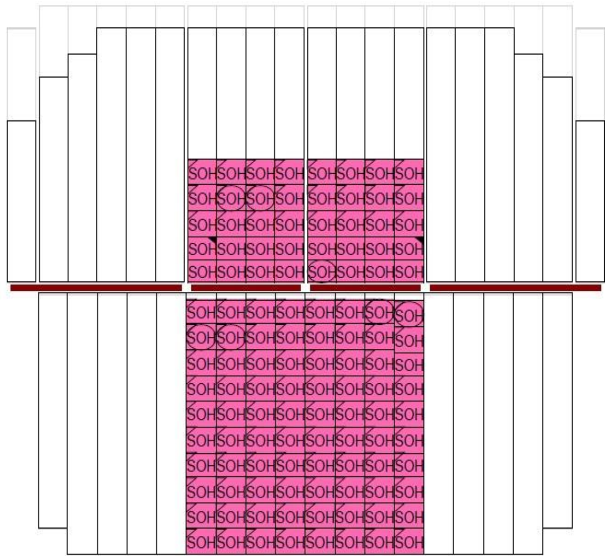


Figure 2: Containers loaded for SOH grouped in the center of the bay

If the stability of the ship is affected during cargo operation, additional movement of containers should be done, thus resulting an increased time and costs. An experimental proposal is presents in the following lines.

Figure 2 represents a starting point where a high reserve capacity is kept, while carrying a small amount of loaded containers. It is obvious that is better to load in the same bay only containers having the same destinations, however this will result in a high reserve capacity.

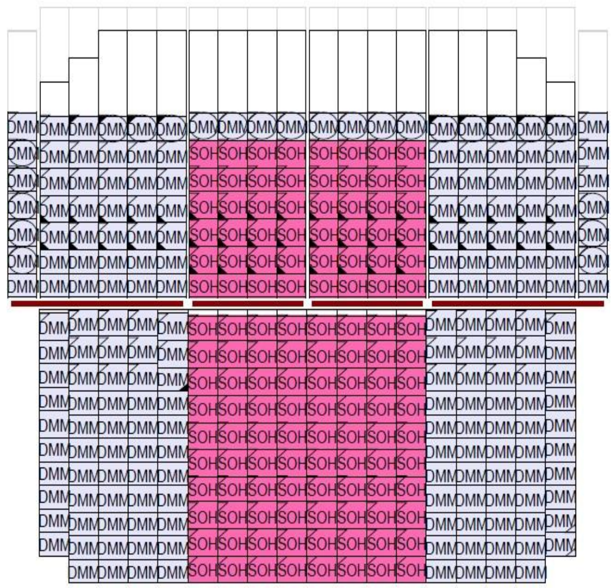


Figure 3: Containers DMM loaded together with SOH in an attempt to reduce the reserve capacity

As being said, there is the need to load also another group of containers in order to reduce the reserve capacity as being seen in figure 3.

Containers having the same destination are to be stowed as a group in the center or only to port and starboard side as cannot be loaded only to one side due to increased list and risk to capsize [9].

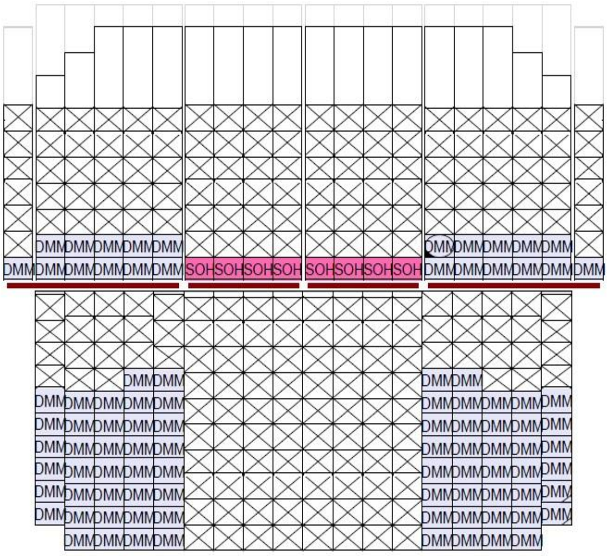


Figure 4: Empty containers with SOH and DMM groups

It is important to check also if the total number of shifting operations for a voyage including multiple ports can be reduced if in some terminals it will be applied the method of temporary loading and unloading of containers [13].

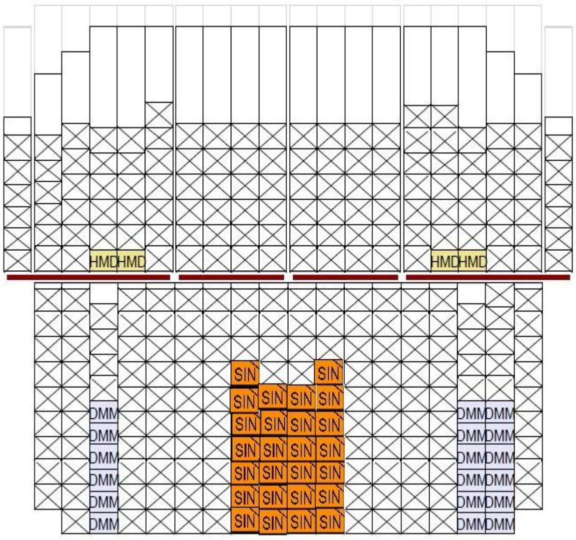


Figure 5: Group SIN of containers loaded below deck to increase GM

There will always be some bays where exists a safety margin (as seen in figures 4 and 5) for shifting or loading more containers if needed. Same as other cases, the containers are grouped into ports of unloading having in mind the stability of the ship [14].

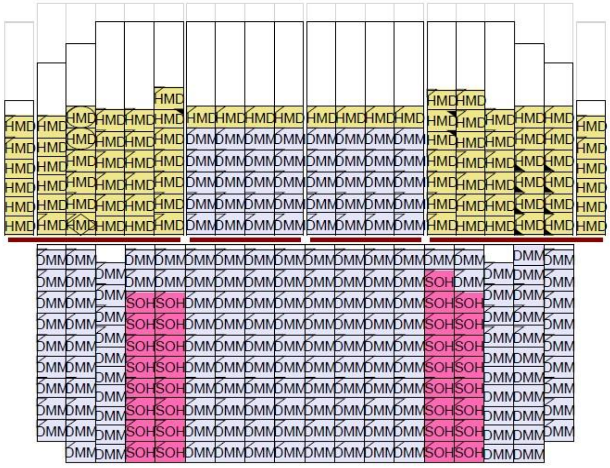


Figure 6: Stowage plan made in SIN for SOH, DMM and HMD

The bending moment and shearing forces on the hull of the ship can be reduced by placing the containers in such a way to increase the stability of the ship, depending of the weight of the containers.

In the stowage plan there is the need to take into account also the longitudinal movements of the cranes [15]. It is important to reduce the overstacking as this will be expensive [8] and also to minimize the number of bays where the containers for a specific port will be unloaded. Regardless of the stowage plan, there will always exist a number of shiftings and the aim is to reduce that number. It is well known that a container ship have multiple bays, and some will remain at the disposal of the planner for a small number of containers to be stowed or shifted.

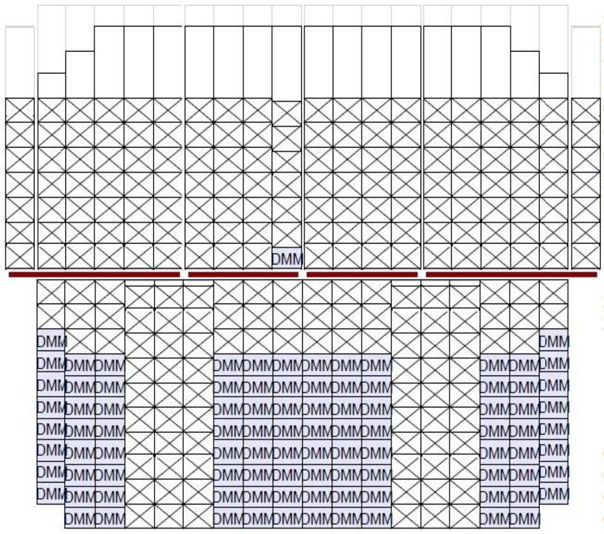


Figure 7: Empty containers stowed with DMM group of containers

A high amount of empty containers are carried between ports. It is a normal practice to carry also empty containers onboard between ports and those containers are to be stowed on top of heavy containers due to the weight restrictions on a stack [17].

It is a challenge of container industry to reduce the amount of empty containers, due to the constraints that this issue is bringing up. By placing the containers to a lower position, the center of gravity will go down and this will increase the GM distance.

Heavy containers for a future port are shifted on the bottom of the stack to increase the GM, because those containers will not be unloaded in the next couple of ports.

It will be checked how these changes are affecting the stability of the ship and how can it be compensated. Any container or group of containers will affect the stowage of other groups also, because the position of the center of gravity will be changed and also the trim and list of the ship.

If the port rotation will be changed before or during the voyage, the stowage plan will be also changed accordingly, having in mind the unloading port of a group, as this will affect the stability or it will increase the number of shifting.

If an optimal way of handling containers is being used, then a considerably amount of time is reduced of transfer operations in ports and also at other transfer areas, therefore increasing the speed and efficiency of transportation.

Although generally a liner have cyclic routes, it is not possible to predict all loading and unloading operations in due time [12]. However, the unproductive shifts and productive stacking for minimizing the total costs can be foreseen. Figures 6, 7 and 8 represents a way of stowage and stacking from multiple groups of containers to a single group of containers, using the reserve capacity filled with empty containers to avoid having space unused.

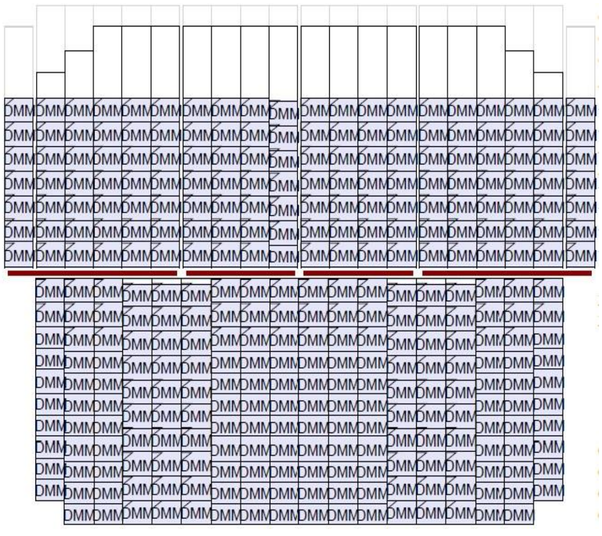


Figure 8: Stowage plan made for a single group of containers – ideal stowage planning

Port competitiveness is now given the utmost importancy. The most important competitiveness components are port efficiency, service and cost-related elements [20]. All these factors are closely related to the subject of the paper as nowadays is more and more about efficiency, safety and sustainability.

5. CONCLUSION AND FUTURE RESEARCH

Future research can be expanded using other constraints or methods for stowage, which can be developed and exported. The objective of the stowage plan problem to minimize cargo handling and the capacity reserve while taking into account the stability of the ship should be a priority and further analysis should be made in future papers. More to be done exists, although this matter is also a practical one and additional constraints are to be taken into account. International maritime transport has grown both in terms of supply and demand.

There is the need to discuss about deep sea shipping and short sea shipping, however this is a problem of higher complexity and can be developed in future papers. [16]. The number of ships and the quantity of goods that can be transported globally are constantly increasing [5] hence the importance of this subject for containerships.

REFERENCES

[1] Ambrosino, D., Sciomachen, A., & Tanfani, E. (2004). Stowing a Containership: The Master Bay Plan Problem. Transportation Research Part A: Policy and Practice 38 (2), 81–99.

[2] Ambrosino, D., Paolucci, M., & Sciomachen, A.. (2013). Experimental Evaluation of Mixed Integer Programming Models for the Multi-Port Master Bay Plan Problem. Flexible Services and Manufacturing Journal 27 (2–3): 263–284.

[3] Ambrosino, D., Paolucci, M., and Sciomachen, A.. (2017). Computational Evaluation of a MIP Model for Multi-port Stowage Planning Problems. Soft Computing 21 (7): 1753–1763

[4] Avriel, M., Michal, P., Naomi, S., & Smadar, W. (1998). Stowage Planning for Container Ships to Reduce the Number of Shifts. Annals of Operations Research 76, 55–71.

[5] Bichou, K. (2009). Port Operations, Planning And Logistics. New York: Informa Law from Routledge.

[6] Chen, T. (1999). Yard Operations in the Container Terminal - a Study in the Unproductive Moves. Maritime Policy & Management 26 (1), 27–38.

[7] Coronado, D., Acosta, M., Cerban, M., & Lopez, M. (2006). Economic Impact of the Container Traffic at the Port of Algeciras Bay. Berlin: Springer.

[8] Delgado, A., Jensen, R. M., Janstrup, K., Rose, T. H., & Andersen, K. H. (2012). A Constraint Programming Model for Fast Optimal Stowage of Container Vessel Bays. European Journal of Operational Research 220 (1), 251–261.

[9] Ding, D., & Chou, M. C. (2015). Stowage Planning for Container Ships: A Heuristic Algorithm to Reduce the Number of Shifts. European Journal of Operational Research 246 (1), 242–249.

[10] Kang, J.-G., & Kim, Y.-D. (2002). Stowage Planning in Maritime Container Transportation. Journal of the Operational Research Society 53 (4), 415–426.

[11] Kim, M., Jeong, Y., & Moon, I. (2020). Efficient stowage plan with loading and unloading operations for shipping liners using foldable containers and shift cost-sharing. Maritime Policy and Management.

[12] Lehnfeld, J., & Knust, S. (2014). Loading, Unloading and Premarshalling of Stacks in Storage Areas: Survey and Classification. European Journal of Operational Research 239 (2), 297–312.

[13] Lu, B., Wang, S. (2017). Container Port Production and Management. Singapore: Springer.

[14] Luna, J. H., Mar-Ortiz, J., Gracia, M., & Moralez-Ramirez, D. (2017). An efficiency analysis of cargo-handling operations at container terminals. Macmillan.

[15] Meiswinkel, S. (2018). On Combinatorial Optimization and Mechanism Design Problems Arising at Container Ports. Wiesbaden: Springer Gabler.

[16] Moura, A., Oliveira, J., & Pimentel, C. (2013). A Mathematical Model for the Container Stowage and Ship Routing Problem. Journal of Mathematical Modelling and Algorithms in Operations Research 12 (3), 217–231.

[17] OECD/ITF (2015). Port Investment and Container Shipping Markets. Paris: OECD.

[18] Wang, T., Cullinane, K., & Song, D. (2005). Container Port Production and Economic Efficiency. New York: Palgrave Macmillan.

[19] Wei-Ying, Z., Yan, L., & Zhuo-Shang, J.. (2005). Model and Algorithm for Container Ship Stowage Planning Based on Bin-Packing Problem. Journal of Marine Science and Application 4 (3): 30–36.

[20] Zhang, X., & Roe, M. (2019). Maritime Container Port Security USA and European Perspectives. Switzerland: Palgrave Macmillan.

CAUSE-EFFECT RELATIONS BETWEEN ORGANIZATIONAL AND SAFETY PERFORMANCE INDICATORS

Dajana Bartulović, M.Sc.
Sanja Steiner, Ph.D.
University of Zagreb, Faculty of Transport and Traffic Sciences
Vukelićeva 4, Zagreb, Croatia
dbartulovic@fpz.unizg.hr, ssteiner@fpz.unizg.hr

ABSTRACT

Safety performance indicators (SPIs) are parameters that show where has organization been; where is it now; and where is it headed, in relation to its safety performance. Organizational indicators (OIs) represent parameters or data sets that show operational performance of an organization. For the purpose of this paper, an actual operational and safety data sets of an aviation organization, are used. Focus of this paper is to find and define correlations between safety performance indicators and organizational indicators, in order to detect cause-effect relations between them. Cause-effect relations can help find organization's deficiencies or emerging threats and handle them timely and properly, by means of safety management. Cause-effect relations can determine precisely which indicator should be increased or decreased in order to improve safety performance of an organization.

Keywords: cause-effect, relations, organizational, safety performance, indicators

1. INTRODUCTION

A Safety Management System (SMS) is a formal organizational system that integrates active safety management tools, including hazard identification, risk assessment, risk mitigation, safety reporting, audits, investigations and remedial actions, safety culture and education supported by clear policies and processes [1]. Safety Management System (SMS) is a mechanism that is used to improve an aviation industry which already has an exceptional aviation safety record.

The modern approach is shifting away from reactive towards a proactive and predictive approach. Modern data collection and analysis capabilities allow us to make predictions that enable us to take a closer look at the previously identified high-risk areas, to gain a better insight into the future.

Globally, International Civil Aviation Organization (ICAO) prescribes 19 Annexes of Standard and Recommended Practices (SARPs) among which Annex 19 [2] brings rules and regulations regarding Safety Management and issues ICAO Safety Management Manual [1] as a guide for each member state to implement State Safety Programs on the national level and Safety Management Systems within each aviation organization.

Implementing and maintaining effective SMS requires each aviation organization to comply with all regulations mentioned above. Effective SMS must have four main components in place in order to work properly and efficiently [3]. Those four components include safety policy, safety risk management, safety assurance and safety promotion. The second component is Safety Risk Management (SRM) and it is the core of efficient SMS. It deals with occurrence (hazard) identification, risk assessment and risk mitigation. [1, 4-12] The third component is Safety Assurance, and it includes safety performance monitoring and measurement, management of change and continuous improvement of SMS [1, 13, 14].

The SMS needs input data to be able to provide viable results, and SMS methodologies are the SMS tool that enables it to acquire necessary safety data [15]. There are three known methodologies of SMS: reactive, proactive, and predictive [1,9, 16-23]. Predictive methodology is not yet well established.

Predictive SMS methodology can use historical and current safety data, safety performance indicators (SPIs) and safety performance targets (SPTs) of an organization [24] as input information to conduct predictive analysis, i.e., make forecasts using predictive (forecasting) methods. The obtained results show trends and behavior patterns of established SPIs in the organization and give a clearer view of the future development of an organization's safety performance, while simultaneously identifying emerging hazards.

Predictive systems do not require the occurrence of a triggering event to launch the safety data capture process. Routine operational data are continuously collected in real time [25]. Predictive systems are based on the notion that safety management is best accomplished by trying to identify a problem instead of simply waiting for something to happen. Therefore, predictive safety data capture systems aggressively seek safety information that could be indicative of emerging safety risks from a variety of sources [24].

Safety performance indicators (SPIs) are the parameters that give the organization a clear view of its safety performance: where it has been; where it is now; and where it is headed, in relation to its safety performance [22]. The set-up of SPIs should therefore be realistic, relevant, and linked to safety objectives of the organization. Safety performance targets (SPTs) define desired achievements of safety performance in the organization. They ensure that the organization is on track to achieving its safety objectives and provide a measurable way of verifying the effectiveness of safety performance management activities. Both SPIs and SPTs provide clear picture of the organization's safety performance.

Continuing research on development of predictive safety management systems revealed significant insights. By using the software for statistics and predictive analytics, cause-effect model of organizational and safety performance indicators, is made and presented in this paper.

The focus of this paper is to establish cause-effect model of defined organizational indicators (OIs) and safety performance indicators (SPIs) in order to present relations between organizational and safety performance indicators in an organization. Detecting relations between indicators shows impacts (causes or effects) of indicators to one another, which in turn provides a possibility to improve planning of future actions with enhanced techniques of prediction that would improve safety performance of an organization.

2. METHODOLOGY, TOOLS, AND DATASET

IBM SPSS Statistics is the world's leading statistical software used to solve business and research problems by means of ad-hoc analysis, hypothesis testing, causal modelling, and predictive analytics. IBM SPSS Statistics is used to understand data, analyze trends, make forecasts, and causal relations to validate assumptions and drive accurate conclusions. [26]. IBM SPSS Statistics is software that is used for research conducted in this paper.

A dataset of actual organizational and safety data was used in this paper. Dataset is representing crucial data of organizational and safety performance indicators of aviation training organization in question (X organization), which requested to stay anonymous [27].

The aviation training organization (X organization) is an organization that provides the services of flight crew training as its core business. Applied safety management methodologies in X organization, in terms of gathering safety data, are reactive and proactive. As a part of the Safety Assurance component, X has established several safety performance indicators (SPIs) and set accompanying safety performance targets (SPTs). SPIs are monitored on monthly basis. The list of organizational indicators (OIs), safety performance indicators (SPIs) and safety performance targets (SPTs) of the X's SMS are presented and in the following Table 1 [27].

Table 1: List of organizational and safety performance indicators in observed dataset

Mark	Name of an indicator	Target (for SPIs)
OI1	Flight hours (aircraft)	/
OI2	Flight hours (simulator)	/
OI3	Total flight hours	/
OI4	Number of used aircraft	/
OI5	Number of used simulators	/
OI6	Number of used aircraft/ simulators	/
OI7	Number of students in training on aircraft	/
OI8	Number of active instructors on aircraft	/
OI9	Number of students in training on simulator	/
OI10	Number of active instructors on simulator	/
OI11	Total number of students in training	/
OI12	Total number of active instructors	/
SPI1	Total number of recorded occurrences	≤2
SPI2	Number of reported MOR occurrences	≤1
SPI3	Number of recorded changes	≤2
SPI4	Number of conducted risk assessments	≤2
SPI5	Number of detected unacceptable risks	≤1
SPI6	Number of held Safety Review Boards	≥1
SPI7	Number of conducted audits/ inspections	≥1
SPI8	Number of determined findings	≤4

Source: Authors

Used dataset is composed of monthly entries for 12 organizational indicators (OIs) and 8 safety performance indicators (SPIs). The observed period is from January 2014 until March 2020. The dataset contains 75 entries. Table 2 shows a dataset of organizational indicators (OIs) and safety performance indicators (SPIs).

Table 2: Dataset of organizational indicators (OIs) and safety performance indicators (SPIs)

Date	OI1	…	OI12	SPI1	SPI2	…	SPI8
01/2014	31.58	…	5	1	0	…	0
02/2014	12.42	…	5	0	0	…	0
03/2014	88.67	…	10	2	1	…	0
04/2014	63.67	…	7	1	0	…	0
05/2014	323.92	…	15	7	0	…	10

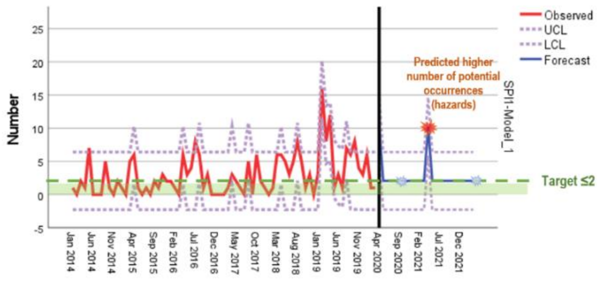
Date	OI1	…	OI12	SPI1	SPI2	…	SPI8
06/2014	159.17	…	12	0	0	…	0
…	…	…	…	…	…	…	…
11/2019	54.92	…	10	4	1	…	13
12/2019	85.92	…	11	3	0	…	0
01/2020	150.42	…	11	6	0	…	6
02/2020	92.42	…	8	1	1	…	0
03/2020	66.50	…	10	1	0	…	0

Source: Authors according to [27]

Next step, after gathering data, is to analyze the data. Analysis of organizational and safety performance indicators is performed by function "Descriptive statistics" of IBM SPSS Statistics software. Subfunctions "Frequencies" and "Explore" were used to obtain histograms and box plots, and to perform tests of normality. It is necessary to analyze and adjust the dataset, so the forecasting and causal modelling can be performed correctly.

Furthermore, it is necessary to make forecasts for each safety performance indicator, using the IBM SPSS Statistics software. Forecasting of safety performance indicators is conducted using function "Forecasting" and IBM SPSS "Expert Modeler". This function includes a variety of applicable predictive methods such as: exponential smoothing, simple seasonal, ARIMA modelling, etc. The Expert Modeler finds the optimal method to conduct the forecast, according to all given values in dataset, as well as isolating the outliers.

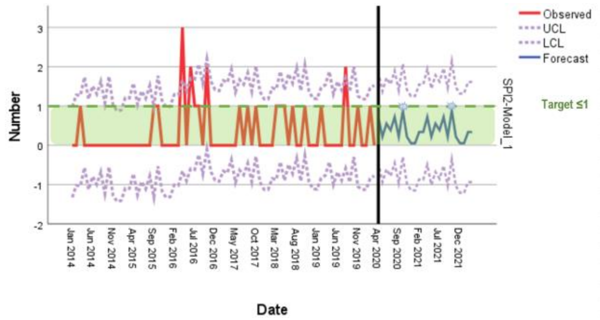
Figure 1 shows predicted values of safety performance indicator SPI1, i.e., it is evident that higher number of potential occurrences (hazards) is anticipated in nearer future.



Source: Authors

Figure 1: Predicted values of safety performance indicator SPI1

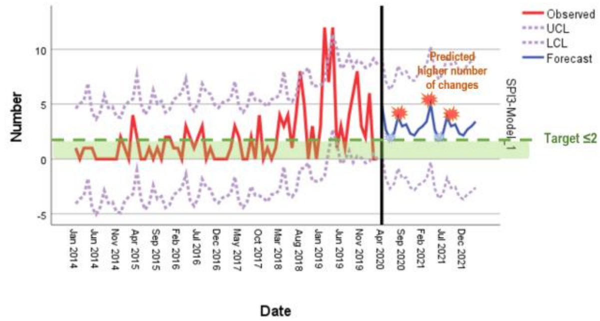
Figure 2 shows predicted values of safety performance indicator SPI2 (number of mandatory occurrences), i.e., it is evident that all the values are in target area, which shows a positive trend of SPI2 in observed future time period.



Source: Authors

Figure 2: Predicted values of safety performance indicator SPI2

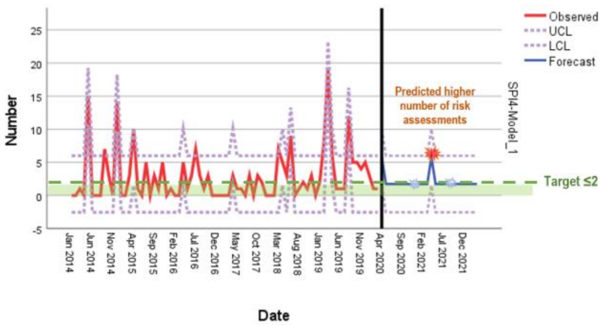
Figure 3 shows predicted values of safety performance indicator SPI3, i.e., higher number of changes is anticipated in nearer future.



Source: Authors

Figure 3: Predicted values of safety performance indicator SPI3

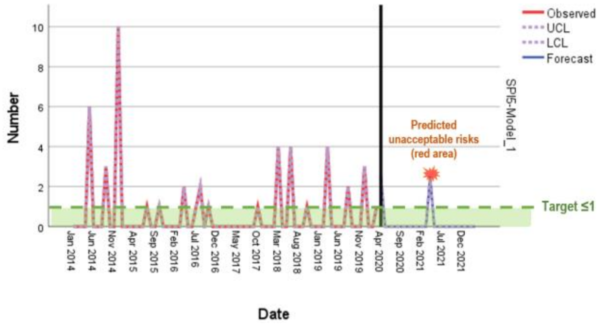
Figure 4 shows predicted values of safety performance indicator SPI4, i.e., higher number of conducted risks assessments is anticipated in the future, which also coincides with results of predicted safety performance indicator SPI1, i.e., higher number of potential occurrences (hazards).



Source: Authors

Figure 4: Predicted values of safety performance indicator SPI4

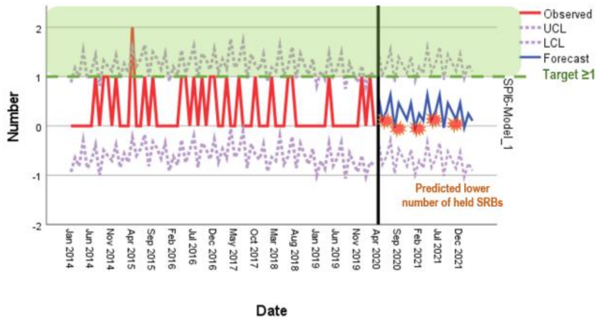
Figure 5 shows predicted values of safety performance indicator SPI5, i.e., higher number of unacceptable risks (red area in safety risk matrix) is anticipated in nearer future, which as well, coincides with results of predicted safety performance indicator SPI1, higher number of potential occurrences (hazards) and SPI4, higher number of conducted risks assessments. Another important observation can be made as well, all three mentioned SPIs with higher predicted values, also coincide in predicted time point, i.e., all three are predicted to have higher values at approximately same time in the future. Hence, even without using causal modelling to establish impact relations between indicators, it is evident from their forecasts which indicators are closely linked together and have influence on each other.



Source: Authors

Figure 5: Predicted values of safety performance indicator SPI5

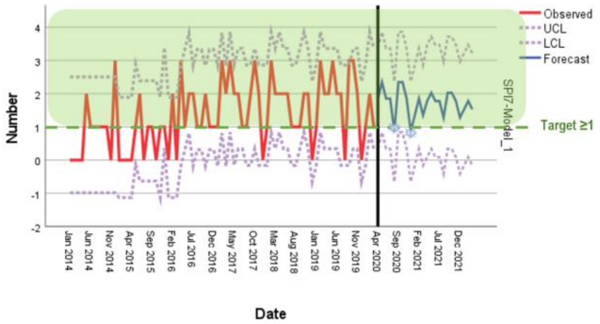
Figure 6 shows predicted values of safety performance indicator SPI6, i.e., lower number of held safety meetings is anticipated in nearer future, according to historical trend.



Source: Authors

Figure 6: Predicted values of safety performance indicator SPI6

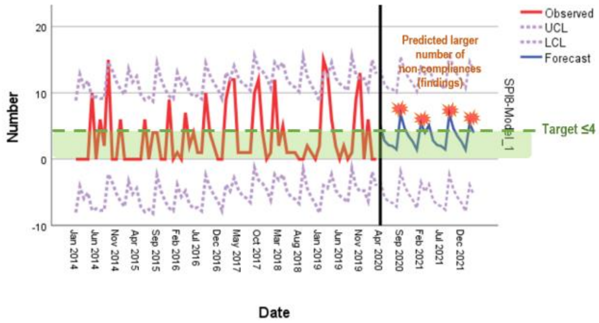
Figure 7 shows predicted values of safety performance indicator SPI7 (number of conducted audits/ inspections), i.e., it is evident that all the values are in target area, which shows a positive trend of SPI7 in observed future time period.



Source: Authors

Figure 7: Predicted values of safety performance indicator SPI7

Figure 8 shows predicted values of safety performance indicator SPI8, i.e., higher number of non-compliances (findings) is anticipated in nearer future.



Source: Authors

Figure 8: Predicted values of safety performance indicator SPI8

3. CAUSAL MODELLING OF ORGANIZATIONAL AND SAFETY PERFORMANCE INDICATORS

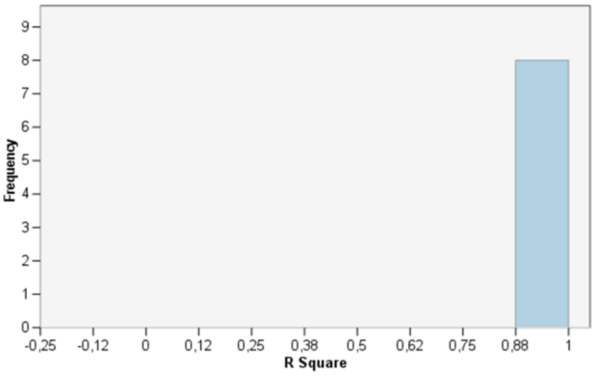
To obtain impact relations between organizational and safety performance indicators, IBM SPSS function "Temporal Causal Modelling" was used. The set-up was made in such way that independent variables are organizational indicators (OIs), i.e., OIs are set to be "inputs" in temporal causal model, and safety performance indicators (SPIs) are dependent and independent variables, i.e., SPIs are set to be "both inputs and targets". Table 3 shows fit statistics for top models generated for each of eight safety performance indicators.

Table 3: Fit statistics for top models

Target Model	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
SPI1	0.28	0.05	-202.24	-65.09	0.98
SPI2	0.58	0.14	-99.05	38.11	0.95
SPI3	2.24	0.30	91.08	228.24	0.95
SPI4	0.99	0.15	-22.63	114.53	0.94
SPI5	2.31	0.39	95.51	232.67	0.93
SPI6	1.96	0.32	72.63	209.79	0.93
SPI7	3.27	0.57	144.38	281.53	0.93
SPI8	0.39	0.09	-151.72	-14.56	0.92

Source: Authors

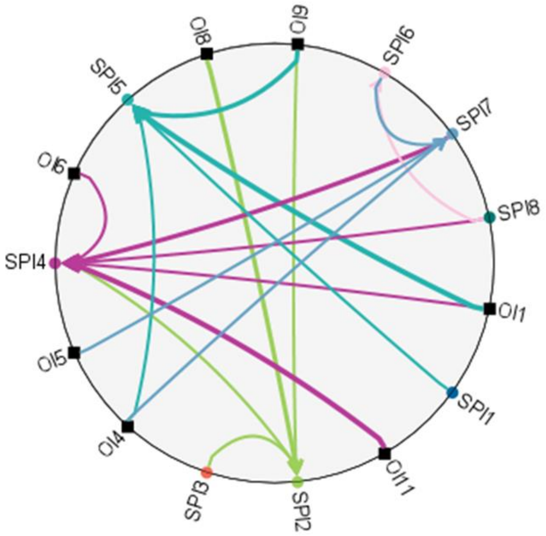
The Figure 9 shows "Overall Model Quality" which shows the distribution of model quality for all the built models (from Table 3). There are many kinds of criteria that can be used to do the evaluation (RMSE, RMSPE, AIC, BIC, R Square). In this case, R Square is selected, which is the default criterion, and the larger the R Square value, the better the model. From the Figure 9, the built models show excellent quality because 100% of the models have R Square values in interval [0.88, 1].



Source: Authors

Figure 9: Overall quality of cause-effect model

Figure 10 shows cause-effect (causal) model of organizational indicators (OIs) and safety performance indicators (SPIs).

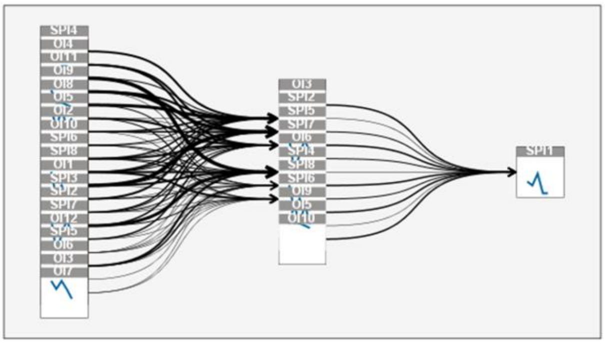


Source: Authors

Figure 10: Cause-effect model of organizational and safety performance indicators in an organization

Next step, after cause-effect model is made, is to examine relations between indicators, and find which impacts the ones in question, hence the causal model shows which of the OIs and SPIs impacts safety performance indicators (SPIs).

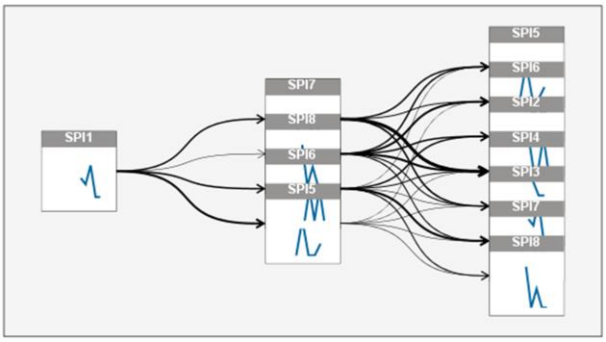
Figure 11 shows impact diagram of causes of safety performance indicator SPI1 (number of occurrences/ hazards). There are eleven OIs and SPIs that directly (first lag in the Figure) impact (cause) the SPI1 values.



Source: Authors

Figure 11: Impact diagram of causes of safety performance indicator SPI1

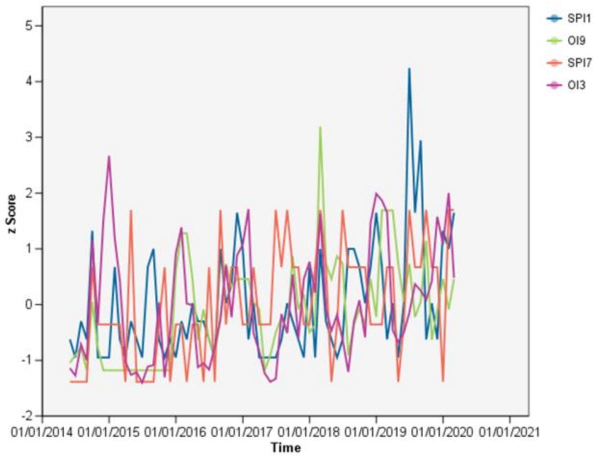
Figure 12 shows impact diagram of effects of safety performance indicator SPI1 (number of occurrences/ hazards). There are four SPIs on which SPI1 has direct (first lag in the Figure) impact (effect).



Source: Authors

Figure 12: Impact diagram of effects of safety performance indicator SPI1

Figure 13 shows top inputs for safety performance indicator SPI1 (number of occurrences/ hazards). There are four detected top inputs (OIs and SPIs) that directly can impact the SPI1 values: OI3, OI9, SPI1 and SPI7.



Source: Authors

Figure 13: Top inputs for safety performance indicator SPI1

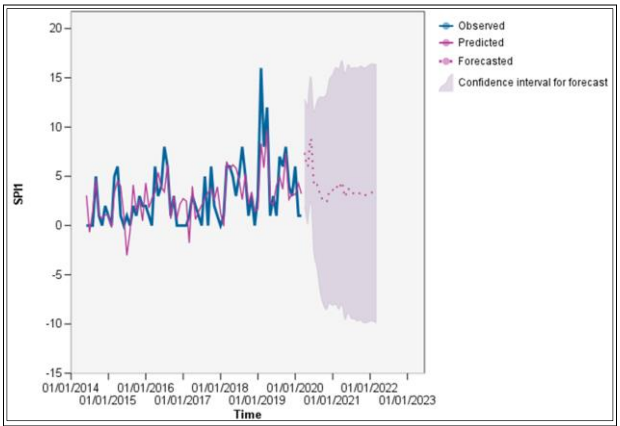
By knowing this, it is possible to simulate increase or decrease of certain OIs and SPIs and see how it would affect the initially predicted values of SPIs. Next chapter shows how predicted values of SPI1 can be affected, due to change (increase/ decrease) of top inputs for SPI1, i.e., OI3, OI9, SPI1 and SPI7.

4. PREDICTING SAFETY PERFORMANCE INDICATORS BY USING CAUSAL MODELLING

The results show how detecting relations between datasets, in this case organizational and safety performance indicators, can help determine correlations and impacts on one another, which in turn can point to week spots in the entire system. The example shows how increasing/ decreasing values of OIs can improve values of SPIs of the organization, i.e., it can improve safety performance of the organization.

Using cause-effect model, specifically their relations, it can be learned which indicators (variables) should be modified to obtained desired level of safety performance target (SPT) in each safety performance indicator (SPI).

For example, Figure 14 shows observed and predicted series for safety performance indicator SPI1, as well as the initial forecast of SPI1.

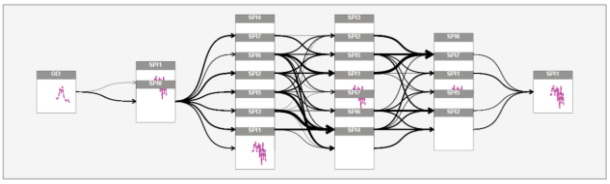


Source: Authors

Figure14: Observed and predicted series for safety performance indicator SPI1

By using an IBM SPSS Statistics function "Apply Temporal Causal Model" and "Run Scenarios", and using the top inputs for SPI1 (Figure 13), first scenario is created, and it examined and revealed how OI3 affects SPI1.

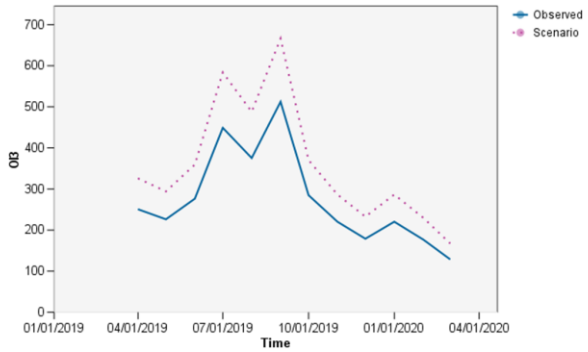
Figure 15 shows impact diagram of organizational indicator OI3 on safety performance indicator SPI1.



Source: Authors

Figure 15: Impact diagram of organizational indicator OI3 on safety performance indicator SPI1

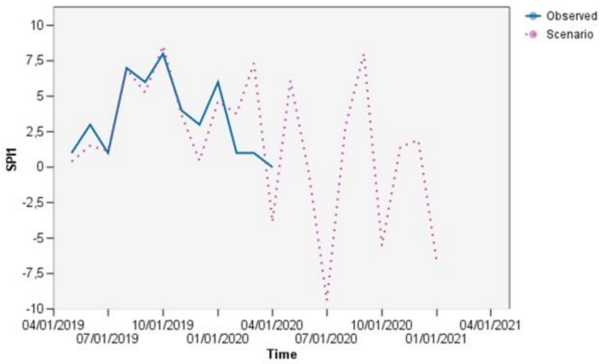
Figure 16 shows two series of organizational indicator OI3. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values which in this case were initial ones increased by 30% in the period from April 2019 until March 2020.



Source: Authors

Figure 16: Increase of organizational indicator OI3

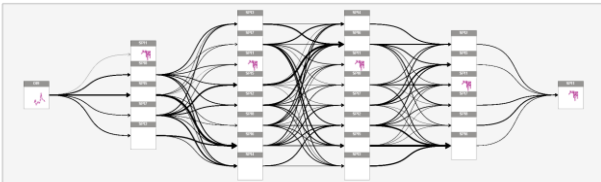
Figure 17 shows two series of safety performance indicator SPI1. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values due to applying causal model relations and increase of OI3, as well as it shows scenario-forecasted values. It can be observed that scenario SPI1 had slightly decreased as well, due to increase of OI3, and, in comparison with initial forecast of SPI1 (Figure 14).



Source: Authors

Figure17: Decrease of safety performance indicator SPI1 due to increase of OI3

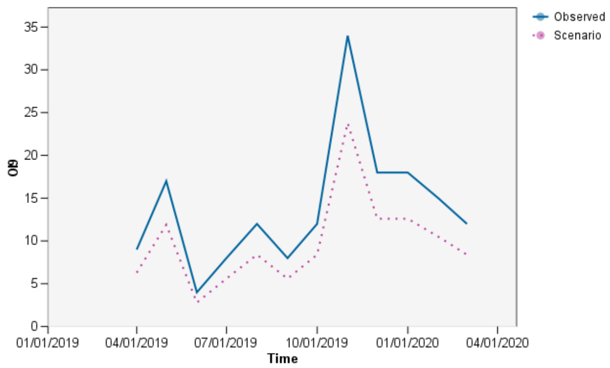
Figure 18 shows impact diagram of organizational indicator OI9 on safety performance indicator SPI1.



Source: Authors

Figure 18: Impact diagram of organizational indicator OI9 on safety performance indicator SPI1

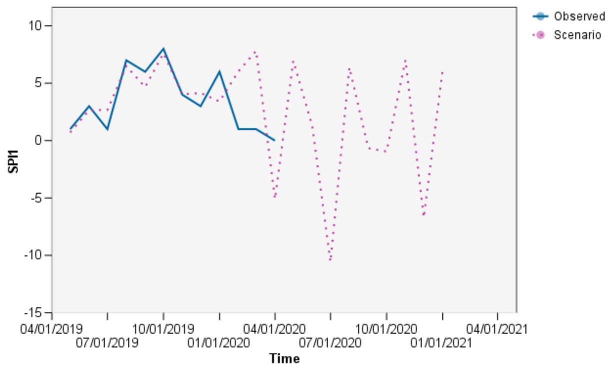
Figure 19 shows two series of organizational indicator OI9. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values which in this case were initial ones decreased by 30% in the period from April 2019 until March 2020.



Source: Authors

Figure 19: Decrease of organizational indicator OI9

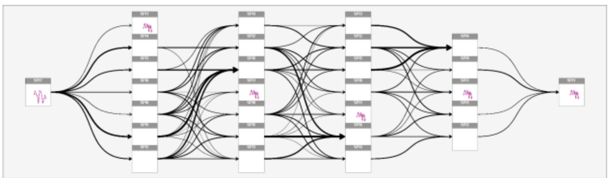
Figure 20 shows two series of safety performance indicator SPI1. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values due to applying causal model relations and decrease of OI9, as well as it shows scenario-forecasted values. It can be observed that scenario SPI1 had slightly decreased as well, due to decrease of OI9, and, in comparison with initial forecast of SPI1 (Figure 14).



Source: Authors

Figure 20: Decrease of safety performance indicator SPI1 due to decrease of OI9

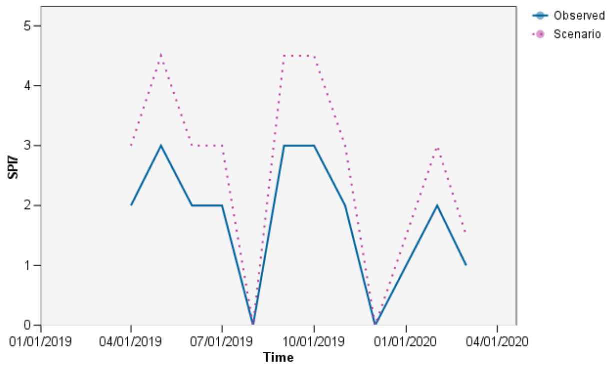
Figure 21 shows impact diagram of safety performance indicator SPI7 on safety performance indicator SPI1.



Source: Authors

Figure 21: Impact diagram of safety performance indicator SPI7 on safety performance indicator SPI1

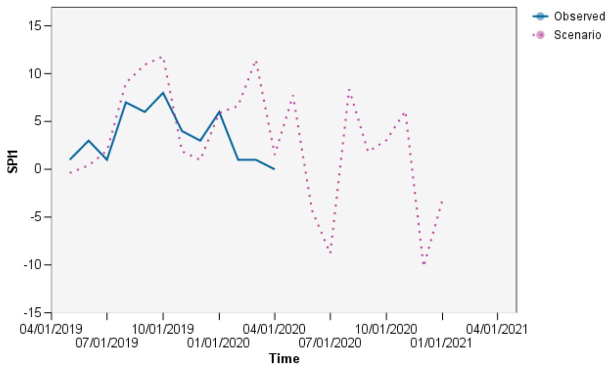
Figure 22 shows two series of safety performance indicator SPI7. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values which in this case were initial ones increased by 50% in the period from April 2019 until March 2020.



Source: Authors

Figure 22: Increase of safety performance indicator SPI7

Figure 23 shows two series of safety performance indicator SPI1. First one (blue) is showing observed (initial) values in the period from April 2019 until March 2020, and second one (pink) shows scenario-adjusted values due to applying causal model relations and increase of SPI7, as well as it shows scenario-forecasted values. It can be observed that scenario SPI1 had decreased as well, due to increase of SPI7, and, in comparison with initial forecast of SPI1 (Figure 14).



Source: Authors

Figure 23: Decrease of safety performance indicator SPI1 due to increase of SII7

6. CONCLUSION

Pursuing further development of predictive safety management systems opened new possibilities and insights.

By using predictive analytics software, it is possible to create a cause-effect models of all variables in observed dataset. This paper shows how such software can be useful in the aspect of aviation safety.

The actual dataset of organizational and safety performance indicators of aviation training organization was used to create cause-effect model. Using cause-effect model, specifically their relations (impacts), it can be learned which indicators (variables) should be modified to obtained desired level of safety performance target in each safety performance indicator.

The same dataset was used to generate initial forecast of all safety performance indicators in the dataset. Software used can create forecast using different predictive methods, such as ARIMA modelling, exponential smoothing, seasonality, etc. Forecasts are more precise and more reliable using these methods.

After creating cause-effect model of organizational and safety performance indicators, scenarios were created to examine impact of each indicator.

Finally, the comparison of initial and scenario forecast of one specific safety performance indicator showed prediction curves with decreasing trend, which are closer to desired safety performance target of that safety performance indicator in the organization.

This research proved that there are relations between organizational and safety performance indicators in the organization. By comparing two forecasts, initial forecast and scenario forecast based on cause-effect model, it is proven that cause-effect model has indeed revealed true impacts of indicators to one another, and by revealing that, it opened the possibility to know which indicators to increase or decrease in order to obtain desired level of safety performance in the organization.

Future research shall be focused on conducting more experiments to further confirm this study, as well as to developing enhanced predictive methods based on causality which will represent the basis for future predictive safety management system.

REFERENCES

[1] International Civil Aviation Organisation. (2018). Safety Management Manual Doc 9859. Fourth Edition. Montreal: ICAO.

[2] International Civil Aviation Organisation. (2016). Annex 19 to the Convention on International Civil Aviation: Safety Management. Second Edition. Montreal: ICAO.

[3] Čokorilo, , O., & Dell'Acqua, G. (2013). Aviation Hazards Identification Using Safety Management System (SMS) Techniques. 16th International conference on transport science (ICTS). Portorož, Slovenia.

[4] Čokorilo, O., Mirosavljević, P., & Gvozdenović, S. (2011). An approach to Safety Management System (SMS) implementation in aircraft operations. African Journal of Business Management, 5(5), 1942-1950.

[5] Jakovljević, I., Čokorilo, O., Dell-Acqua, G., & Mirosavljević, P. (2017). Aircraft Departure Control Systems: Hidden Safety Risks. International Journal for Traffic and Transport Engineering (IJTTE), 7(3), 298-311. DOI: 10.7708/ijtte.2017.7(3).02

[6] Velazquez. J. & Bier, N. (2015). SMS and CRM: Parallels and Opposites in their Evolution, Journal of Aviation/Aerospace Education & Research, 24(2), 55-78. DOI: 10.15394/jaaer.2015.1616

[7] Ferguson, M. D. & Nelson, S. (2014). Aviation Safety: A Balanced Industry Approach, 1st Edition, New York: Delmar.

[8] Cusick, S. K., Cortes, A. I. & Rodrigues, C. C. (2017). Commercial Aviation Safety, 6th Edition, New York: McGraw-Hill.

[9] Croatian Government (2015). State Safety Programme, Official Gazette, (NN 141/2015).

[10] Steiner, S. (1998). Elements of Air Traffic Safety, 1st Edition, Zagreb: Faculty of Transport and Traffic Sciences.

[11] Bartulović, D. (2012). Risk Assessment Methodology in Air Traffic Safety Management System, Thesis, Zagreb: Faculty of Transport and Traffic Sciences.

[12] Oster Jr., C. V., Strong, J. S. & Zorn, K. (2013). Analyzing Aviation Safety: Problems, Challenges, Opportunities, Research in Transportation Economics, 43(1), 148–164. DOI: 10.1016/j.retrec.2012.12.001.

[13] Stolzer, A. J. & Goglia, J. J. (2015). Safety Management Systems in Aviation, 2nd Edition, Farnham: Ashgate.

[14] Adjekum, D. K. (2014). Safety Management Systems in Aviation Operations in the United States: Is the Return on Investment Worth the Cost?, Prime Journal of Business Administration and Management (BAM), 4(4), 1442-1450.

[15] Burin, J. (2013). Being Predictive in a Reactive World, ISASI Journal, 46(1). Available online: https://www.skybrary.aero/bookshelf/books/3337.pdf, [accessed on 26 January 2022].

[16] Ancel, E., Shih, A. T., Jones, S. M., Reveley, M. S., Luxhøj, J. T., & Evans, J. K. (2015). Predictive Safety Analytics: Inferring Aviation Accident Shaping Factors and Causation, Journal of Risk Research, 18(4), 428-451. DOI: 10.1080/13669877.2014.896402.

[17] Čokorilo, O., Ivković, I. & Kaplanović, S. (2019). Prediction of Exhaust Emission Costs in Air and Road Transportation, Sustainability, 11(17), 1-18. DOI: 10.3390/su11174688.

[18] Luxhoj, J. T. (2013). Predictive Safety Analytics for Complex Aerospace Systems, Procedia Computer Science, 20, 331-336. DOI: 10.1016/j.procs.2013.09.281.

[19] Stanton, N., Salmon, P., Harris, D., Marshall, A., Demagalski, J., Young, M. & Dekker, S. (2008). Predicting Pilot Error: Testing a New Methodology and a Multi-Methods and Analysts Approach. Applied Ergonomics, 40, 464-471. DOI: 10.1016/j.apergo.2008.10.005.

[20] Hsiao, Y. L., Drury, C., Wu, C. & Paquet, V. (2013). Predictive Models of Safety Based on Audit Findings: Part 1: Model Development and Reliability, Applied Ergonomics, 44(2), 261-273. DOI: 10.1016/j.apergo.2012.07.010.

[21] Hsiao, Y. L., Drury, C., Wu, C. & Paquet, V., (2013), Predictive Models of Safety Based on Audit Findings: Part 2: Measurement of Model Validity, Applied Ergonomics, 44(4), 659-666. DOI: 10.1016/j.apergo.2013.01.003.

[22] Bartulović, D. & Steiner, S. (2020). Liaison Between Proactive and Predictive Methodology of Aviation Safety Management System, Proc. 19th International Conference on Transport Science, Portorož, Slovenia, 17-18 September, 34-41.

[23] Boeing. (2012). Boeing Safety Management System Overview. Available online: http://www.aviationunion.ru/Files/7%20En%20Boeing%20SMS%20Overview.pdf, [accessed on 27 January 2022].

[24] Bartulović, D. (2021). Predictive Safety Management System Development, Transactions on Maritime Science, 10(1), 135-146. DOI: 10.7225/toms.v10.n01.010.

[25] Brockwell, P. J., & Davis, R. A. (2016). Introduction to Time Series and Forecasting. New York: Springer International Publishing.

[26] IBM SPSS Statistics. Available online: https://www.ibm.com/hr-en [accessed on 20 December 2021].

[27] X organization. (2014-2020). Internal official SMS documentation, hazard logs and reports. Operational data. Audits and inspection reports. Findings logs and reports.

GENERAL CLASSIFICATION OF ANCHOR HANDLING TUG SUPPLY VESSELS BY GROSS TONNAGE AND BOLLARD PULL

Zlatko Boko, M.Eng.
Zaloa Sanchez Varela, Ph.D.
Ivica Skoko, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
zboko@pfst.hr ; zsanchezv@pfst.hr ; iskoko@pfst.hr

David Boullosa-Falces, Ph.D.
Faculty of Engineering in Bilbao, University of the Basque Country UPV/EHU
María Díaz de Haro 68, Portugalete, Spain
david.boullosa@ehu.eus

ABSTRACT

The offshore oil and gas industry involves extracting oil and gas from rock formations beneath the seabed, and it is an unavoidable component of the world's energy supply. Most offshore installations need to be supplied, monitored, and moved daily. These tasks can only be achieved using different environmentally-friendly and cost-efficient offshore supply boats. The crucial part of the offshore supply fleet is anchor handling tug supply vessels. This paper presents a classification of anchor handling tug supply vessels by gross tonnage and bollard pull. The obtained results will serve as a basis in further research of stability limit parameters for this type of ship.

Keywords: Offshore, anchor handling supply vessels, bollard pull, gross tonnage

1. INTRODUCTION

In the late 18th Century, the first drilling for natural gas and crude oil in ocean waters began offshore in California [1] upon first entrepreneurs discovered that the wells nearest the ocean were the best producers. Offshore is defined as "out of sight of the land". "The wells were drilled from piers extending from land out into the channel" [2]. Kerr-McGee drilling rig, known as Kermac Rig No.16, was the first to exploit oil in the Gulf of Mexico out of sight of the land [3].

Modern-day offshore industry practice suggests that drilling, exploration, natural gas and crude oil production will continue to move in deeper water. As a result, the importance of supply and safety requirements will increase significantly [4].

The logistic support in offshore business relay on offshore support vessels, with equipment, technology and crew capable of working in harshest working conditions.

The offshore industry is diverse and requires many vessel types to perform different tasks, each with unique equipment and a broad range of systems.

Distinct types of vessels involved in offshore oil field operation are Anchor Handling Tug Supply (AHTS),

Platform Supply Vessels (PSV), Fast Supply Vessels (FSV), Dive Support Vessels, Pipe Lay Vessels, Crane Vessel, Seismic Vessel, Well Intervention Vessel and Multi-Purpose Offshore Support Vessels.

The scope of this paper is to put into perspective the relationship between AHTS vessel's size and bollard pull, considering various aspects of ships measures like gross tonnage, length, beam and their ratio, brake horsepower and draft. Vessels researched are presently operating in the North Sea and their year of build range from 1998 to 2016.

2. LITERATURE REVIEW

The offshore vessels industry is a relatively new discipline, but few articles have been published in books or scientific journals. Experienced ship captain Michael Hancox wrote some of the first reference books that helped practitioners form sound background knowledge of the subject [5]. Hancox researched characteristics of anchor handling vessels and evolution from previous designs, covering most everyday anchor handling operations (AHO) from Master and crew points of view.

After the capsizing of the AHTS vessel Bourbon Dolphin (2007, Shetland Islands), with the tragic loss of 8 lives, Nilsson [6] describes the stability aspects that must be considered when performing AHO and questions intact stability criteria (IS code) for AHTS vessels. The author researched regulations regarding specific anchor handling equipment in terms of winches, wires and question loss in bollard pull power due to using the primary propulsion system.

Motivated with the same Bourbon Dolphin accident, T. Moan and G.R. Gunnu [7-9] add further research for the correlation of the mooring load, control forces (propulsion and rudders), environmental loads and ships stability, proposing amendments to IS code regulations.

Lars Andreas Wennersberg [10] researched computer simulations of anchor handling vessels that can be used to evaluate the forces acting on them and gain valuable insight into their operational limitations. The simulator can simulate both anchor deployment and anchor recovery operations in real time. The vessel model is matched up against an actual anchor handling vessel to give natural thrust characteristics.

To improve understanding of AHTS and initiate people's interest in exploring the future progress of these vessels, Chen Wenming [11] researched the development of AHTS with emphasis on health, safety and environmental culture.

Many of the published articles have the safety of the operations as a primary concern. They may be found as "Safety manuals" made by different shipping owners and operators, with intended use onboard by the ship's crew.

Ivica Skoko [12] "focused on offshore supply chain and reviewing usage of different types of vessels in cost-efficient, environmentally friendly and technically "fit for purpose" way.

Sanchez-Varela et al. [13] analyse incidents onboard AHTS from 2014 to 2015, indicating possible causes and outcomes.

3. THE CONCEPT OF BOLLARD PULL

Bollard is a metal structure used on docks or piers to moor the vessel by securing ships lines.

Bollard pull (BP) is a measure of the pulling power of the vessel, calculated by connecting a pier bollard with a towing system on the boat and measuring the force of tension developed in the connection by a load cell or similar mechanism [14]. It is commonly expressed in tonnes; even it is being force. Presents one of the key performance indicators for AHTS boats, the value of BP defines the vessel's functionality for a particular job. Every ship expected to pull an additional load apart of its weight requires a Bollard Pull certificate from one internationally accepted classification society.

The ship's propulsion system directly affects BP. The maximum certificated value gained in test conditions is not always possible to achieve while operating in the oil field due to the use of side thrusters and main propellers in offshore weather conditions.

BP tests and trials follow a set of guidelines provided by classification societies but do not have a standardised set of rules [15]. The higher figure on the Bollard Pull certificate is a common goal for vessel owners. If real pulling power is different, it may be a severe safety concern due to implications on ship stability when engaged in towing/AHO. Uncertainty in BP predictions should receive considerable attention during the various stages of the vessel's design, test, and operations [16].

4. AHTS VESSELS

AHTS vessels (Figure 1) play a crucial role in the offshore oil and gas industry, and they are considered multipurpose vessels [17].

Source: Naval-gazing 2017

Figure 1: AHTS stern view, working wire over the stern

AHTS vessels have extensive deck cargo capability, under-deck dry and liquid bulk cargo capacity and add-on roles as firefighting, oil pollution control and rescue capability. Still, their specific function is to undertake towing and AHO. AHTS comes with assorted designs but always with large after deck, used for deck cargo, towing and handling of anchors. The deck is protected with barriers and bulwarks from both sides. Stern is open to the sea, with a fitted roller to facilitate pulling anchor out or dropping it over the stern. Accommodation structure is always found on the forward section of the vessel. Winch house with various towing and working wires, winches and other anchor handling equipment is aft of the accommodation. Drilling rigs are not stationary; they work at many separate locations and are often moved. Rig positioning involves rig towing, anchors retrievals and anchors deployment to secure the rig for the seabed. As the industry moves in deeper water, the number of anchor line positioning systems and subsequently AHO increases. AHTS capacity is significantly higher, more horsepower and sufficient BP are needed to complete demanding and high-risk operations in a specific time frame and with as much safety margin as possible. Particulars of each AHTS vessel are distinct and different from others apart from the ships built from the same general plans, contributing to the complexity of AHO [18].

5. CLASSIFICATION OF AHTS VESSELS IN THE NORTH SEA 2022 BY SIZE AND BOLLARD PULL COMPARISON

The North Sea is the most challenging area for offshore crude oil and gas production due to powerful currents, gale-force winds and high seas. Table 1 presents AHTS vessels based in that part of the Atlantic Ocean in February 2022, together with the following data: year of build, gross tonnage, BP, length overall, beam, brake horsepower and draft.

Table 1: AHTS in the North Sea, 2022 made by authors based on Clarkson's Platou [19] data from February 2022

No	Year of Built	Gross Tonnage (GT)	BP (t)	Length Over All (m)	Beam (m)	Break Horse Power (BHP)	Draft (m)
1	1998	2556	173	73,5	16,40	15014	6,90
2	1998	2590	180	73,5	16,40	14832	6,90
3	1998	2750	165	74,9	18,00	14742	6,60
4	1999	2556	174	73,5	16,40	15014	6,90
5	2000	6536	282	90,3	23,00	23480	7,80
6	2001	4700	240	81,0	20,00	20000	7,50
7	2002	2000	176	80,0	18,00	17500	6,60
8	2002	2258	207	67,4	15,50	16322	6,20
9	2002	4350	275	82,1	20,00	23500	7,00
10	2003	2263	180	67,4	15,50	16500	6,20
11	2003	3164	206	75,5	18,00	20000	6,60
12	2003	4350	261	82,1	20,00	23300	7,50
13	2006	3050	201	78,3	17,20	16085	6,80
14	2006	4089	183	86,2	18,50	19906	7,00
15	2007	4727	205	85,8	19,50	16100	7,31
16	2007	4727	205	85,8	20,50	16100	6,80
17	2007	6245	187	78,3	17,20	16085	6,99
18	2007	6335	230	93,3	22,00	22000	7,70
19	2007	5733	227	86,3	22,00	22000	8,00
20	2008	2806	202	74,5	17,20	16092	6,80
21	2008	3070	187	78,3	17,20	14688	6,80
22	2008	7176	272	92,7	22,00	27472	8,60
23	2009	3500	200	74,5	17,20	16200	6,90
24	2009	3500	211	73,5	17,20	16092	6,90
25	2009	4678	178	73,2	20,00	15540	7,60
26	2009	4678	181	73,2	20,00	15300	7,75
27	2009	6455	292	92,0	22,00	27744	7,53
28	2009	6821	255	90,3	23,00	23500	7,80
29	2009	6839	277	93,8	23,00	26140	8,00
30	2009	6839	277	93,8	23,00	26140	8,00
31	2009	7473	274	91,0	22,00	28000	7,90
32	2009	7473	285	91,0	22,00	28000	7,90
33	2009	6838	285	93,8	23,00	26140	8,00
34	2010	6455	294	92,0	22,00	27744	7,53
35	2010	6798	258	90,3	23,00	23500	7,80
36	2010	7558	310	91,0	22,00	28000	7,95
37	2010	7862	337	95,0	24,00	32600	7,80
38	2010	8053	339	95,0	24,00	32600	7,80
39	2011	6279	251	85,2	22,00	19050	7,60
40	2011	6357	250	85,2	22,00	19050	7,60
41	2011	7473	305	91,0	22,00	28000	7,95
42	2011	8222	350	109,0	24,00	36000	7,80
43	2011	8360	399	95,2	24,00	34000	8,85
44	2011	8360	393	95,2	24,00	34000	8,85
45	2012	6186	230	85,2	22,00	16094	7,60
46	2013	8269	319	93,6	24,00	27940	7,80
47	2014	5100	230	85,0	22,00	16094	7,60
48	2014	6170	272	87,4	21,00	24371	7,80
49	2016	8143	307	93,6	24,00	26764	7,80
50	2017	5000	235	84,0	19,50	21760	7,50
51	2018	8000	270	95,0	25,00	26000	8,70

Table 1 serves as a base for the authors' research on the relationship between collected data.

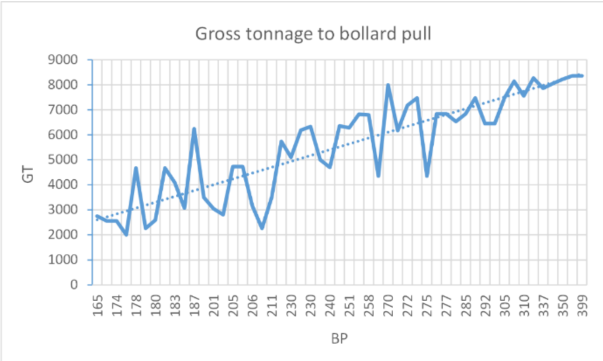


Figure 2: Gross tonnage to bollard pull (t) ratio

In Figure 2 the trend for the past 24 years (dotted line) is evident. The design of AHTS did not change much from the second part of the 20th Century and "early" days of offshore but power and size are increasing. New build boats have higher BP due to the difference in tensions, forces, and loads vessels encounter.

This upward trend is expected due to market requirements and more sophisticated technology implemented.

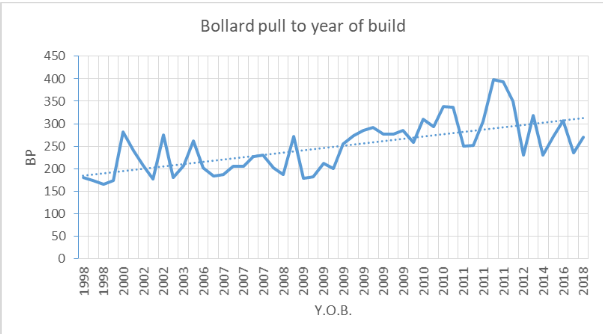


Figure 3: Bollard pull (t) to year of build ratio.

In Figure 3 the trend shows new build vessels have higher BP due to constantly evolving industry and market competition. From 2006 to 2008, increased gas and oil prices stimulated demand for new AHTS; the market hit the record high of 362 vessels in 2007, dropped to 201 in 2008 and declined rapidly to 56 new units in 2011 due to oversupply of boats [12]. As oil and gas fields move into deep and ultra-deep waters, vessels will follow with more brake horsepower, larger deck size and improved BP.

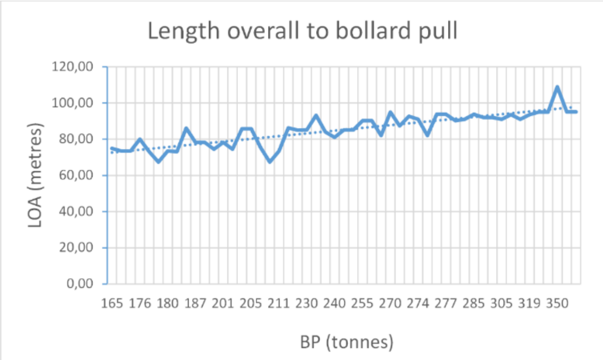


Figure 4: Length overall to bollard pull

Longer ships will have stronger BP, as can be seen in Figure 4, but generally, length overall not significantly affects the BP pull value. Ship size matters most when it comes to stability in operating conditions. Length overall does not change much as time pass by, but BP force almost doubled in the past 24 years. Improvement in ship's design – the shape of the bow or hull line, for example, allows shipyard engineers to achieve speed or economic fuel consumption without drastically changing the vessel's length. At the same time, compared to larger ships, smaller reserve buoyancy and smaller size of compartments negatively affect stability. Ships with small frames are more sensitive to damage, which is a permanent issue with AHTS because they work close to offshore installations.

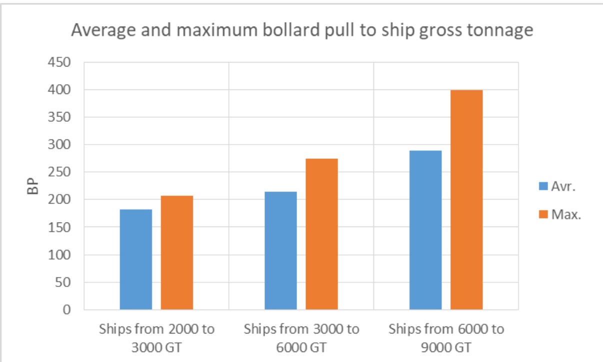


Figure 5: Average and maximum bollard pull to ship gross tonnage

AHTS fleet has a clear intention to grow in GT and BP. Figure 5 shows that modern vessels tend to vary more in the ratio between average and maximum BP as a direct consequence of industry expectations and diversity in locations and environmental conditions of oil fields today. Hence, the following division was observed:

- Ships from 2000-3000 GT average BP 182t, maximum BP 207t.
- Ships from 3000-6000 GT average BP 215t, maximum BP 275t.
- Ships from 6000-9000 GT average BP 289t, maximum BP 399t.

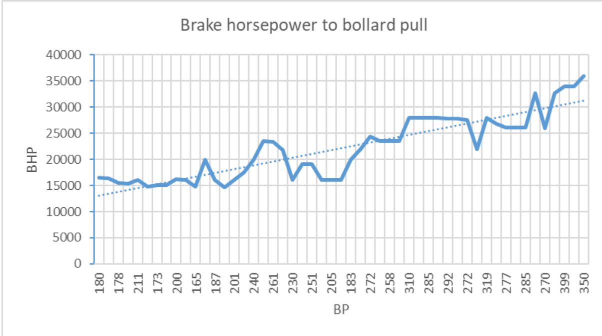


Figure 6: Brake horsepower to bollard pull

As expected, Figure 6 presents that a 245% increase in BHP leads to a 242% increase in BP, the linear impact of BHP on BP.

Those two values are inseparable, being the main reason to charter the boat. More BHP and stronger BP means a higher daily rate for the vessel and more comprehensive marketing options in general.

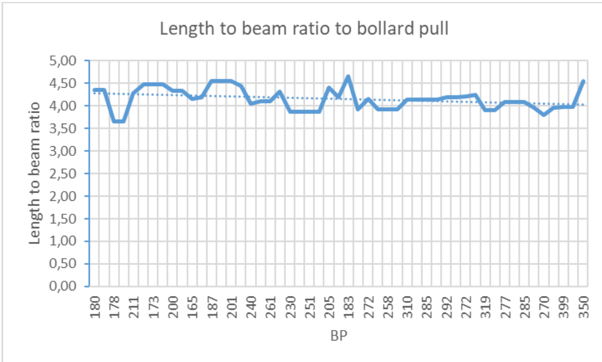


Figure 7: Length to beam ratio to bollard pull

The breadth and length ratio (factor X) of AHTS vessels are high compared to conventional cargo vessels due to the particularity of their operations. There is no clear relationship between the length-to-beam ratio (factor X) and BP, as shown in Figure 7.

While engaged in towing, retrieving or deploying anchors, factor X and BP ratio will affect ship stability in extreme situations. That will be the aim of future studies on stability for AHTS.

6. DISCUSSION AND SUMMARY OF FINDINGS

As one of the primary energy sources consumed worldwide, the offshore gas and oil industry constantly needs larger and stronger support vessels. AHTS vessels will continue to progress in gross tonnage, brake horsepower, BP and winch capacity. Because of these developments, AHTS vessels are subjected to even higher operational loads during towing and AHO. Incident evaluation during operations performed by AHTS vessels shows that equipment failure and human error have been the leading causes of the incidents [15]. Mighty ships, more capable winches, and higher BP mean less reaction time for the Master or operator, and time is essential when calculating actual stability and comparing allowed values. Even with the help of a computer-based dynamic position system that is standard equipment on all AHTS chartered, time is essential for the vessel crew to make the right decisions in extreme working conditions.

Figures 2 and 3 confirm the quality of AHTS design which has remained almost the same since the beginning of offshore operations and presents a clear trend of increase in GT and BP due to the demands of the still-growing industry.

As seen in Figures 4 and 5, the average bollard pull for the largest class of AHTS is 289 t, which was state of the art for industry standards 20 years ago. Such robust ships will need clear stability instructions for intense phases of operations.

Figures 6 and 7 point out the linear relationship between BHP and BP, dismissing the impact of the length-to-beam ratio (factor X) on BP.

The trend shown in research brings "over dimensioning" of AHTS as a potential issue in the future, both from a safety and environmental point of view – large vessels use more fuel, leave more disposal, and are more expensive to build.

REFERENCES

[1] Marine Mammal Commission. (2022, February 5). History of oil and gas development in the U.S Continental shelf. Retrieved from: https://www.mmc.gov/priority-topics/offshore-energy-development-and-marine-mammals/offshore-oil-and-gas-development-and-marine-mammals/history-of-oil-and-gas-development-in-the-u-s-outer-continental-shelf-ocs/

[2] Offshore Energy. (2010, July 25). Offshore drilling: History and overview. Retrieved from: https://www.offshore-energy.biz/offshore-drilling-history-and-overview/

[3] Wells B.A. and Wells K.L. (2021, Novembre 7). Offshore Petroleum History. Retrieved from: https://aoghs.org/offshore-history/offshore-oil-history/

[4] Hancox M. (1994). Towing, vol. 4. London: Oilfield Seamanship.

[5] Hancox M. (1992). Anchor Handling, vol. 3. London: Oilfield Seamanship..

[6] Nilsson, M. (2009). Stability aspects during anchor handling operations (Doctoral dissertation, M. Sc. Thesis in Naval Architecture, Department of Aeronautical and Vehicle Engineering, KTH, Royal Institute of Technology).

[7] Gunnu, G. R., & Moan, T. (2017). An assessment of anchor handling vessel stability during anchor handling operations using the method of artificial neural networks. Ocean Engineering, 140, 292-308. doi: 10.1016/j.oceaneng.2017.05.030.

[8] Gunnu, G. R., & Moan, T. (2018). Stability assessment of anchor handling vessels during operations. Journal of Marine Science and Technology, 23(2), 201-227.

[9] Gunnu, G. R. (2017). Safety and efficiency enhancement of anchor handling operations with particular emphasis on the stability of anchor handling vessels, Institut for Marine Teknikk.

[10] Wennersberg, L. A. L. (2009). Modeling and simulation of anchor handling vessels (Master's thesis, Institutt for teknisk kybernetikk).

[11] Chen, W. (2013). Design and operation of anchor handling tug supply vessels (AHTS) (Master's thesis, University of Stavanger, Norway).

[12] Skoko, I., Jurčević, M., & Božić, D. (2013). The logistics aspect of offshore support vessels on the West Africa market. Promet-Traffic&Transportation, 25(6), 587-593.

[13] Sanchez–Varela, Z., Boullosa-Falces, D., Larrabe-Barrena, J. L., & Gómez-Solaetxe, M. A. (2018). Incident Evaluation During Operations Carried Out by Anchor Handler Tug Vessels. Journal of Maritime Research, 15(1), 20-23.

[14] Ajay M. (2021, November). What is bollard pull. Retrieved from https://www.marineinsight.com/naval-architecture/bollard-pull-everything-you-wanted-to-know/

[15] Dev, A. K. (2016, November). Various Aspects of Bollard Pull Tests and Analysis of Test Results. In SNAME Maritime Convention. OnePetro. Vrijdag, A., de Jong, J., & van Nuland, H. (2013). Uncertainty in bollard pull predictions. In 3rd International Symposium on Marine Propulsors (pp. 447-453).

[16] Skoko, I., Lušić, Z., & Pušić, D. (2020). Commercial and strategic aspects of the offshore vessels market. Zeszyty Naukowe Akademii Morskiej w Szczecinie.

[17] Gunnu, G. R. S., Wu, X., & Moan, T. (2012). Anchor handling vessel behaviour in a horizontal plane in a uniform current field during operation. In The 2nd marine operations speciality symposium. Research Publishing Services, Singapore.

[18] Clarksons Platou. (2022, February). Clarksons offshore.Retrieved from: https://www.clarksons.com/services/broking/offshore-support-vessels/

WATERWAY SIGNS AND MARKING ON THE RIVER DRAVA

Tanja Brcko Satler, Ph.D
Peter Vidmar, Ph.D.
Jure Srše, M.Sc.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, 6320 Portorož, Slovenia
tanja.brcko@fpp.uni-lj.si, peter.vidmar@fpp.uni-lj.si, jure.srse@fpp.uni-lj.si

ABSTRACT

In an effort to develop tourism in the Drava Valley, the adjacent municipalities have taken the initiative to harmonise regulations in preparation to manage such activities as the navigation of motorboats on Lake Mariborsko jezero. An important segment in the definition of the waterway is the marking of areas dangerous for navigation, the location of passenger terminals, moorings and other important markings that serve to inform the users of the waterway. The marking of the waterway is part of the navigation study conducted at the Faculty of Maritime Studies and Transport UL on behalf of the client, the municipality of Maribor.

Keywords: River Drava, Safety of Navigation, Waterway Marking

1. INTRODUCTION

Slovenia has numerous rivers, some of which are navigable and suitable for the establishment of navigation. The Drava is considered one of the most water-rich rivers in Slovenia, which is why flowing hydroelectric power plants have been built in the past. There are no less than 12 large and small hydroelectric power plants on the Drava, which together with four solar power plants generate almost a quarter of the total electricity in Slovenia (Dravske elektrarne Maribor, 2022). The damming of the Drava created reservoirs, one of which is Lake Mariborsko jezero, which stretches between the Fala power plant and the Mariborski otok power plant and is about 15.6 km long. The slopes are steep in some places, especially around the Fala cliff, but mostly covered with autochthonous vegetation, except in the urban areas. The bridge over the Drava in Ruše is the only road connection between the left and right banks in the entire area of the reservoir (Direkcija Republike Slovenije za vode, 2018).

Until 1998, when the decree on the restriction of the use of motorboats on Mariborsko jezero came into force, this reservoir was an attractive destination for motorboats, especially in summer (Lešnik, 2019). Today, only row boats, sailing boats and surfboards are allowed in the appropriately marked area. Exceptionally, motor propulsion is allowed for public transport and boats with the consent of the reservoir operator, with a maximum speed of 10 km/h (Mestna občina Maribor, 2010). The restriction on the use of motorboats is also due to Natura 2000. The Drava is the most important area for birds in Slovenia, as more than 20,000 birds regularly winter here and no fewer stop during spring or autumn migration (Božič, 2003).

Encouragement for the revival of river navigation on the part of the Drava has been aroused in recent years by the Drava Cycle Route, which runs along the right bank of the river in the area of Lake Mariborsko jezero. To create a more attractive route that allows cyclists to cross the river at several points, the municipalities have taken the initiative to lift the restrictions on the use of motorboats on the Drava, in particular for passenger boats that have deck space for bicycles. As part of the initiative, a navigation study was carried out to regulate the navigability on the reservoir. Measurements and site visits were made of the existing berths, the planned river passenger terminals, and the potential locations for the establishment of a service point for ships, ramps for ships, and a harbour to serve as the main berth for passenger ships (including the possibility of wintering). The existing berths were examined for their suitability for technical usability and safety for the users. The calculation of individual river sections was carried out and the appropriate speed of vessels was determined according to the water depth, current velocity, shape and dimensions of the riverbed, natural and artificial obstacles, transparency, etc., in accordance with the standards and technical recommendations for rivers and river ports.

2. DETERMINATION OF THE NAVIGABLE AREA ON THE RIVER

According to the Inland Waterways Navigation Act, the local municipality may prescribe a navigation regime for a specific navigable area of an individual inland waterway, i.e., determine the navigable area in which navigation is permitted for economic, touristic, sporting, and recreational purposes, taking into account the dangers posed by rising water levels or other emergencies. The regime also determines the guardian of the waterway, the type of vessels and their propulsion, ports, passenger terminals and the manager of these places. If there are bathing waters in the area, they must be located and designated in the general law, the time when navigation is allowed must be specified and, last but not least, the rules under which conditions navigation can be prohibited in order to ensure the protection of human life and the environment (Uradni list RS, 2002).

Waterways must have adequate depth, width and clear height for passage to ensure the safe navigation of vessels and ports qualified to receive vessels using the waterway. A system of international markings must also be established and properly maintained to mark the waterway. Nevertheless, safe navigation on inland waterways depends above all on a good knowledge of the navigation area and the characteristics of the vessel involved in inland navigation. Regardless of their size and speed, rivers are constantly changing their depth and sediment configuration, while also changing the shape of the waterways, even if the banks remain externally unchanged. Therefore, mechanical removal of debris and sediments, consolidation and prevention of shoreline erosion is necessary to maintain a safe waterway.

2.1. Waterway marking

The signs used depend on the width of the river, its navigability taking into consideration all characteristics in all seasons and the purpose of navigation. In accordance with the requirements for regular monitoring and maintenance of the underwater part of the river, waterway signs are of great importance for ensuring safe navigation. They are used to identify the waterway and to inform users about the prescribed navigation regime, prohibitions, and dangers.

Figure 1: Destroyed signalization by the river Drava

Marking a waterway is done both on the water and on the shore. The signs need to be properly maintained as they can become a resting place for various birds or be overgrown by shore vegetation. Maintenance also includes replacing destroyed or scratched signs.

When placing a sign on the water, a buoy, a suitable fastening system is required. The purpose of the fastening system is to hold the buoy in a sufficiently accurate position to perform its function. The system can be temporary or permanent. The mooring consists of a flexible mooring rope (and/or chain) connecting the buoy to the mooring device. The most common form of mooring cable is a steel chain, as it can absorb significant amounts of energy and has good abrasion resistance. The traditional fixed mooring is a concrete block or a sinker to which a chain is attached. If a concrete block is not an option for the area in question, the buoy can also be moored with an anchor or mooring ring set. The construction of the mooring depends on following:

- the depth of water at the mooring,
- the buoyancy of the buoy,
- the conditions of the riverbed at the site,
- the loads exerted on the mooring by the buoy due to wind, swell, river current and ice,
- loads exerted on the mooring cable by the river current,
- local conditions causing wear and corrosion on the mooring,
- available maintenance facilities,
- required service life of the mooring (IALA Guideline, 2010).

The type of the mooring may be transitional, slack, or taut. The transitional type of mooring is an ideal mooring condition in which the chain acts directly at the mooring point (sinker) as a tangent to the riverbed at the moment it acts on the buoy with maximum load due to wind, change in water height or current. The mooring force therefore acts horizontally on the sinker and is thus most effective.

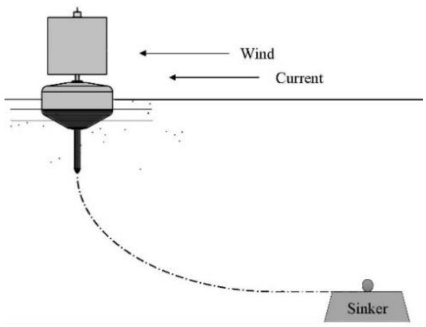


Figure 2: Transitional mooring type

With a slack mooring, the chain is permanently on the seabed. When the load on the buoy is at its greatest, part of the mooring chain lies on the bottom of the river, at a certain distance from the sinker.

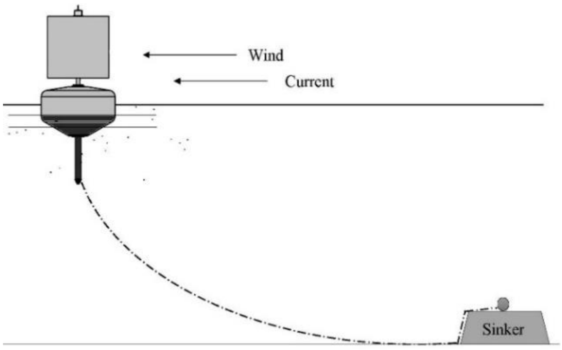


Figure 3: Slack mooring type

The chain on the bottom increases the safety of the mooring, but also has an impact on the sinker, which can be smaller with this type of mooring.

If the rotation of the buoy is too great for the safety requirements, a taut mooring is considered. This type of mooring is also used in areas where the riverbed is an important ecosystem. Then it is necessary to design a taut mooring so that most of the mooring chain hangs on a buoy and the chain does not slide on the riverbed. Due to the shorter mooring rope or chain, the force on the sinker increases under the influence of wind, current and waves, necessitating the choice of a heavier sinker (IALA Guideline, 2010).

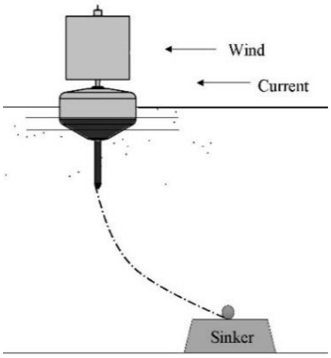


Figure 4: Taut mooring type

Friction on the riverbed is considered when calculating the required weight of the concrete block. The minimum weight of a concrete block is calculated using the following equation (IALA Guideline, 2010):

$$M_{block} \geq K \frac{T_{h0}\,\delta}{g\left(\delta - \rho_w\right)\tan \emptyset} + \frac{T_{v0}}{g}, \quad (1)$$

where:

M_{block} – weight of the concrete block [kg]

K – safety coficient

T_{h0} – horizontal load on the buoy equal to the horizontal load on the anchor [N]

T_{v0} – vertical load due to chain weight (in water) + vertical load on the anchor [N]

δ – medium density of a concrete block [kg/m3] (2400 kg/m3 for concrete)

g – gravitational acceleration [m/s2]

ρ_w – density of a water [kg/m3]

∅ – internal angle of riverbed friction. 450 (0.7855 in radians) is the approximation most commonly used. The clay and gravel surface of the bottom provides smaller friction angle.

2.2. Placing the watermarks and signs

Inland navigation is particularly challenging when not all parts of the waterway, dangerous places and various obstacles, are marked. When buoys are used for marking, they must be anchored at a distance of at least five metres from the boundary of the hazard they mark. Given the width of the navigable channel and river, this is not feasible in many cases. Embankments and shoals may be marked with pillars or buoys and shall be placed at the edge of these hazards, usually in front of them and at a sufficient distance to allow the maintenance vessel to approach these marks from all sides. In any case, it should be emphasized that all vessels on the waterway must keep a sufficient distance from these markings to avoid the risk of collision with them or grounding.

In order to properly set up the signals for safe navigation, one must take into account which vessels will use the waterway and the characteristics of the river itself, regardless of the size and geographical location of the inland waters. The basic requirement for marking is good visibility of the markings and signals, both by day and by night. The type and size of the signs must be chosen accordingly. The degree of visibility of the sign, like any other object, depends mainly on the size of the viewing angle, the color and light contrast and the weather conditions. The maximum daytime viewing angle for simple shapes (square, triangle, circle, etc.) must be between 3.5º and 5º. For complex shapes (numbers, letters, symbols, etc.) this value must be between 5º and 8º. For the navigator to recognize the shape of the mark at a reasonable distance and visibility by eye, the following formula can be used to calculate the dimensions of the mark (Inland Transport Committee, 2015):

$$H = L \cdot tg\,\alpha \cong L \cdot \sin \alpha, \quad (2)$$

where:

H – the height of the mark [m]

L – distance to the mark [m]

α – viewing angle [º]

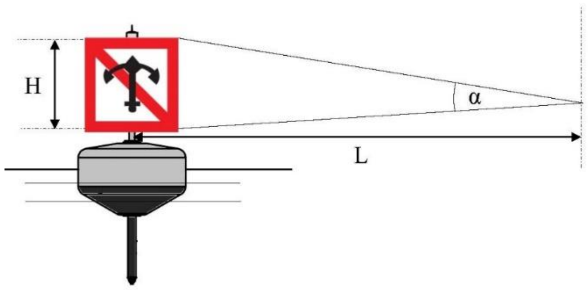


Figure 5: Graphical representation of the size of a mark

Table 1 shows the sizes of the marks (H) in metres for different distances (L) in metres at different viewing angles in degrees. When marking dots, lines and arrows, a reduction in visibility of 15% must be expected, and even 30% for complex drawings. The size of the markings and the exact shape are specified in the Slovenian Inland Waterways Navigation Act. The regulations are somewhat outdated, as the size of the markings may differ from the European Code for Inland Waterways regulations.

Table 1: H values for different distances (L)

α [º]	**L [m]**									
	100	200	300	400	500	600	700	800	900	1000
	H [m]									
3º	0.087	0.174	0.262	0.349	0.436	0.524	0.611	0.698	0.785	0.872
4º	0.116	0.233	0.349	0.465	0.582	0.698	0.814	0.931	1.047	1.163
5º	0.145	0.291	0.436	0.582	0.727	0.873	1.018	1.163	1.309	1.454
6º	0.175	0.349	0.523	0.698	0.873	1.047	1.222	1.396	1.571	1.745
7º	0.204	0.407	0.611	0.814	1.018	1.222	1.425	1.629	1.832	2.036
8º	0.233	0.465	0.698	0.931	1.163	1.396	1.629	1.862	2.094	2.327

Source: (Inland Transport Committee, 2015)

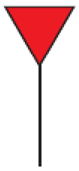
Below are the waterway signs and markings that could be of importance in the area under consideration:

- Prohibitory signs:

a) no entry

The sign marks the boundary on the river beyond which navigation is not permitted for boats. The reason for this restriction is the safety of human life. The sign should be placed on the Drava at a reasonable distance from the hydroelectric power plants.

b) danger point on a right-hand side

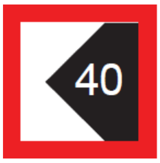


At the place below the Fala cliff it is obligatory to mark the dangerous shoal.

c) no passing outside the marked area

The sign is one of the prohibition signs. It indicates safe passages under bridges or dams. On the Drava, the sign is placed under the bridge Ruški most, which is dangerous for the passage of boats due to the remains of the underwater pillars of the old bridge (Fig. 6).

d) distance a channel lies from the right bank



The sign indicates that the fairway is at a certain distance from the right (left) bank; the number on the sign indicates the distance (in metres) that vessels must keep clear, the distance measured from the sign. The sign is particularly important in individual areas where there are sport and recreational routes for rowing boats.

Source: https://mariborinfo.com/novica/lokalno/most-cez-reko-dravo-v-rusah-bo-zaradi-obnove-leto-in-pol-za-promet-povsem-zaprt

Figure 6: Remains of the old bridge Ruški most, which pose a potential danger to navigation

- Recommendatory signs:

e) weir

The marking of hydroelectric power plants is placed together with the prohibition signs (a). On the Drava River, there is currently a ban on boating 500 metres from the hydroelectric power plants.

f) ferry boat not moving independently

In an effort to connect the right and left banks of the river, the plan is to revive ferry boat traffic, which, due to its peculiarities, cannot manoeuvre freely and avoid other vessels on the waterway. The sign informs other users that there is a ferry boat nearby that has priority on the route.

g) making fast to the bank permitted

This sign indicates the place where mooring on the shore is permitted. This place may be provided with a pier or a ramp suitable for landing vessels.

h) turning area

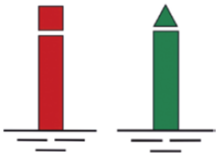
The sign warns users that the area is safe for turning the vessel. The sign is usually placed in front of the sign "no entry".

i) launching or beaching of vessels permitted

Launching ramps for boats are located at several places in the fairway concerned. The sign indicates the exact position of the ramp.

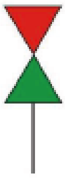
Buoyage of fairway limits in the waterway

j) right (red) and left-hand (green) side of the fairway



The use of these markings is particularly useful in areas where traffic is to be restricted to the waterway lane. This may be the case in bathing waters, spawning areas and other protected areas of the river.

k) bifurcation



Marking an obstacle such as an island in the middle of the waterway should be a bifurcation buoy.

Figure 7: An example of the placement of signs at a Lake Mariborsko jezero

3. DISCUSSION

As rowing and sailing are traditional activities on the river, it is important that signs and markings for the waterway are predominantly placed on land, as vessels could collide with markings placed on the river. For water signs to be placed on the river itself, a transitional mooring type is suggested, as the fluctuations of the water level change daily and are regulated by the HE Fala. The size of the sign should be sufficient for distances up to 400 m to mark the waterway, i.e. about 60 cm, which should apply to information and recommendation signs. However, prohibition signs and signs marking the fairway must be made in the size prescribed by the legislation in force.

4. CONCLUSION

The Slovenian Transport Development Strategy envisages the regulation of inland navigation, which is currently not sufficiently regulated by 2030 (Ministrstvo za infrastrukturo Republike Slovenije, 2017). Slovenia has a series of inland waterways that are suitable for transporting goods and people, but they are hardly used because legislation in this area is not harmonised across ministries. It is necessary to determine the navigable categories of inland waterways in Slovenian rivers and lakes (reservoirs) and to establish the corresponding conditions for them. The categorisation of waterways according to Slovenian waters would also prescribe uniform navigation regimes, which would facilitate the management of waterways and improve the efficiency of their control. An important part of the planning includes their marking, which is not a one-time event but a continuous activity. This starts with the basic planning of the placement of signs, and all further steps depend on the users of the waterway, who constantly assess the accuracy of the signs and their suitability in the field. The manager of the waterway is responsible for the placement and maintenance of the signs, of course in addition to other activities determined by the local municipality.

REFERENCES

[1] Božič, L. (2003). Mednarodno pomembna območja za ptice v Sloveniji 2. Retrieved from Živi z Naturo 2000: http://www.natura2000.si/narava/obmocja/SI5000011/

[2] Direkcija Republike Slovenije za vode. (2018). Strokovne podlage za pripravo Uredbe o uporabi plovil na motorni pogon na akumulacijskem jezeru hidroelektrarne Mariborski otok na reki Dravi. Ljubljana.

[3] Dravske elektrarne Maribor. (2022). O družbi. Retrieved from https://www.dem.si/sl/o-druzbi/

[4] IALA Guideline. (2010). 1066 The Design of Floating Aid to Navigation Moorings, Edition 1.0. Saint Germain en Laye, France: IALA.

[5] Inland Transport Committee. (2015). CEVNI – European Code for Inland Waterways, 5th Edition. UNITED NATIONS PUBLICATION.

[6] Lešnik, T. (2019, maj 19). Se bo kdaj vrnil nekdanji blišč kampa v Bresternici? Retrieved from Maribor24.si: https://maribor24.si/lokalno/se-bo-kdaj-vrnil-nekdanji-blisc-kampa-v-bresternici

[7] Mestna občina Maribor. (2010). Odlok o ureditvi plovbe po reki Dravi (MUV, št. 4/98, 12/10). Retrieved from Lex Localis: http://www.lex-localis.info/KatalogInformacij/PodrobnostiDokumenta.aspx?SectionID=e62335cc-3676-4ef8-83e7-a1ab387e1f0c

[8] Ministrstvo za infrastrukturo Republike Slovenije. (2017). Strategija razvoja prometa v Republiki Sloveniji do leta 2030. Ljubljana: Ministrstvo za infrastrukturo Republike Slovenije.

[9] Uradni list RS. (2002). Zakon o plovbi po celinskih vodah (Uradni list RS, št. 30/02, 29/17 – ZŠpo-1 in 41/17 – PZ-G). Retrieved from http://pisrs.si/Pis.web/pregledPredpisa?id=ZAKO3301#

STORAGE OF THE SHIP MANEUVERING CAPABILITIES INTO THE POSTGRES DATABASE

Vladimir Brozović
Rino Bošnjak, Ph.D.
Danko Kezić, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, 21000 Split, Croatia
vladimir.brozovic@pfst.hr, rino.bosnjak@pfst.hr, danko.kezic@pfst.hr

Filip Brozović
SEAL AG
Wettingen, Switzerland
fbrozovic@seal.ch

ABSTRACT

For the calculation of avoiding routes in case of an imminent collision, the maneuvering capabilities of each involved ship are taken into account. This article shows how and which data for each ship are stored in a Postgres database and how these data are used in a concrete case. When calculating the maneuvering capabilities, the current meteorological conditions are also taken into account. To reduce the amount of data, multidimensional interpolation is used. In order to be able to search the corresponding ship data for the interpolation in the database in real time and still be able to introduce new entries for a ship in any order afterwards, some auxiliary indices are used in the database entries. These are also explained in the article. After first explaining the database structure, the maneuvering capabilities of the ship are determined as an example of a concrete situation. The most important C code parts for the operations with the database are presented. An example of multidimensional interpolation using data from the database with associated C code is also presented.

Keywords: Collision Avoidance, Maneuvering Capabilities, Database with Ship Skills

1. INTRODUCTION

An important part of an automatic "**C**ollision **A**voidance **S**ystem" is the automatic calculation of the new avoidance vessel routes in case of an imminent collision. Ship maneuvering skills must also be included in these calculations. Ship maneuvering skills depend on several factors. A method for storing the maneuvering skills of each ship under specified conditions has been developed. From individual ship data stored in this way, it is then possible to estimate the maneuvering capabilities of the ship in the current circumstances at specified positions. A database was created for storing of maneuevering skills. A database for forecasted meteorological conditions was also created. Postgres is used as the database software for solving all database tasks throughout the project.

Various aspects of determining the maneuvering capabilities of a ship at a given position can be divided into 4 groups. These are constructive characteristics of a ship, percentage loading, meteorological conditions and lastly the cost of an evasive maneuver calculated in this way. The linking of all these knowledge elements happens in a database. This article reports on the description of the data model of this database and how to use it.

The paper is organized as follows:

Section 2 gives an overview of the whole system in which the presented storage of ship maneuvering capabilities is used. Section 3 describes the used multidimensional interpolation. Section 4 provides information on the database software used and describes the data model set up for ship maneuvering capabilities with a description of the database tables and the fields in these tables. Section 5 describes the data model set up for meteorological conditions with a description of the database tables and the fields in these tables. Section 6 shows how to determine the maneuvering capabilities of a ship in a specific situation with a given position, speed and course, taking into account the prevailing meteorological conditions. Section 7 shows the most important parts of the C code.

2. SYSTEM OVERVIEW

In Figure 1 the system for collision detection and avoidance is shown.

The inputs to the system are signals from various sensors as well as information such as nautical charts, meteorological forecasts, etc. The system consists of three main blocks. The first is the Collision Detection block, where an imminent collision is detected based on the predicted ship routes. The second one is the block where the avoidance rules are selected. In the third block (collision avoidance), the new ship routes for avoiding the impending collision are calculated. In this article solutions of certain tasks from the third block are presented.

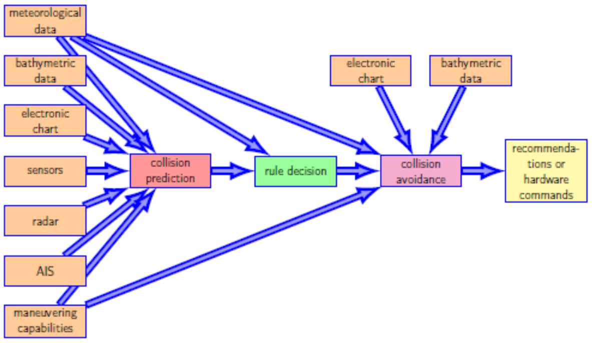


Figure 1: Architecture of collision detection and avoidance system

All inputs (orange boxes) to the presented system are made via the database. Thus, the system can be designed independently of different data formats of real inputs.

The database software used throughout the project is Postgres with PostGIS extension. The detailed insights into Postgres can be found in [1], and into PostGIS in [2].

3. MULTIDIMENSIONAL INTERPOLATION

We use linear interpolation to calculate the values for the specified operating point from the database values. This is based on Taylor's series for functions of m variables according to the formula:

$$F(x_1 + h_1, x_2 + h_2, \dots, x_m + h_m) = F(x_1, x_2, \dots, x_m) + \left(h_1 \frac{\partial}{\partial x_1} + h_2 \frac{\partial}{\partial x_2} + \cdots + h_m \frac{\partial}{\partial x_m}\right) F(x_1, x_2, \dots, x_m)$$

If necessary, we enter many records into the database for non-linear dependencies and thereby linearize the interpolation. This replaces a non-linear dependency with a series of linear segments.

It is important to emphasize here that in algorithms for finding evasive routes the estimated maneuvering capabilities of the ship are not exhausted to the maximum. In these algorithms these capabilities are used with a safety factor, and in most experiments a factor of 0.3 was used.

4. DATA MODEL FOR MANEUVERING CAPABILITIES

The *ship_skills* database, whose entries describe the ship's maneuvering capabilities, consists of 5 tables. These tables and their fields are described in the following subsections.

The entries of these tables are essentially the function values $\boldsymbol{F}_i$ in working points (x_1, …, x_m) and the corresponding partial derivates so that the interpolation can be calculated according to the formula from section 3.

The choice of the data model was also influenced by the need to be able to add new details to the ship data at any time without affecting the speed of the search.

4.1. Table *ship*

This table contains records with basic information about ships. The meaning and variable type of the entry fields are:

ship_id This is the index of the ship's entry and is assigned by the database. The field type is int32_t.

name This is the name of the ship. The field type is varchar.

mmsi This is the mmsi of the ship. The field type is int64_t.

imo This is the imo of the ship. The field type is int64_t.

length This is the length of the ship in meters. The field type is int32_t.

min_draft This is the minimum draft in meters. The field type is real (4 byte floating point).

max_draft This is the maximum draft in meters. The field type is real (4 byte floating point).

max_speed_min_draft This is the maximum speed in knots at minimum draft. The field type is real (4 byte floating point).

max_speed_max_draft This is the maximum speed in knots at maximum draft. The field type is real (4 byte floating point).

4.2. Table skills

The entries in this table indicate the ship skills under conditions given in the same entry. The meaning and variable type of the entry fields are:

skill_id This is the index of the skills's entry and is assigned by the database. The field type is int64_t.

ship_id This field contains the value from 4.1 . The field type is int32_t.

draft_percentage This field contains the percentage of draft. 0% corresponds to the minimum draft from 4.1 and 100% corresponds to the maximum draft from 4.1 . The field type is real (4 byte floating point).

vessel_speed This field contains the speed in knots at which the skills in the four following fields are specified. The field type is real (4 byte floating point).

ccs_starboard This field (**c**ourse **c**hange **s**peed starboard) gives the maximum speed of the course change (rate of turn) in starboard direction. The units are °/s. The field type is real (4 byte floating point).

ccs_portside This field (**c**ourse **c**hange **s**peed portside) gives the maximum speed of the course change (rate of turn) in portside direction. The units are °/s. The field type is real (4 byte floating point).

acceleration This field gives the maximum acceleration. The units are m/s^2. The field type is real (4 byte floating point).

deceleration This field gives the maximum deceleration. The units are m/s^2. The field type is real (4 byte floating point).

meteo_id This field contains the index *meteo_id* of the record with meteorological conditions from the table *meteo* described in 4.3. This entry connects the ship skills in an entry of this table *skills* with specific meteorological conditions. The field type is int64_t. If this field of an entry is zero, no weather dependency exists for maneuvering capabilities of this ship in the working condition specified by this entry.

gradients_id This field contains the index *gradients_id* of the record with gradients from the table *gradients* described in 4.4. This entry connects the skills in an entry of this table *skills* with their specific gradients. The field type is int64_t. These gradients are then used for multidimensional interpolation.

By combining the two indices *meteo_id* and *gradient_id*, different gradients can be specified for different meteorological conditions at the same ship speed and draft.

draft_index This and the next field are used to define the order of searching for the nearest working point in the table of ship skills for the purpose of interpolation for determining the current skills. In this way it is possible to make new entries for a ship already in the table at any time, without slowing down the search for the closest working point in the table and without the need to reorganize the table. The first index for the search is draft_index and the second is speed_index. In the search the second index is incremented faster. The field type is int32_t.

speed_index See text about draft_index . The field type is int32_t.

4.3. Table meteo

Each entry in this table defines a combination of the meteorological conditions. The meaning and variable type of the entry fields are:

meteo_id This is the index of the meteo entry and is assigned by the database. The field type is int64_t.

wind_speed The units are m/s. The field type is real (4 byte floating point).

wind_direction Direction, relative to the ship's course, from which the wind is coming. The units are °. The field type is real (4 byte floating point).

wave_height The units are m. The field type is real (4 byte floating point).

wave_direction Direction, relative to the ship's course, from which the waves are coming. The units are °. The field type is real (4 byte floating point).

current_strength The units are m/s. The field type is real (4 byte floating point).

current_direction Direction, relative to the ship's course, from which the current is coming. The units are °. The field type is real (4 byte floating point).

swell_height The units are m. The field type is real (4 byte floating point).

swell_direction Direction, relative to the ship's course, from which the swell is coming. The units are °. The field type is real (4 byte floating point).

4.4. Table gradients

This table contains partial derivatives which are needed for a multidimensional interpolation. Only a few of the gradient list are described here due to space limitations. The meaning and variable type of the entry fields described:

gradients_id This is the index of the gradients entry and is assigned by the database. The field type is int64_t.

d_ccs_s_d_draft This field has the following value:

$$\frac{\partial}{\partial draft} ccs\_starboard$$

The units are °/%s. The field type is real (4 byte floating point).

d_ccs_s_d_speed This field has the following value:

$$\frac{\partial}{\partial speed} ccs\_starboard$$

The units are °/m. The field type is real (4 byte floating point).

d_ccs_s_d_wind_speed This field has the following value:

$$\frac{\partial}{\partial wind\_speed} ccs\_starboard$$

The units are °/m. The field type is real (4 byte floating point).

d_ccs_s_d_wind_dir This field has the following value:

$$\frac{\partial}{\partial wind\_direction} ccs\_starboard$$

The units are s^{-1}. The field type is real (4 byte floating point).

Other gradient fields not described here are:

1. d_ccs_s_d_wave_height
2. d_ccs_s_d_wave_dir
3. d_ccs_s_d_current_strength
4. d_ccs_s_d_current_dir
5. d_ccs_s_d_swell_height

6. d_ccs_s_d_swell_dir
7. ccs_portside gradients in the same manner
8. d_acc_d_draft
9. d_acc_d_speed
10. d_acc_d_speed
11. d_acc_d_wind_speed
12. d_acc_d_wind_dir
13. d_acc_d_wave_height
14. d_acc_d_wave_dir
15. d_acc_d_current_dir
16. d_acc_d_swell_height
17. d_acc_d_swell_height
18. d_acc_d_swell_dir
19. deceleration gradients in the same manner

4.5. Table costs

The meaning and variable type of the entry fields in this table are:

costs_id This is the index of the costs entry and is assigned by the database. The field type is int64_t.

additional_way That is the cost of the additional route. The units are m^{-1}. The field type is real (4 byte floating point).

maximum_ccs_starboard That is the cost of the maximum course change speed in starboard direction. The cost of current course change speed is the product of this field value and the ratio between the current ccs and the maximum ccs. This field has no units. The field type is real (4 byte floating point).

maximum_ccs_portside That is the cost of the maximum course change speed in portside direction. The cost of current course change speed is the product of this field value and the ratio between the current ccs and the maximum ccs. This field has no units. The field type is real (4 byte floating point).

5. DATA MODEL FOR METEOROLOGICAL CONDITIONS

The database with meteorological values consists of several tables. These tables are described in the following text.

5.1. Database table meteo_conditions_range

This table contains certain information about the entries in the much larger tables with values (*wind_values*, *wave_values*, *current_values*, *swell_values*), with the help of which the required information can be searched for much more quickly in the large table.

Entries in this table are:

meteo_index This is the record index assigned automatically by Postgres. The type of this index is *bigserial*. **table_name** This field indicates to which meteorological table (wind/wave/current/swell) this entry refers. The type of this field is *varchar(64)*.

low_index This field gives the first index of the record sequence in the table specified by *table_name,* to which (record sequence) the following fields of this entry refer. The type of this field is *bigint*.

high_index This field gives the last index of the record sequence in the table specified by *table_name*, to which the following fields of this entry refer. The type of this field is *bigint*.

start_time This field gives the start time for the meteorological data given in the specified index range (*low_index*,*high_index*) of the specified table *table_name*. The type of this field is *bigint*.

end_time This field gives the end time for the meteorological data given in the specified index range (*low_index*,*high_index*) of the specified table *table_name*. The type of this field is *bigint*.

area_long_west This is the western longitude of the geographical area in which the points with meteorological data are located. The type of this field is *double precision*.

area_lat_south This is the southern latitude of the geographical area in which the points with meteorological data are located. The type of this field is *double precision*.

area_long_east This is the eastern longitude of the geographical area in which the points with meteorological data are located. The type of this field is *double precision*.

area_lat_north This is the northern latitude of the geographical area in which the points with meteorological data are located. The type of this field is *double precision*.

5.2. Database tables with meteorological values

These tables essentially contain the geographic coordinates of the points with associated information about the meteorological conditions and the time when these conditions are valid.

5.2.1. Database table wind_values

The records of this table have the following fields:

wind_index This is the record index assigned automatically by Postgres. The type of this index is *bigserial*.

wind_time This is the time to which the wind values in this record refer. The type of this field is *bigint*.

wind_point_long This is the longitude of the geographical point to which the wind data refers. The type of this field *double precision*.

wind_point_lat This is the latitude of the geographical point to which the wind data refers. The type of this field *double precision*.

wind_speed The units are [m/s]. The field type is *real*.

wind_direction This is the azimuth of the direction in which the wind blows. The units are [°]. The field type is *real*.

5.2.2. Database table wave_values

The records of this table have the following fields:

wave_index This is the record index assigned automatically by Postgres. The type of this index is *bigserial*.

wave_time This is the time to which the wave values in this record refer. The type of this field is *bigint*.

wave_point_long This is the longitude of the geographical point to which the wave data refers. The type of this field *double precision*.

wave_point_lat This is the latitude of the geographical point to which the wave data refers. The type of this field *double precision*.

wave_height This is the average height of the waves.The units are [m]. The field type is *real*.

wave_direction This is azimuth of the direction in which the waves are moving. The units are [°]. The field type is *real*.

wave_speed The units are [m/s]. The field type is *real*.

wave_distance This is the distance between the peaks of the two adjacent waves. The units are [m]. The field type is *real*.

wave_maxheight This is the maximum height of the waves. The units are [m]. The field type is *real*.

wave_maxaverrat This is the average number of waves with the average height until another wave with the maximum height comes. The field type is *real*.

5.2.3. Database table current_values

The records of this table have the following fields:

current_index This is the record index assigned automatically by Postgres. The type of this index is *bigserial*.

current_tim This is the time to which the current values in this record refer. The type of this field is *bigint*.

current_point_long This is the longitude of the geographical point to which the current data refers. The type of this field *double precision*.

current_point_lat This is the latitude of the geographical point to which the current data refers. The type of this field *double precision*.

current_strength The units are [m/s]. The field type is *real*.

current_direction This is azimuth of the direction in which the current flows. The units are [°]. The field type is *real*.

5.2.4. Database table swell_values

The records of this table have the following fields:

swell_index This is the record index assigned automatically by Postgres. The type of this index is *bigserial*.

swell_time This is the time to which the swell values in this record refer. The type of this field is *bigint*.

swell_point_long This is the longitude of the geographical point to which the swell data refers. The type of this field *double precision*.

swell_point_lat This is the latitude of the geographical point to which the swell data refers. The type of this field *double precision*.

swell_height This is the average height of the swell.The units are [m]. The field type is *real*.

swell_direction This is azimuth of the direction in which the swell is moving. The units are [°]. The field type is *real*.

swell_speed The units are [m/s]. The field type is *real*.

swell_distance This is the distance between the peaks of two adjacent swell waves. The units are [m]. The field type is *real*.

swell_maxheight This is the maximum height of the swell waves. The units are [m]. The field type is *real*.

swell_maxaverrat This is the average number of swell waves with the average height until another swell wave with the maximum height comes. The field type is *real*.

6. DETERMINATION OF THE CAPABILITIES BASED ON THE DATABASE ENTRIES

In this section we will explain how the maneuvering skills for given position and time are estimated for a specified ship based on the data stored in the database.

The following procedure is used:

1. Input parameters are coordinates (*long, lat*), time *given_time* and identification of the ship (*mmsi* or *imo*).
2. In the database with meteorological data, the data for given coordinates at the given time are searched. This happens in the following way:
   - (i) In database table 5.1 entries are searched for which the following condition is fulfilled:

     given_time ∈ [*start_time, end_time*].
   - (ii) In the entries found in the last step the entries are searched, in which for the given point coordinates (long, lat) these conditions are valid: (*area_long_west* ≤ *long* ≤ *area_long_east*) ∧ (*area_lat_south* ≤ *lat* ≤ *area_lath_north*).

(iii) Assuming that the meteorological data in tables 5.2.1, 5.2.2, 5.2.3, 5.2.4, were sorted by coordinates from (area_long_west,area_lat_south) to (area_long_east,area_lat_north) with increasing longitude first, and then by time, we first look for the 4 points $\left(long_{i,t_1}, lat_{i,t_1}\right), i \in [1,4]$ that border the given point (*long, lat*) at the time t_1 that is the last time point in the table before the *given_time* and such 4 points $\left(long_{j,t_2}, lat_{j,t_2}\right), j \in [1,4]$ for the time t_2 that is the first time point in the table after the *given_time*.

(iv) The IDW (**I**nverse **D**istance **W**eighting) interpolation is used to calculate the meteorological values on the coordinates (long,lat). This results in the following interpolation formulas with values from the previous step:

$$F_{t_1} = \frac{\sum_{i=1}^{4} \frac{1}{d_i} F_{i,t_1}}{\sum_{i=1}^{4} \frac{1}{d_i}} \quad \text{and} \quad F_{t_2} = \frac{\sum_{j=1}^{4} \frac{1}{d_j} F_{j,t_2}}{\sum_{i=j}^{4} \frac{1}{d_j}}$$

$$d_i = distance\_f\left((long, lat), \left(long_{i,t_1}, lat_{i,t_1}\right)\right), \quad i \in [1,4]$$

$$d_j = distance\_f\left((long, lat), \left(long_{j,t_2}, lat_{j,t_2}\right)\right), \quad j \in [1,4]$$

ST _Distance from PostGIS is used as *distance_ f unction*. More about IDW interpolation methods can be found in [3]. and [4]. .

(v) With "Inverse Distance Weighting" interpolation described above, the meteorological value ***F*** at the time *given_time* is finally estimated as follows:

$$\boldsymbol{F}(given\_time) = \frac{\frac{F_1}{given\_time - t_1} + \frac{F_2}{t_2 - given\_time}}{\frac{1}{given\_time - t_1} + \frac{1}{t_2 - given\_time}}$$

In this special case of IDW interpolation with only two points, corresponding algebraic transformation gives the well known formula for linear interpolation:

$$F(given\_time) = F_1 + (given\_time - t_1)\frac{F_2 - F_1}{t_2 - t_1}$$

3. The next step is to combine the directional data from the previous step with the ship's COG (**C**ourse **O**ver **G**round). The result of this linkage are directions of meteorological conditions (wind, current, waves and surf) relative to the ship's course.
4. Now the database of maneuvering skills is searched in the following way:

(vi) The *ship_id* and characteristic ship values are searched in the table *ship* for given *mmsi* or *imo* number. The value *calc_draft_percentage* is calculated from the ship values *min_draft*, *max_draft* and the current draft.

(vii) Afterwards all entries for *ship_id* are searched in the table *skills*, where *draft_percentage* is greater than or equal to the calculated *calc_draft_percentage*. The search results are sorted by *draft_percentage* (1st criteria) and *vessel_speed* in increasing order.From the entries found, only those are used where *draft_percentage* is equal to or immediately greater than the *calc_draft_percentage* and the *vessel_speed* which are the closest values to the current *sog*. These two closest values are called *speed_below_sog* and *speed_above_sog*.

(viii) Now we compare which of the two speed entries is closer to the current sog. The values assigned to this entry are then used in the interpolation.

(ix) In the next step for the selected *vessel_speed* the meteorological conditions are searched according to the most similar amplitude and relative angle.

(x) And finally, the index *gradients_id* is read from the entry found in this way in the previous step. This gradient index is then used to read the gradient values from the table *gradients*. Read values are then used for the interpolation described in section 3 .

7. C CODE

This section presents the most important parts of the C code for the tasks described in previous sections:

- Finding the meteorological conditions for given coordinates at given time.
- Finding ship capabilities in the database for similar meteorological conditions.

6.1. Finding the meteorological conditions for given coordinates

In the presented C code in Listing , the conditions for given coordinates at given time are estimated from the database with predicted meteorological conditions.

```c
#include <libpq-fe.h>

#include "meteo_conditions.h"

int find_wind_meteo_conditions(PGconn * conn, double longitude, double latitude, uint64_t time, struct meteo_wind_conditions *
        meteo_wind_conditions )
{
 PGresult *result ;
 char PGcommand_string[4096];
 char *pgresult_value ;
 long n;
 int64_t low_index, high_index ;
 int64_t last_index_before_time, first_index_after_time, time_before, time_after ;
 double point_bottom_left_long, point_bottom_right_long, point_top_left_long, point_top_right_long ;
 double point_bottom_left_lat, point_bottom_right_lat, point_top_left_lat, point_top_right_lat ;
 float wind_speed_bottom_left, wind_speed_bottom_right, wind_speed_top_left, wind_speed_top_right ;
 float wind_direction_bottom_left, wind_direction_bottom_right, wind_direction_top_left, wind_direction_top_right ;

   sprintf( PGcommand_string, "SELECT * FROM meteo_conditions_range WHERE table_name='wind' AND area_long_west < %.15lf AND
        area_long_west > %.15lf AND area_lat_south < %.15lf AND area_lat_north > %.15lf AND start_time < %" PRIu64 " AND end_time >
        %" PRIu64 ";", longitude, longitude, latitude, latitude, time, time) ;
   result = PQexec( conn, PGcommand_string);
   n = PQntuples( result );
   if( n > 0 )
   {
      pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "low_index") );
      sscanf( pgresult_value, "%" SCNd64 , &low_index );
      pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "high_index") );
      sscanf( pgresult_value, "%" SCNd64 , &high_index );
      PQclear( result );
      sprintf( PGcommand_string, "SELECT * FROM wind_values WHERE wind_index >= %" PRId64 " AND wind_time =< %" PRIu64 "
            ORDER BY wind_index ASC ;", low_index, time );
      result = PQexec( conn, PGcommand_string);
      n = PQntuples( result );
      if( n > 0 )
      {
         pgresult_value = PQgetvalue( result, n - 1, PQfnumber( result, "wind_index") );
         sscanf( pgresult_value, "%" SCNd64 , &last_index_before_time);
      }
      PQclear( result );
      sprintf( PGcommand_string, "SELECT * FROM wind_values WHERE wind_index <= %" PRId64 " AND wind_time => %" PRIu64 "
            ORDER BY wind_index DESC ;", high_index, time );
      result = PQexec( conn, PGcommand_string);
      n = PQntuples( result );
      if( n > 0 )
      {

         pgresult_value = PQgetvalue( result, n - 1, PQfnumber( result, "wind_index") );
         sscanf( pgresult_value, "%" SCNd64 , &first_index_after_time);
      }
      PQclear( result );
      sprintf( PGcommand_string, "SELECT * FROM wind_values WHERE wind_index <= %" PRId64 " AND wind_point_long =< %.15lf
            AND wind_point_lat =< %.15lf ORDER BY wind_index DESC LIMIT 1;", last_index_before_time , longitude, latitude );
      result = PQexec( conn, PGcommand_string);
      n = PQntuples( result );
      if( n > 0 )
      {
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "wind_time") );
         sscanf( pgresult_value, "%" SCNd64 , &time_before );
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "wind_point_long") );
         sscanf( pgresult_value, "%lf", &point_bottom_left_long );
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "wind_point_lat") );
         sscanf( pgresult_value, "%lf", &point_bottom_left_lat );
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "wind_speed") );
         sscanf( pgresult_value, "%f", &wind_speed_bottom_left );
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "wind_direction") );
         sscanf( pgresult_value, "%f", &wind_direction_bottom_left );
      }
      PQclear( result );
```

Listing 1: C Code Example for Finding the meteo Conditions

6.2. Finding ship capabilities for similar meteorological conditions

In the presented C code in Listing , the capabilities are searched from the maneuvering capabilities database for the specified ship in the most similar meteorological conditions.

```c
#include <libpq-fe.h>

#include "meteo_conditions.h"
#include "ship_skills.h"

int find_ship_skills(PGconn * conn, uint64_t mmsi, uint64_t imo, float speed_over_ground, float course_over_ground, float draft,
struct meteo_wind_conditions * meteo_wind_conditions,
struct meteo_wave_conditions * meteo_wave_conditions,
struct meteo_current_conditions * meteo_current_conditions,
struct meteo_swell_conditions * meteo_swell_conditions
)
{
 PGresult *result ;
 char PGcommand_string[4096];
 char *pgresult_value ;
 long n, i, j, k ;
 int32_t draft_index, first_draft_index ;
 int32_t ship_id , ship_length ;
 float min_draft, max_draft, max_speed_min_draft, max_speed_max_draft, calc_draft_percentage ;
 float vessel_speed, speed_below_sog, speed_above_sog ;
 int32_t speed_index, speed_index_below_sog, speed_index_above_sog ;

   sprintf( PGcommand_string, "SELECT * FROM ship WHERE mmsi = %" PRId64 " OR imo = " PRId64 " ORDER BY ship_id DESC LIMIT
        1;", mmsi, imo) ;
   result = PQexec( conn, PGcommand_string);
   n = PQntuples( result );
   if( n > 0 )
   {
      pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "ship_id") );
      sscanf( pgresult_value, "%ld" , &ship_id );
      pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "min_draft") );
      sscanf( pgresult_value, "%f" , &min_draft);
      pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "max_draft") );
      sscanf( pgresult_value, "%f" , &max_draft);
      calc_draft_percentage = ( draft - min_draft ) / ( max_draft - min_draft ) ;
      PQclear( result );
      sprintf( PGcommand_string, "SELECT * FROM skills WHERE ship_id = %ld AND draft_percentage >= %.5f ORDER BY
            draft_percentage ASC, vessel_speed ASC ;", ship_id, calc_draft_percentage );
      result = PQexec( conn, PGcommand_string);
      n = PQntuples( result );
      if( n > 0 )
      {
         pgresult_value = PQgetvalue( result, 0, PQfnumber( result, "draft_index") );
         sscanf( pgresult_value, "%ld" , &first_draft_index );
         speed_below_sog = 0.0 ;
         speed_above_sog = 100.0 ;
         for( i=0 ; i<n ; i++ )
         {
            pgresult_value = PQgetvalue( result, i, PQfnumber( result, "draft_index") );
            sscanf( pgresult_value, "%ld" , &draft_index );
            if( draft_index = first_draft_index )
            {
               pgresult_value = PQgetvalue( result, i, PQfnumber( result, "vessel_speed") );
               sscanf( pgresult_value, "%f" , &vessel_speed );
               pgresult_value = PQgetvalue( result, i, PQfnumber( result, "speed_index") );
               sscanf( pgresult_value, "%ld" , &speed_index );
               if( (vessel_speed < speed_over_ground) && ( vessel_speed > speed_below_sog ) )
               {
                  speed_index_below_sog = speed_index ;
                  speed_below_sog = vessel_speed ;
               }
               if( (vessel_speed > speed_over_ground) && ( vessel_speed < speed_above_sog ) )
               {
                  speed_index_above_sog = speed_index ;
                  speed_above_sog = vessel_speed ;
               }
```

Listing 2: C Code Example for Finding the Ship Skills

8. CONCLUSIONS

Some aspects of the possible way of estimation of ship capabilities at given meteorological conditions were presented. There is a subset of the problems solved for the realization of a system described in section 2 with an embedded hardware. The data models for the use of the Postgres database were designed in such a way that they can be used in the real-time application on the hardware developed in the project. The appropriate configuration of the Postgres search planner together with search direction specifications (ASC, DESC) in search commands in shown C examples accelerate the execution. Also, in the design of the whole software structure, attention was paid to the fact that many computational tasks can be automatically distributed by the operating system to different cores in order to make maximum use of the hardware.

REFERENCES

[1] T. P. G. D. Group. (2021). Postgresql 14.1 documentation, [Online]. Available: https://www.postgresql. org/files/documentation/pdf/14/postgresql-14-A4.pdf (visited on 02/02/2022).

[2] T. O. S. G. Foundation. (2022). Postgis 3.3.0dev manual, [Online]. Available: https://postgis.net/docs/ manual-dev/ (visited on 02/02/2022).

[3] D. Shepard, "A two-dimensional interpolation function for irregularly-spaced data," in *Proceedings of the 1968 23rd ACM national conference*, Association for Computing Machinery, New Yorki, NY, United States, 1968, pp. 517–523, ISBN: 978-1-4503-7486-6.

[4] L. Mitas and H. Mitasova, "Spatial interpolation," in *Geographical Information Systems (GIS): Principles, Tech- niques, Management and Applications*, P. A. Longley, M. F. Goodchild, D. J. Maguire, and D. W. Rhind, Eds. John Wiley, New York, NY, United States, 1999, pp. 481–492.

REAL TIME PREDICTION OF THE SHIP POSITION WITH THE POSTGIS FUNCTION ST_PROJECT

Vladimir Brozović
Danko Kezić, Ph.D.
Rino Bošnjak, Ph.D.
Igor Vujović, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, 21000 Split, Croatia
vladimir.brozovic@pfst.hr, danko.kezic@pfst.hr, rino.bosnjak@pfst.hr, igor.vujovic@pfst.hr

ABSTRACT

In this article it is shown how future ship positions in a CAS (Collision Avoidance System) can be predicted in real time from the AIS data with the help of the PostGIS function ST_Project. PostGIS is an extension of the Postgres database software. Different subproblems of this predic- tion with corresponding solutions are explained. These are resampling of the real time AIS data to a fixed time grid, FIR data filtering with filter design of the corresponding filter and using the ST_Project function of PostGIS. The differences between the PostGIS function argument types *geometry* and *geography* are shown. C code examples of using PostGIS functions in a C program are presented. On the basis of the recorded real AIS data, comparisons of the predicted and the real sailed ship positions are made. These comparisons are shown for prediction intervals of 5, 10, 20 and 30 minutes in the future.

Keywords: Collision Avoidance, Position Prediction, PostGIS extension

1. INTRODUCTION

In order to realize a reliable collision avoidance system in real time, one of the most important tasks is the real time prediction of the ship's position. The predicted ship positions at each computation time t_{now} form a set of the 3-tuples ($longitude_i$, $latitude_i$, $timestamp_i$) for future time points with index *i*. The future time points $timestamp_i$ lie on a fixed time grid. This prediction can be done in different ways. The results of all these prediction methods can be combined together to improve the prediction quality. In this article one of the basic prediction methods, used in a real system under development, is presented. The method presented here is based on the received AIS data. This paper shows how to process AIS data to obtain the above-mentioned 3-tuples. For real time AIS data acquisition as input to the prediction algorithms and for the storage of prediction results for the purpose of checking the quality of the predictions, a Postgres database is used. For calculations on the Spheroid the PostGIS extensions are used.

The paper is organized as follows:

Section 2 presents the main idea of detection of a potential collision and, in connection with this idea, the need for time-grid oriented position prediction of all observed ships. Section 3 presents the principles of position prediction from AIS data. Section 4 explains the resampling of the real-time AIS data to a fixed 10s time grid. Section 5 explains the basic principles of FIR filtering of AIS data and the design of the filter used. Section 6 provides information about the database software used (Postgres) and about the geographical extensions of this software (PostGIS). The differences between the data types *geometry* and *geography* are explained. Section 7 explains the most important C code parts for interface to the Postgres from own software. Section 8 shows the prediction results using the recorded real AIS data.

2. DETECTION OF A POTENTIAL COLLISION

Figure 1 shows the basic principle of detecting a potential collision. The black dots are the predicted ship positions on the fixed time grid. In our case the time grid is 10s. The time used is the so-called epoch time (time in [s] since 1/1/1970) For time points t_i of the predicted positions the following condition is fulfilled:

$t_i \bmod 10 = 0,\ i \in [1, max\_prediction\_points]$

At any current time τ on the selected grid, ship positions for all observed ships are predicted for all time grid points from the future time interval

$(\tau, \tau + \text{max\_prediction\_time}]$.

For all these positions and for all possible ship pairs it is calculated whether the circles drawn around the position intersect or not. If they do (orange circles in Figure 1), there is a danger of collision at this point.

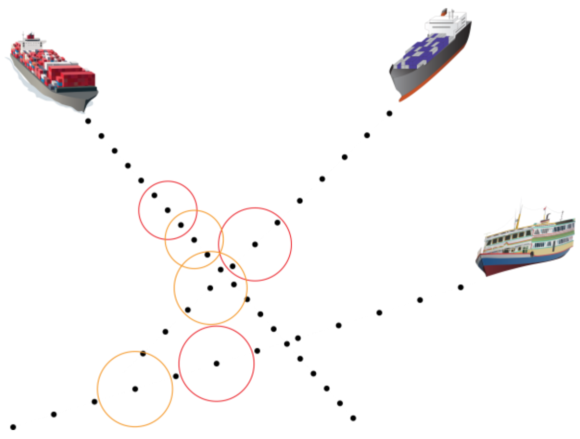


Figure 1: Principle of detection of a potential Collision

3. PRINCIPLES OF PRESENTED POSITION PREDICTION

The basic idea of the presented position prediction for the future time $t_{now} + \tau$, τ is prediction interval, is simple. The ship's **s**peed **o**ver **g**round (SOG) is used to calculate the distance travelled during the time τ . Starting from the current position the point is searched on the spheroid, which has the calculated distance from the current position and forms with the current position an azimuth which corresponds to the current **c**ourse **o**ver **g**round (COG). This is known as the direct geodesic problem. To minimize interferences (e.g. waves), the *SOG* and *COG* data are filtered with digital signal processing algorithms.

4. REAL-TIME AIS DATA RESAMPLING TO FIXED 10S TIME GRID

In order to apply the algorithms for digital signal processing (e.g. for low-pass filtering) to the AIS data, it is necessary to resample the data to a fixed time grid. For our application we decided to use 10s time grids for position prediction and checking for a possible collision. In this section one type of resampling is briefly described. During this resampling we try to avoid information loss as far as possible.

1. Calculations of predicted positions are performed on the 10s grid. (0 s, 10 s, ..., 50 s). The time points on this grid are denoted by $\boldsymbol{t}_{10,n}$, $n \in \mathrm{N}$.
2. Input data for filtering are on the 1s grid. The time points on this grid are denoted by $\boldsymbol{t}_{1,k}$, $k \in \mathrm{N}$.
3. Missing samples on the 1s grid are calculated by the linear interpolation. The last input sample for digital filter at time $\boldsymbol{t}_{10,n}$ is the sample for point $\boldsymbol{t}_{10,n-1}$. This is because between the times $\boldsymbol{t}_{10,n-1}$ and $\boldsymbol{t}_{10,n}$ samples are expected (at least one), which are used for the interpolation up to and with the time $\boldsymbol{t}_{10,n-1}$. If the new samples are not available between $\boldsymbol{t}_{10,n-1}$ and $\boldsymbol{t}_{10,n}$, the sample value last received before time $\boldsymbol{t}_{10,n-1}$ is used as sample value up to time $\boldsymbol{t}_{10,n-1}$.
4. The 1s samples obtained in this way are passed through a low-pass filter. Since the AIS data is sent in intervals of <= 3 s for category A ships, the low-pass cutoff frequency has been set to 0.2. Thus, only the measurement components that need at least 5 s or longer for a change are allowed to pass through the filter.
5. The prediction on the 10s grid is then calculated as follows:
    - Starting position for the prediction is the last received AIS position.
    - Time for calculating the path is the time distance to the future 10s time grid of interest + the time from the last received AIS record to the current 10s time grid.
    - *SOG* for the calculation of the future path and the *COG* for the position calculation are the filter outputs at the time of the last received AIS record.
    - In case there are still insufficient values in the FIR filter, the last *SOG* and *COG* values are used unfiltered for the calculations.

More about different possibilities of digital signal processing with non-uniform distributed sampling times can be found e.g. in [1] .

5. FIR FILTERING AND FILTER DESIGN

In order to reduce the data scattering, which is caused e.g. by various effects such as waves, filtering of AIS data is performed. For this filtering the FIR filter structure is used, which is shown in figure 2 . More about digital FIR filters can be found in [2] .

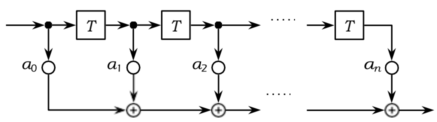


Figure 2: Finite impulse response filter of order n

For data filtering a low pass filter is used. The filter structure is FIR shown above and the filter has 61 taps. For the filter design, the Iowa Hills FIR Filter Designer Version 7.0 is used. Figure 3 shows the design parameters of the filter selected as good enough. Table 1 contains the coefficients of the low pass filter calculated in this way.

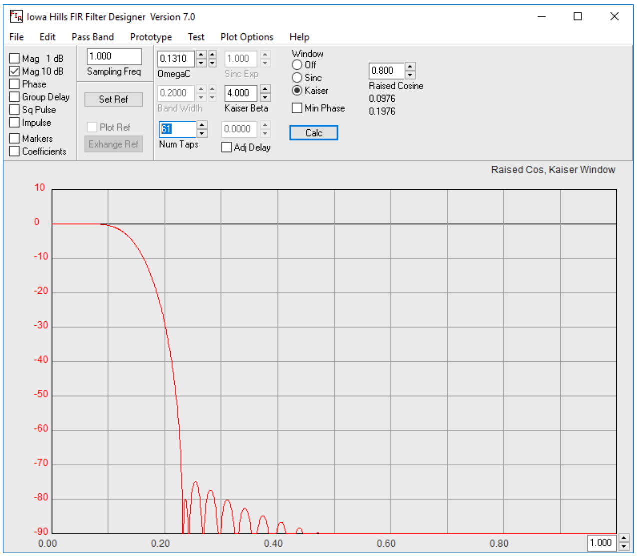


Figure 3: Iowa Hills FIR Filter Designer, 61 Tap Low Pass Filter

Table 1: 61 Tap Low Pass Filter Coefficients

H(1)	= H(61)	= -1.031742846733459730E-12
H(2)	= H(60)	= 24.74685491684478220E-6
H(3)	= H(59)	= 34.65960067235647560E-6
H(4)	= H(58)	= -7.855236799765730640E-6
H(5)	= H(57)	= -139.8056370567045410E-6
H(6)	= H(56)	= -372.8868951416583850E-6
H(7)	= H(55)	= -666.4320441040980540E-6
H(8)	= H(54)	= -911.0176657929513340E-6
H(9)	= H(53)	= -936.9066765004608900E-6
H(10)	= H(52)	= -556.5412606783379490E-6
H(11)	= H(51)	= 360.9556341073587760E-6
H(12)	= H(50)	= 0.001800231456810117
H(13)	= H(49)	= 0.003525605156161184
H(14)	= H(48)	= 0.005059017938201859
H(15)	= H(47)	= 0.005740461193483355
H(16)	= H(46)	= 0.004881494750531875
H(17)	= H(45)	= 0.001992529017679588
H(18)	= H(44)	= -0.002967303094150807
H(19)	= H(43)	= -0.009391724144675508
H(20)	= H(42)	= -0.015958140198158943
H(21)	= H(41)	= -0.020744623387955845
H(22)	= H(40)	= -0.021546236382046433
H(23)	= H(39)	= -0.016347204192751538
H(24)	= H(38)	= -0.003851579989310786
H(25)	= H(37)	= 0.016058705546178761
H(26)	= H(36)	= 0.042069930475890589
H(27)	= H(35)	= 0.071480977125602918
H(28)	= H(34)	= 0.100571918516179221
H(29)	= H(33)	= 0.125240366142250731
H(30)	= H(32)	= 0.141775389781124972
H(31)	= 0.147595214834324834	

6. POSTGRES DATABASE SOFTWARE AND POSTGIS EXTENSION

Postgres database software is used for the whole 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. The good knowledge about these strategies as well as about possible influences of these strategies often enable a massive reduction of the search times. (often several hundred times)

A good insight into Postgres, including the whole history of its creation, is given in [3].

6.1. 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_Azimuth*, *ST_Distance*, *ST_Intersection*, *ST_Intersects*, *ST_Project*, etc.

A good insight into Postgres is given in [4].

6.2. 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. Figure 4 shows the function calls of the function *ST_Distance* from the interactive postgres interface with the same argument values but different types (geometry and geography). The difference in the result is visible.

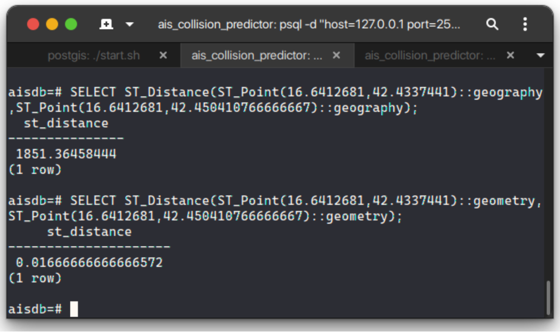


Figure 4: *ST_Distance* Call with different Argument Types

6.3. PostGIS function *ST_Project*

The arguments of the function are point (longitude, latitude), distance (in m) to the new point and azimuth (in radians) of the direction from the point . The function performs this calculation on the WGS84 spheroid. The result is the coordinates of the future position. Figure 5 shows the function call from the interactive postgres interface.

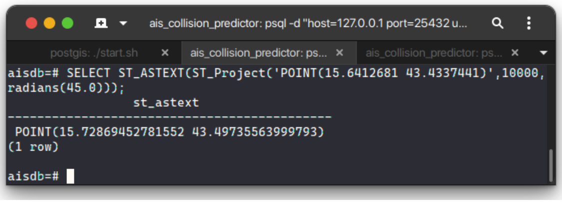


Figure 5: *ST_Project* Call

7. C CODE USED

In this section, C code is presented for the following tasks:

- Connection to the database.
- Calling the *ST_Project* function
- Evaluating the result string.

7.1. Connection to the database

In order to use the PostGIS functions from your own software, it is first necessary to open the connection to the database using the Postgres library functions. How this is done is shown in the C code example in Listing 1 . Other necessary include files are intentionally omitted in this part of the example code.

```
#include <libpq-fe.h>

int main(int argc, char **argv)
{
 PGconn *conn ;
 char conninfo[1024];

   strcpy( conninfo, "host=127.0.0.1 port=25432 user=
         docker password=docker dbname=" );
   strcat( conninfo, argv[1] );

   conn = PQconnectdb( conninfo ) ;

   if( PQstatus(conn) != CONNECTION_OK )
   {
      fprintf(stderr, "Connection to database failed: %s \n\r"
            , PQerrorMessage(conn)) ;
      PQfinish(conn) ;
      return 1 ;
   }
   else
   {
      printf("Connection to database %s OK\n\r", argv[1]);
   }
```

Listing 1: C Code Example for Connection to Database

7.2. Calling the *ST_Project* function

Line 1 in listing 2 shows how the distance is calculated in meters. Line 2 of the code writes in string *PGcommand_string* the postgres command as shown in the interactive example of the postgres interface in Figure 5 . With PQexec in line 3 this string is then executed as a Postgres command.

```
1  predicted_distance = predictor_filter_output_sog * (
       predictor_filter_time - ship_in_system[l][SPM].
       last_ais_times[0] + prediction_time * ( m + 1 ) ) *
        1852 / 3600 ;
2  sprintf(PGcommand_string,"SELECT ST_AsText(
       ST_Project('POINT(%lf %lf)'::geography, %lf,
       radians(%lf)));", ship_in_system[l][SPM].
       last_longitudes[0], ship_in_system[l][SPM].
       last_latitudes[0], predicted_distance,
       predictor_filter_output_cog ) ;
3  result = PQexec( conn, PGcommand_string );
4  pgresult_value = PQgetvalue( result, 0, 0);
5  n = PQntuples( result );
6  if( n>0 )
7  {
8     sscanf( pgresult_value, "POINT(%lf %lf", &
           predicted_longitude, &predicted_latitude );
9  }
10 else{
11    predicted_longitude = 270.00 ;
12    predicted_latitude = 180.00 ;
13 }
14 PQclear( result ) ;
```

Listing 2: C Code Example for ST_Project Function Call

7.3. Result String Evaluation

Function *PQgetvalue* in line 4 in Listing 2 returns pointer to a string with the first field (index 0) from the result. Function *PQntuples* in line 5 returns number of records in the result of database command. And finally, function *PQclear* in line 14 frees the memory allocated by function *PQexec* for the returned structure *result*.

8. PREDICTION RESULTS

In this section the results of the previously described position prediction are presented. The recorded real AIS data are used in the experiments. The converted ship data from these recordings are entered into a database for easier processing.

The results of the prediction were checked by storing the predicted position for future time point ($t_n + \tau$) for each time point t_n on the 10s time grid. At time ($t_n + \tau$) the actual current ship position is then compared with the position predicted and stored at time t_n for future interval τ .

Prediction results are shown for prediction intervals τ of 5, 10, 20 and 30 minutes in the future in Figures 6, 7, 8 and 9 . Because of the plot functions used, the time axis in figures has an offset of 1464700000 seconds, that means the time of 46000 on the time axis corresponds to the epoch time 1464746000 s.

The first position on the curves with real position is the position when the AIS receiver first received the vessel data. For this reason it can be seen that the predictions are less accurate at the beginning until the FIR filter described in section 5 is filled with received data. Also it can be seen in the images that the error increases with increasing prediction interval.

9. CONCLUSIONS

In this article, a way is shown how the prediction of the future ship position can be made using the received AIS data. It was shown in more detail how the received data is resampled to fixed time grid and then processed with algorithms for digital signal processing. It was explained how the future position is predicted with this processed data using PostGIS functions for the solution of the classical geodetic problem. Lastly, the comparisons of predicted positions with actually achieved positions were shown. At this point it should also be emphasized that the presented algorithms run on the hardware developed in the project in real time for all ships in the observed aquatorium.

Presented method of ship position prediction is one of several methods used in our system under development. It gives directly good results for long prediction intervals (up to half an hour) for ships that have constant course and speed on the open sea. In areas with many islands and other obstacles, the calculated positions for shorter prediction intervals can often be applied directly. The calculated data for longer intervals are applied together with electronic charts and other additional information in specially developed maximum likelihood predictor algorithms.

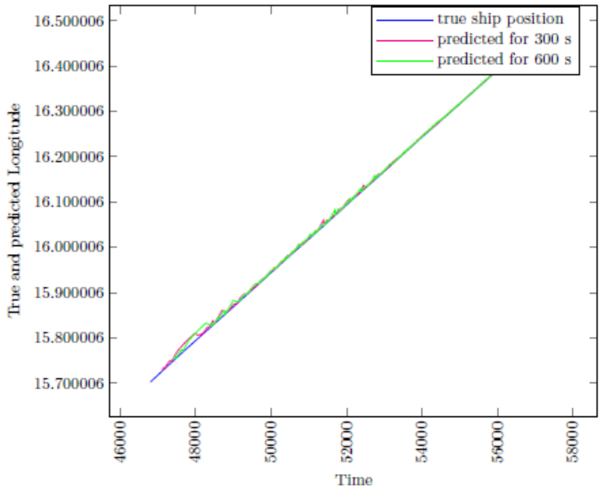


Figure 6: Longitude Prediction 300 s and 600 s in the Future for Regina della Pace on Wednesday, June 1, 2016 2:06:40 AM (GMT)

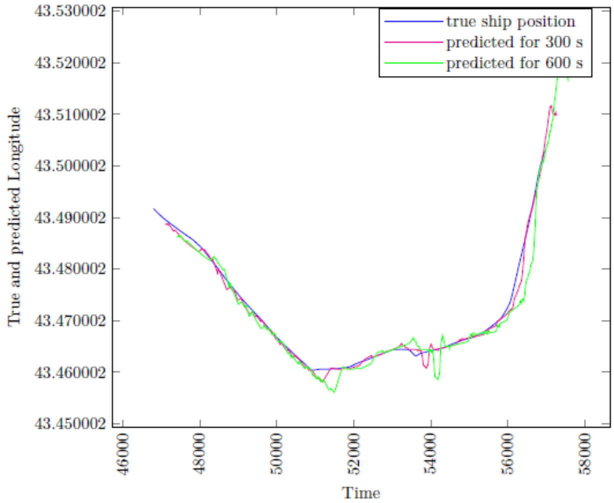


Figure 7: Latitude Prediction 300 s and 600 s in the Future for Regina della Pace on Wednesday, June 1, 2016 2:06:40 AM (GMT)

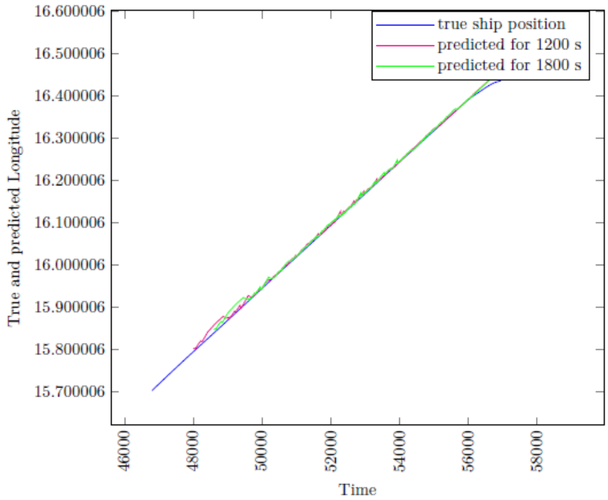


Figure 8: Longitude Prediction 1200 s and 1800 s in the Future for Regina della Pace on Wednesday, June 1, 2016 2:06:40 AM (GMT)

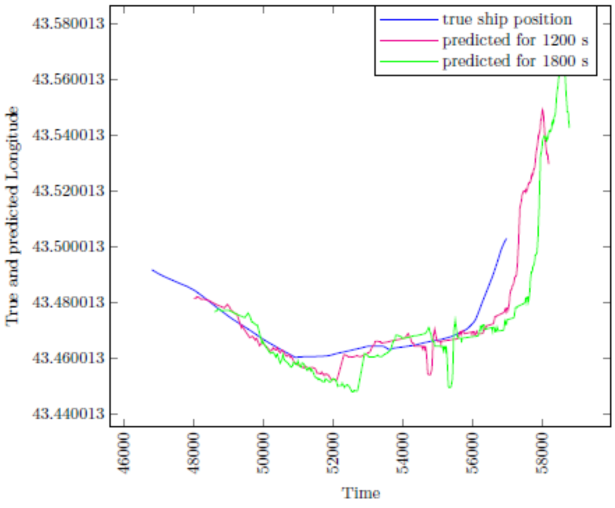


Figure 9: Latitude Prediction 1200 s and 1800 s in the Future for Regina della Pace on Wednesday, June 1, 2016 2:06:40 AM (GMT)

REFERENCES

[1] A. I. Russell, "Regular and Irregular Signal Resampling," Doctoral Thesis, MASSACHUSETTS INSTI- TUTE OF TECHNOLOGY, 2002.

[2] J. Proakis, *Digital signal processing : principles, algorithms, and applications*. Upper Saddle River, N.J: Prentice Hall, 1996, isbn: 0-13-394289-9.

[3] T. P. G. D. Group. (2021). Postgresql 14.1 documentation, [Online]. Available: https://www.postgresql. org/files/documentation/pdf/14/postgresql-14-A4.pdf (visited on 02/02/2022).

[4] T. O. S. G. Foundation. (2022). Postgis 3.3.0dev manual, [Online]. Available: https://postgis.net/ docs/manual-dev/ (visited on 02/02/2022).

ROOT CAUSE ANALYSIS USING ISHIKAWA DIAGRAM FOR REDUCING LOSS OF CONTROL IN FLIGHT (LOC-I)

Olja Čokorilo, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, Belgrade, Serbia
o.cokorilo@sf.bg.ac.rs

Jelena Golubović, M.Sc.
Aviation Highschool
Bulevar Vojvode Bojovića 2, Belgrade, Serbia
golubovic.j@vakademija.edu.rs

Srdjan Čokorilo, M.Sc.
Aviation Academy Belgrade
Bulevar Vojvode Bojovića 2, Belgrade, Serbia
cokorilo.s@vakademija.edu.rs

ABSTRACT

This paper analyses the problem of Loss of Control in Flight (LOC-I) and provides causal factors that contribute to this event. LOC-I occurs when an aircraft deviates from its intended flight path or when adverse flight conditions places an aircraft outside the normal flight envelope, with the pilot unable to maintain control of the aircraft. These accidents are complex because they occur due to a number of causal and contributing factors that can act separately or jointly by several factors at the same time. The purpose of this paper is to provide deep analysis of LOC-I through the historical data, as well as to develop the Ishikawa diagram (Fishbone Diagram) which could reflect those findings in the future. Through the Ishikawa diagram, all possible causes of this problem are identified and presented in graphical form. The causes are presented at different levels of detail in related branches. The most distant branches on the diagram indicate the roots (basic) causes of this problem. Authors determined total number of 126 causal factors for the LOC-I problem in this study. By reducing the number of causes or their impact, especially the root causes, their combinations are reduced and thus build a safer aviation system. Proposed measures and system defenses are based on international organizations (IATA, ICAO) recommendations for using qualitative and quantitative methods for such events, since they provide a good insight into the essence of the problem. Provided pillars in proposed analysis could be implemented in other safety issues in aviation.

Keywords: Aviation; Accident, Loss of Control in Flight (LOC-I), Root Cause Analysis, Ishikawa Diagram

1. INTRODUCTION

Loss of control in flight - LOC-I is one of the most influential causes of fatal accidents in commercial air transport. LOC-I occurs when the aircraft deviates from the intended flight path or when unwanted flight conditions affect the controllability of the aircraft and the pilot cannot maintain control over it. This can create a surprise factor for pilots [4].

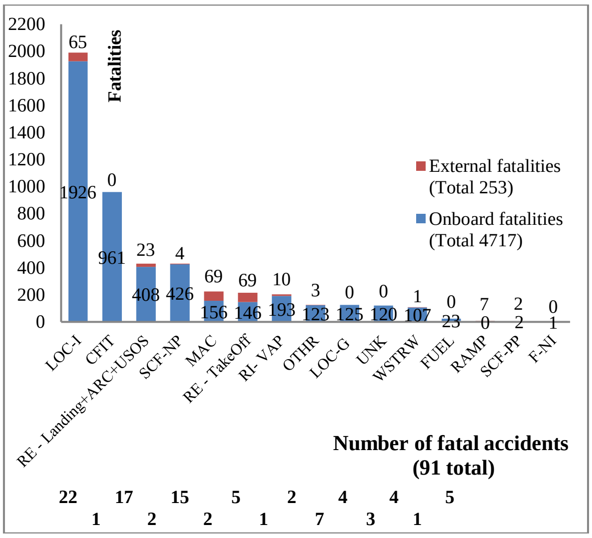
Accidents due to LOC-I in flight are complex and they can occur due to numerous causal and contributing factors, which act alone, or more often, in combination. For this reason, there is no single prevention strategy to prevent these accidents [1]. In order to gain a better understanding of LOC-I and possible prevention strategies, this paper will present a detailed analysis of data on LOC-I accidents, including the worst case combinations of causal and contributing factors. Future potential risks are also taken into account.

The purpose of this paper is to look at LOC-I through the events and causes that have led to this problem in the past, as well as analysis through one of the methods (Ishikawa diagram) to identify and graphically represent all possible causes of LOC-I problems.

2. RESEARCH INCLUDING LOC-I PROBLEM

As already mentioned, LOC-I is one of the most influential factors that contributed to fatal plane crashes. LOC-I is the category that has largely led to the fatal accidents of commercial jet aircraft in the world, and in the period from 1999 to 2008 resulted in 22 accidents and 1991 deaths (Figure 1). In order to develop effective prevention strategies for the prevention of LOC-I accidents, it is necessary to analyze how these events unfold [1].

Note: LOC-I - Loss of control in flight, CFIT - Controlled Flight Into Terrain, RE - Runway Excursion, SCF-NP - System/Component Failure or malfunction (non powerplant), MAC - Mid Air collision, RI - Runway Incursion, LOC-G - Loss of control - Ground, UNK - Unknown, WSTRW - Windshear or Thunderstorm, Fuel - Fuel Related, RAMP - Ground Handling, SCF-PP - System/Component Failure or malfunction (powerplant), F-NI - Fire/Smoke Non-Impact.

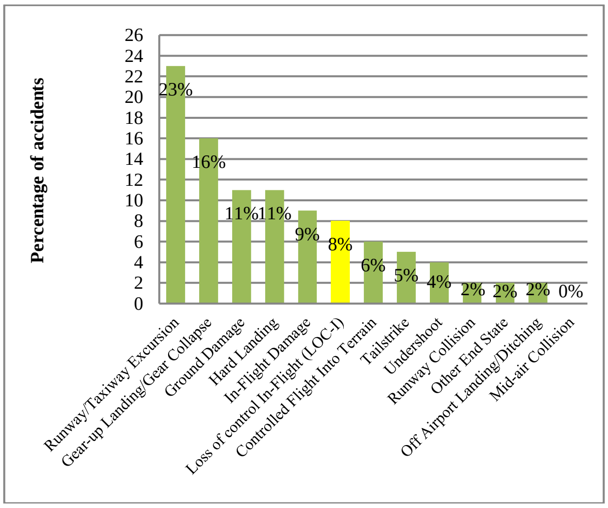


Source: [2]

Figure 1: Statistics of air accidents of commercial jet aircraft in the world from 1999-2008

2.1. Comparison of LOC-I accidents in relation to other categories of accidents

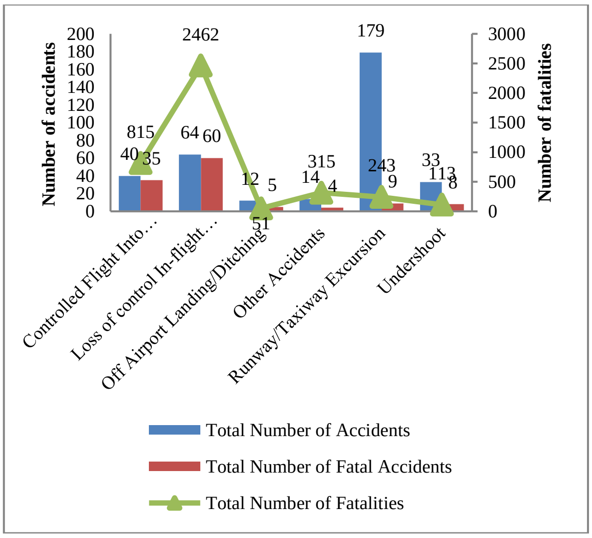
In commercial aviation, a total of 777 accidents were recorded in the IATA GADM Accident Database, and about 8%, or 64 accidents, were classified as LOC-I by the Accident Classification Technical Group (ACTG). Figure 2 illustrates the global overview of accidents by all accident categories. It should be noted that in 767 accidents ACTG had enough data available to determine the category of the accident (End State), while for the remaining ten accidents there was not enough data [4].



Source: [4]

Figure 2: Percentage of commercial accidents by categories in relation to the total number of accidents

Of the 777 accidents, 135 accidents were fatal, resulting in 4,075 deaths. LOC-I was the most common category of fatal accidents, with 60 such accidents or about 44% of fatalities. These LOC-I accidents resulted in 2462 deaths among passengers and crew. LOC-I is one of the categories of accidents with the lowest survival rate. Data for the first six categories of fatal accidents, as recorded for the observed 10 years (2009-2018), are shown in Figure 3 [4].



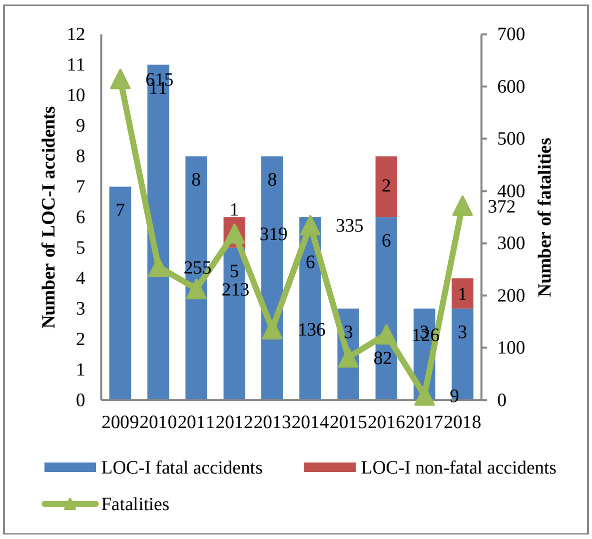
Source: [4]

Figure 3: Data on the first six categories of fatal accidents

Despite the fact that LOC-I accidents accounted for only about 8% of all commercial accidents considered, this category has the highest number of fatal accidents. As a result, this problem deserves a lot of attention from the aviation industry [4].

2.2. LOC-I accident data

Over a ten-year period, a total of 64 LOC-I accidents were reported to the IATA GADM accident database, with an average of about 7 accidents per year. However, the global number of annual LOC-I accidents and deaths is declining. Figure 4 shows the annual distribution of LOC-I fatal and non-fatal accidents, as well as the number of deaths associated with this category of accidents. The data show that the number of deaths (82) recorded in 2015 significantly decrease compared to 2014 (335). The number of deaths (126) recorded in 2016 was higher than in 2015. However, the number of deaths (9) in 2017 was marked as the lowest in the observed decade. Three LOC-I accidents that occurred in 2018 resulted in 372 deaths. LOC-I accidents in 2018 accounted for 8% of all observed LOC-I accidents, but caused 60% of deaths. As such a category, LOC-I retained its high risk of death status [4].



Source: [4]

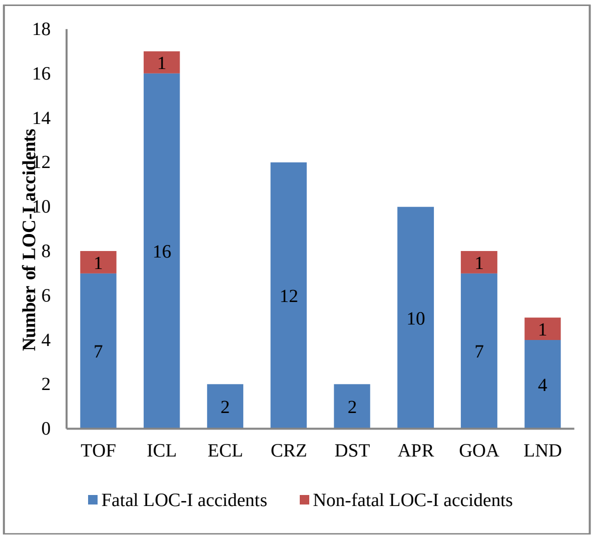
Figure 4: Annual distribution of LOC-I fatal and non-fatal accidents, 2009-2018

2.3. LOC-I accidents by flight phase

LOC-I accidents can occur at any flight phase, but for the observed period LOC-I was the most common during the initial climb (ICL), as can be seen in Figure 5. In the initial climb there were 17 fatal and non-fatal LOC-I accidents, which is above average compared to almost seven accidents per year. Take-off (TOF) and ICL record for 39% of all LOC-I accidents. LOC-I accidents in TOF and ICL are often the result or combination of the following factors:

- Aircraft system malfunction;
- Exciding aircraft operational limits;
- Lack or poor decision making;
- Inadequate inspection and crew crosscheck;
- Operations in low weather conditions;
- Non-compliance with Standard Operating Procedures (SOPs);
- Inadequate training including simulator, etc.

One of the crutial defenses against LOC-I accidents is pilot awareness. Cockpit decision-making and prioritizing tasks are of key importance. Pilots must be focused on flying all the time, during normal and abnormal operations. True surveillance of aircraft trajectories and aircraft systems, as well as active cross-checking of actions between crew members during critical phases of flight can be the last line of defense. If such a layer of defense is not present, the error may remain undetected, leading to serious safety consequences or undesirable situations. By improving surveillance and cross-checking, a pilot is more likely to spot an error before it occurs. Pilots need to be trained to recognize the phases of flight in which poor piloting can be most problematic [7]. Pilots should strategically plan their workload to maximize surveillance during these "areas of vulnerability" [4].

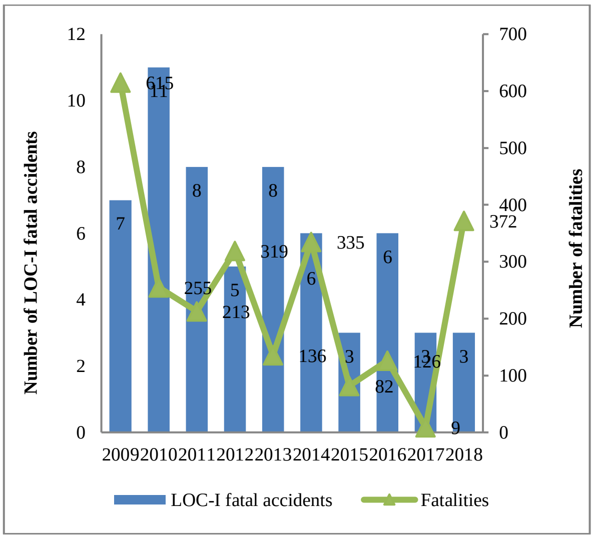


Source: [4]

Figure 5: Distribution of LOC-I accidents by flight phase

Note: TOF - Take-Off, ICL - Initial Climb, ECL - En Route Climb, CRZ - Cruise, DST - Descent, APR - Approach, GOA - Go-around, LND - Landing.

LOC-I is the major cause of fatal accidents of commercial aircraft. Figure 6 shows the annual distribution of 60 fatal LOC-I accidents that occurred in the period 2009-2018. Although the number of LOC-I fatal accidents has varied over the years, the average LOC-I fatal accident has decreased from an annual average of eight fatal accidents over five years from 2009-2013 to four fatal accidents per year from 2014-2018.



Source: [4]

Figure 6: Annual distribution of LOC-I fatal accidents

2.4. Factors contributing to LOC-I accidents

LOC-I accidents are the result of a number of factors that can occur individually, but most often occur in combination. These accidents are mainly caused by a malfunction of one of the aircraft systems, environmental ocurences and/or pilot errors. Identification and analysis of contributing factors to

LOC-I accidents could be useful in developing measures to reduce their impact on aviation safety.

IATA, through ACGT, includes an analysis of the impact of contributing factors to accidents, in order to better understand the correlation. Contributing factors, which are pillars for development and implementation of TEM (Threat and Error Management), are divided into the following groups:

- Latent conditions: Conditions present in the system before the accident and caused by various possible factors;
- Environmental and airline impacts: An event or error that occurs without the influence of the flight crew, but which requires the attention and response of the crew so as not to compromise safety;
- Flight crew errors: Deviation from organizational procedures or crew tasks;
- Undesired aircraft conditions: The condition of the aircraft taken by the flight crew, which reduces the safety margins; ineffective error management leading to a safety breach.

Table 1: The most common contributing factors are LOC-I accidents

Latent Conditions	%	Flight Crew Errors	%
Safety Management	38%	SOP Adherence/SOP Cross-verification	42%
Flight Operations	36%	Manual Handling/Flight Controls	42%
Regulatory Oversight	31%	Intentional	22%
Flight Ops: Training Systems	27%	Unintentional	18%
Flight Ops: SOPs & Checking	22%	Pilot-to-Pilot Communication	18%
Environmental Threats	%	Undesired Aircraft States	%
Mereorology	44%	Vertical/Lateral/Speed Deviation	31%
Lack of Visual Reference	15%	Operation Outside Aircraft Limitations	31%
Poor Visibility/IMC	15%	Unnecessary Weather Penetration	16%
Icing Conditions	15%	Unstable Approach	13%
Wind/Wind shear/Gusty wind	15%	Abrupt Aircraft Control	11%
Airline Threats	%	Countermeasures	%
Aircraft Malfunction	44%	Overall Crew Performance	42%
Contained Engine Failure/Powerplant Malfunction	27%	Monitor/Cross-check	27%
Maintenance Events	11%	Leadership	20%
Operational Pressure	9%	Captain should show leadership	20%
		In-flight desision-making/contingency management	18%

The most common contributing factors to LOC-I accidents are listed in Table 1. From the IATA Accident Database, 9 LOC-I accidents (14%) were not classified due to lack of data. These accidents are not included in the analysis of the frequency of contributing factors [4].

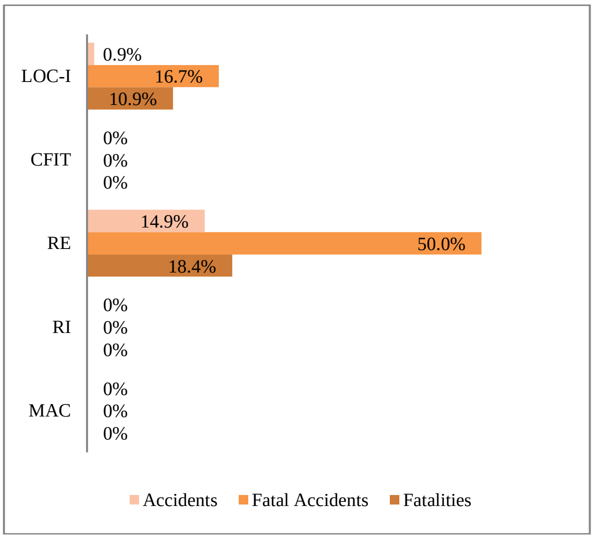
Numerous contributing factors have had an impact on the occurrence of LOC-I accidents:

- Lack of implementation of the Safety Management System (SMS);
- Inadequate training standards and inadequate classroom and simulator training;
- Non-compliance with SOPs;
- Overall crew performance;
- Aircraft system failure;
- Late or lack of decision making;
- Work in abnormal meteorological conditions;
- Inadequate oversight, crosschecking and behavior of senior managers;
- Inadequate response of the crew to the actual situation, which causes the aircraft to be at the limit of functional condition, or out of return to operational condition;
- Reluctance to turn off automation, or change the level of automation.

2.5. High-risk Categories of Occurrence - HRCs

Based on the actual number of deaths [8], as well as the high risk of fatal accidents and the results of safety data analysis collected from proactive and reactive sources by ICAO and other organizations, ICAO has identified five categories of high risk events (HRCs) as safety global priority:

1. Controlled flight into terrain - CFIT;
2. Loss of control in flight - LOC-I;
3. Mid-air collision - MAC;
4. Runway excursion - RE;
5. Runway Incursion - RI.



Source: [5]

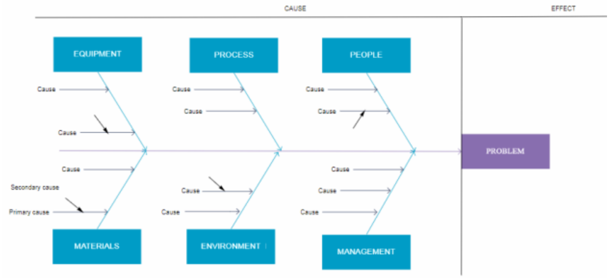
Figure 7: HRCs accident statistics in 2019

3. CAUSAL MODELS / METHODS FOR RISK ASSESSMENT

Causal models / methods deal with failures of certain technical systems and their components that can lead to an accident (plane crash). Failures can be the result of a number of related causes and can occur on an airplane or in an air traffic control (ATC / ATM) system. Causal methods / models for risk assessment and safety assessment of aircraft operations and ATM / ATC operations establish a theoretical framework of causes that can lead to a plane crash. In addition, these models can be used to assess the relative benefits of various prevention measures aimed at preventing accidents in the future. Some of the qualitative methods are Root Cause Analysis (RCA), Common Cause Analysis (CCA), Ishikawa Diagram, FMEA (which is both qualitative and quantitative), while some of the quantitative ones are Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Bayesian Belief Network (BBN), etc. [3], [6], [9].

4. THE STRUCTURE OF THE ISHIKAWA DIAGRAM AND ITS APPLICATION TO THE LOC-I PROBLEM

The Ishikawa diagram, in the structure of herringbone, shows the factors Equipment, Process, People, Materials, Environment and Management affecting the overarching problem (Figure 8).



Source: [6]

Figure 8: The structure of the Ishikawa diagram for the main categories

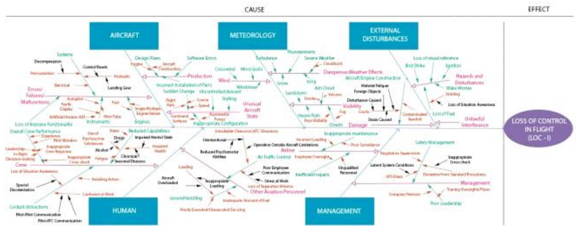


Figure 9: Step 3 and the overall structure of the Ishikawa LOC-I problem diagram

Figure 9 provides an overview of all causative factors of LOC-I problems through the herringbone diagram included in this study. Blue bones, which enter the spine of the fish, represent five main categories. The factors of the first level of branching are shown in pink, while the factors of the second level are represented in green. Moreover, the bones are painted orange, which illustrates the factors of the third level. At the very end are the factors of the fourth level, represented by the black bones in this diagram. These bones are the smallest and are the root causes of the problem. They are difficult to detect because they are usually hidden in the system. They are the most critical factors, ie. those that need to be addressed first to prevent LOC-I.

For the category *Aircraft*, 33 causal factors were found (three factors of the first level, 11 factors of the second level, 16 factors of the third level and three factors of the fourth level). The category *Meteorology* consists of 20 causal factors (three factors of the first level, 12 factors of the second level and five factors of the third level). *External Threats* are a category led by 17 causal factors (three first-level factors, six second-level factors, three third-level factors and five fourth-level factors). The *Human Factor* category consists of 39 factors (two first level factors, five second level factors, 18 third level factors and 14 fourth level factors), and the *Management* category consists of 17 causal factors (two first level factors, four second level factors, nine third level factors and two factor of the fourth level). The total number of all causal / contributing factors found for the LOC-I problem in this study is 126 factors.

For the LOC-I problem, some of the smallest black bones are pilot situation awernes problem, crosscheck, cracks caused by material fatigue, latent conditions in the system, etc. It can be seen from the figure 9 that some of the causal factors are recurring. These are poor communication between employees, poor cross-checking, loss of awareness of the situation (or spatial disorientation), fuel problems, improper loading, reduced psycho-motor skills, work effort (or fatigue).

When the *External Threat* factor is observed, it is noticed that the loss of awareness of the situation can lead to the aircraft holding. If the pilot fails to regain control of the aircraft, he will run out of fuel. This leads to the conclusion that it is not just one thing / cause that lead to an accident, but it takes a number of causes and mostly a combination of them to cause an accident. For that reason, it is important to look at and influence the reduction of these causes (and pay special attention to the root causes), in order to reduce the probability of an accident. By reducing the number of causes or their impact, their combinations are also reduced, thus building a safer air traffic system.

The Ishikawa diagram for the LOC-I problem was compiled based on available historical data, causal / contributing factors that have already influenced this problem and data collected through the Aviation Safety Network and Skybrary.

5. CONCLUSION

LOC-I represents a very broad category of accidents. For this reason, it is very difficult to create unique effective guidelines to prevent this problem. Analysis of LOC-I issues ranges from aircraft design considerations to pilot training, regulatory oversight and safety management. The formation and use of causal methods is very important in order to understand the overall problem and each individual factor.

Methods such as the Ishikawa diagram show in a quality way the influence of causal factors, not only on the LOC-I problem, but also on similar problems that have a high rate of accidents and deaths (such as Runway Excursion, CFIT, Runway Incursion, etc. The recommendation of all international organizations (IATA, ICAO, etc.) is to use qualitative and quantitative methods for such events, because they provide a good insight into the essence of the problem. Brainstorming makes it easier to discover the root causes and graphically interpret their importance, which is necessary for the development of prevention measures. Preserving and ensuring the safety of air traffic is achieved by reducing the root causes and influencing the most critical parts of the system.

REFERENCES

[1] Belcastro, C.M., & Foster, J.V. (2010). Aircraft Loss of control accident analysis. NASA Langey Research Center.

[2] Boeing. (2009). Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959-2008.

[3] Čokorilo, O., & Dell'Acqua, G. (2013). Aviation Hazards Identification Using Safety Management System (SMS) Techniques. 16th International conference on transport science ICTS 2013 (pp. 66-73). Portorož, Slovenia, 27th May 2013.

[4] IATA (International Air Transport Association). (2019). Loss of Control In-Flight Accident Analysis Report Edition 2019. Montreal, Canada.

[5] ICAO (International Civil Aviation Organization). (2020). ICAO Safety Report. Montreal, Canada.

[6] Netjasov, F. (2016). Air navigation safety assessment methods [In Serbian: Metodi ocene bezbednosti vazdušne plovidbe] 2nd edition. Faculty for traffic and transport engineering, Belgrade, Serbia.

[7] Petrović, I., & Petrović, J. (2022). Personality Traits in Selection of Military, Civil and Sports' Pilots: Hybridized-IT2FS-MCDM Approach. International Journal for Traffic and Transport Engineering, 12(1), 1-20.

[8] https://aviation-safety.net/database/record.php?id=20191124-0

[9] https://skybrary.aero/index.php/Loss_of_Control#Contributory_Factors

THE IMPORTANCE OF MARITIME EDUCATION AND TRAINING QUALITY CONTROL: THE CASE OF MONTENEGRO

Tatijana Dlabač, Ph.D.
Milena Dževerdanović Pejović, Ph.D.
Jelena Nikčević, Ph.D.
Vera Kapetanović, M.Sc.
University of Montenegro, Faculty of Maritime Studies Kotor
Put I Bokeljske brigade 44, 85330 Kotor, Montenegro
tanjav@ucg.ac.me, milenadz@ucg.ac.me, jelenag@ucg.ac.me, verak@ucg.ac.me

ABSTRACT

With the aim of achieving adequate competence of seafarers for the international labour market, the International Maritime Organization (IMO) established the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), aiming to standardize the competencies of seafarers at the international level.

STCW convention from 1978, as amended, lays down requirements for seafarers competencies carried out through education and training mandatory for seafarers, institutions (Maritime education and training – MET) involved in education and training, maritime companies and maritime administration, that is, for a member state. Education and training of seafarers vary from country to country and they fall under the jurisdiction of different institutions, affecting to a large extent the way of their organization and implementation and quality control. The quality of MET offered by a country is an essential factor in determining the level of competence. A great number of MET institutions worldwide aim to provide seafarers with adequate skills and competencies. MET institutions should follow the development of new technologies, harmonize their curricula and offer accreditations to new training courses. New approaches are fundamental in the education and training process, which came to the surface during the Covid-19 pandemic. Of particular importance is monitoring MET institutions' work as appropriate control will undoubtedly lead to work improvements and the establishment of mechanisms based on which the control of a country is performed (internal and external control).

Montenegro, as a member country, numbering approximately 6000 seafarers, has MET institutions conducting seafarers' education and training. In Montenegro, the education of seafarers is under the jurisdiction of one ministry, and the training of seafarers under the other. The control of MET institutions from the aspect of the STCW convention is under the jurisdiction of recognized organizations. The paper highlights the need to find a mechanism to improve cooperation, monitoring and control over the work of MET institutions in Montenegro to achieve higher quality education and training for seafarers. We provide guidelines on how the maritime administration in Montenegro can be more efficient in delivering high-quality professional training and education to seafarers and following new technologies and trends in implementing the training and education process.

Keywords: MET, Montenegro, STCW, seafarers' competencies, monitoring, quality control

1. INTRODUCTION

Shipping encompasses all types of activities relating to the sea. Maritime traffic represents the most important form of transportation activity, knowing that 90 percent of merchant trade is carried out by sea (Tusher et al., 2021). The work of seafarers is very responsible and challenging, and there is an undeniable relationship between their personal safety and efficient ship's business and ship's safety. In order to ensure maximum safety of the ship and to enable the protection of seafarers, it is necessary to have not only a technically equipped ship, but also a qualified and trained ship crew (Bao et al., 2021; Nikčević G., 2015a; Nikčević, 2015b; Radulović, 1997). Maritime education and training have a crucial role in the process of creating the required skills and competencies of seafarers, enabling them to carry out their tasks efficiently (Marušić, 2010; Sharma & Nazir, 2021; Tuljak-Suban & Suban, 2013).

International Maritime Organization (IMO) adopted the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) in 1978, by which the competencies of the seafarers were put forward at the international level. The STCW Convention comprises three sections. First, the role of the articles is to lay down legal responsibilities which have to be met by a party. Secondly, the annexes provide technical details on how legal responsibilities should be met in the articles. The Annex contains eight chapters: Chapter I: General provisions; Chapter II: Master and deck department; Chapter III: Engine department; Chapter IV: Radiocommunication and radio personnel; Chapter V: Special training requirements for personnel on certain types of ships; Chapter VI: Emergency, occupational safety, medical care and survival functions; Chapter VII: Alternative certification; Chapter VIII: Watchkeeping. The third section of the Convention, the STCW Code specifies technical details in more depth in the Annex. It comprises part A (mandatory standards of training, certification and watchkeeping) and part B (recommended guidelines - not mandatory - on training, certification and watchkeeping).

The most salient changes and amendments to the convention were conducted in 1995 at the diplomatic conference in London (entered into force on 1st February 1997) and in 2010 at the diplomatic conference in Manilla (entered into force in 1st January 2012).

Montenegro formally became a party of the STCW Convention by notice of succession after becoming a member of the IMO on 16th October 2006.[1]

STCW convention lays down, among other things, the requirements for competencies for seafarers acquired through maritime training institutions (MET). STCW convention, on the one side, prescribes minimum conditions that oblige member countries, that is, all those involved in MET (seafarers, maritime educational institutions, centres for training of seafarers, maritime companies and the whole maritime administration). On the other side, it equates to national regulations for obtaining qualifications and certificates of seafarers aimed to raise the general level of proficiency of the crew of maritime ships, which is at the same time the purpose of the convention.

In Montenegro, the production of qualified and trained seafarers is carried out through education and training. Education of seafarers means acquiring knowledge and skills within regular schooling, whereas training means acquiring knowledge and skills through training and a mastery of professional programmes of a particular purpose.

Education and training of seafarers in Montenegro are under jurisdiction of different competent ministries. Education of seafarers is under the Ministry of education, science, culture and sports, whereas training of seafarers is performed under the ministry to which shipping belongs, that is, the Ministry of capital investments.

It is noteworthy to mention the importance of education and training of seafarers through lifelong learning. Namely, a seafarer's learning and professional development must not be completed upon acquiring a specific qualification, especially bearing in mind frequent and dynamic changes in shipping. Therefore, professional development should be cherished during a whole career. Therefore, it is of the interest of the Montenegrin seafarers, sailing across the seas, to be recognized by competent bodies in Montenegro. In this light, lifelong learning must be recognized as a vital component of maritime education and training.

The quality of MET offered by a country is a significant factor in determining the level of seafarers' competencies. There is a large number of MET institutions worldwide. All of them aim to enable seafarers to acquire related knowledge and skills. MET institutions should follow the development of new technologies, adapt their syllabi and teaching materials and accredit new courses. In addition, special attention should be paid to taking exams, issuing certificates to seafarers, monitoring the situation in the field when delivering certificates, resources policy and technical capacities of institutions providing education and training of seafarers. In addition, MET institutions must meet the requirements of the new situation triggered by the COVID 19 pandemic in adapting to the new approaches in the education and training of seafarers.

The control of all actors involved in MET is a crucial factor for high-quality MET institutions, and the production of qualified maritime resources.

2. MARITIME EDUCATION AND TRAINING IN MONTENEGRO

Montenegro is a country with a rich maritime tradition. The beginning of maritime education in Montenegro is linked with the education of the Russian noblemen in a school of famous captain Marko Martinović in Perast at the end of the 17th century. The Maritime High School in Kotor was founded in 1849 and it is one of the oldest schools in Montenegro (Boljević-Vuleković, 1974; Milošević, 2010). Maritime Faculty Kotor of the University of Montenegro is among the oldest higher education institutions in Montenegro. This institution started with work in 1959 as Maritime College. Since 1981 the Maritime College has turned into higher education institution – Maritime Faculty Kotor and then in 2016 into the Faculty of Maritime Studies Kotor.

Today, the education process of seafarers in Montenegro takes place through high school dedication, higher education and adult education (Table 1).

Secondary education of seafarers is implemented through two educational programmes: nautical officer at the operational level and marine engineering officer at the operational level.

[1] This is due to the fact that after the breakdown of the former Republic of Yugoslavia, the Montenegrin Parliament enacted on 3rd June 2006 a Decision of Succession of Montenegro as an independent state to all international instruments Yugoslavia used to be a party to. Decision on Succession Law on Ratification of the 1978 STCW ("Official Gazette of SFRY – International Treaties", No.3/84)

Table 1: A review of educational institutions in Montenegro

Education level	Educational institution	
Secondary	Maritime High School Kotor	Vocational school Bar
Higher	Faculty of Maritime Studies Kotor University of Montenegro, Kotor	Maritime Faculty of the University of Adriatik, Bar
Adult education	Maritime High School Kotor	Maritime Academy Kotor

Acquiring competencies of seafarers or qualifications of seafarers at the nautical officer at the operational and marine engineer officer at the operational level through the adult education system in Montenegro is carried out by the Maritime High School in Kotor and Maritime Academy from Kotor based on the acquired licence from the competent ministry, that is, Ministry of education, science, culture and sports.

Montenegro has two higher education maritime institutions: Faculty of Maritime Studies Kotor of the University of Montenegro (state faculty) and Maritime Faculty Bar of the University of Adriatic (private faculty), dealing with the education of seafarers.

At the Faculty of Maritime Studies Kotor, the education process is carried out according to model 3+2+3 starting from 2017/18. There are four academic study programmes in the basic studies: Nautical Studies and Transportation, Marine Engineering, Marine Electrical Engineering and Maritime Management and Logistics. Within master and doctoral studies, there are departments Maritime Sciences and Maritime Management and Logistics (Nikolić, 2017). This model of studies allows for acquiring the highest ranks in shipping and the highest academic titles, respectively.

There are three study programmes at the Maritime Faculty in Bar: Nautical Studies, Marine Engineering and Port Management. The first year of the basic studies at all study programmes is organized through joint education, including one elective subject, whereas students choose the selected profile in the second year (*Strategija razvoja pomorske privrede 2020-2030*, 2020).

The Ministry of capital investments has a significant role in the training of seafarers in Montenegro. It has jurisdiction for issuing approvals for training seafarers at maritime educational institutions and maritime training centres, conducting controls and licence revocation if the stated institutions do not fulfil anticipated conditions or if a non-compliance in their work is established.

Education of seafarers is organized by five training centres: Azalea Maritime – Bijela, Training Centre of the Faculty of Maritime Studies Kotor of the University of Montenegro, Centre for seafarers training at the Maritime High School Kotor, Centre for training– Faculty of Mediterranean business studies and BMV Shipping Services – Center for seafarers training and Training Centre of the Maritime Faculty (*Strategija razvoja pomorske privrede 2020-2030*, 2020).

Seafarers training in Montenegro is carried out in accordance with the Rulebook on vocation and certification of seafarers in Montenegro, conditions for acquiring competencies and certificates of crew members (*"Official Gazette of Montenegro", Nos. 51/2015*, *44/2016*, *63/2018* and *50/2020*, *77/21*). The Rulebook, in accordance with Article 1, regulates types of vocations, certificates on competencies and special competencies, closer conditions in terms of professional qualification and seagoing service for acquiring competencies for the sake of issuing certificates, program and method of training and taking exams on special competencies, program, method of training and taking examinations for revalidation of certificates of competencies and special competencies. It also defines forms of certificates, the manner of issuing certificates and registers of the issued certificates to the crew members (in further text: seafarer), closer conditions that a maritime school should fulfil and the legal entity for seafarers' training in terms of equipment, spaces, staff and standards of the quality system and conditions that the examination committee members should meet.

We would like to mention that centres for seafarers' training are not only limited to conducting or performing courses defined in the Rulebook of Montenegro, but there is the possibility of conducting other relevant courses, depending on the requirements of the labour market.

3. QUALITY CONTROL IN MARITIME EDUCATION AND TRAINING

According to STCW, member states are obliged to apply a standard of quality and determine a level of knowledge, understanding, skills and competencies through adequate examinations and assessment.

All member states of the STCW convention must have a quality management system in maritime educational institutions and maritime training centres, that is, in all domains of maritime affairs.

In Montenegro, Article 114 of the Law on Safety of Maritime Navigation (LSMN)2 ("Official Gazette of Montenegro", Nos. 62/2013, 6/2014, 47/2015 71/2017, 34/2019 and 77/2020) prescribes that all Montenegrin educational institutions for the education of seafarers

[2] In the further text we shall also use the abbreviation LSMN.

should comply their education programmes and curricula with the regulations of the STCW convention and model courses IMO. Furthermore, LSMN provides that, starting from 1st June 2022, all institutions involved in seafarers' education, apart from the work licence, must have Certification on applying the IMO model courses in the teaching plans and programs issued by a recognized organization. Therefore, there is no doubt that engaging a reputational organisation for the control (check) of all Montenegrin educational institutions in terms of checking the compliance with the STCW convention, that is IMO model courses, and with the aim of acquiring Certificates, will significantly contribute to strengthening the systems of control and high-quality education of seafarers. In addition, the same Article, Line 3 of the Law on Safety of Maritime Navigation states that in case that maritime educational institution does not have a Certificate but issues a document on acquired qualification, such a document shall not be acknowledged in the procedure of acquiring qualifications and issuing certificates for seafarers.

Bearing in mind the consequences that a candidate may have, we find that an intervention of the employer in terms of introducing penalty clause in this part is necessary.

Regarding the training of the seafarers Article 110 of the Law on Safety of Maritime Navigation, there is an anticipated obligation of complying with the STCW for the training of seafarers in light of training courses aimed at acquiring qualifications on specialized competencies of the crew members. Articles 110, 111, and 112 of the Law on Safety of Maritime Navigation state that a competent ministry issues an approval to carry out training courses, but at the same time, can revoke it (cancel) in case it is determined that legal entities carrying out training do not fulfil conditions on the basis of which the certificate was issued, or non-compliance in work was determined. Furthermore, it is anticipated that a related ministry will monitor legal entities carrying out training of seafarers. Therefore, the Law on Safety of Maritime Navigation does not contain a legal note that would provide an engagement of a recognized organization in light of conducting control over legal entities for seafarers' training, which certainly leaves space for legal ambiguities and causes legal uncertainty. In particular, having in mind regulation Article 51 line 4 of the Law on Safety of Maritime Navigation which precisely states that technical control over ships and issuance of adequate ship documents and books may be carried out also by a recognized organisation. Similar steps should be taken to formulate new legal norms in this segment. We would emphasize that in the previous practice, a corresponding ministry has always engaged a recognized organization to exercise control over legal entities conducting the training of seafarers in part of checking the conformity with the STCW convention requirements and after obtaining a report by a recognized organization, and it would issue an appropriate approval.

Regarding the Faculty of Maritime Studies Kotor, the control over seafarers' education and training is conducted by recognized organizations Bureau Veritas (BV) and Croatian Register of Shipping (CRS). The faculty obtained a Certificate from the Croatian Register of Shipping that the management quality system is under the requirements of the norm EN ISO 9001:2015 with a validation period of three years and regular annual controls. After an expiration date, in three years, it is necessary to revalidate the certificate. In September 2020, there was a successful revalidation of the certificate for Management Systems of Maritime Simulator Centres and Management Systems of Maritime Training Institutes by Bureau Veritas with a five-year validation period. In a previous period, these recognized organizations also checked the compliance with specific training courses with the STCW convention.

Knowing that Montenegro is making an effort towards acceding the family of European families and becoming a full member of the European Union, the fulfilment of the requirements of the EU (compliance with) presents an imperative. In that context, the Montenegrin maritime administration is aware that it must take into consideration the right of European Union (Directive 2008/106/EC on the minimum level of training of seafarers, that is, Directive 2012/35/EU amending Directive 2008/106/EC on the minimum level of training of seafarers), and all requirements laid down by the European Maritime Safety Agency (EMSA) as a vital organization in the area of the European Union responsible for, inter alia, qualifications of seafarers.

In addition to the above, maritime educational institutions in Montenegro must fulfil conditions put forward by the corresponding laws relating to higher education, secondary education and adult education and obtain a work licence, respectively. In the case of higher educational institutions, these processes are under the Agency for Control and Quality Assurance of Higher Education in Montenegro. However, during this control and as far as the provision of the higher education quality is concerned in higher education institutions, there is no established mechanism that would answer the question of whether the programmes are accredited/reaccredited according to the requirements of the STCW convention. AKOKVO (Agency for Control and Quality Assurance of Higher Education in Montenegro) through the application of the European standards and guidelines of the institutions of higher education ensures the integration of the Montenegrin into the European system of higher education and contributes to the improvement of the quality of the higher education institutions in Montenegro. Through the external education (accreditation and reaccreditation and of the study programmes) of the higher education institutions, this control body assesses the fulfilment of the requirements for each institution applying. We highlight that the Agency in its requirements does not lay down specific conditions that should be fulfilled by a higher education institution regarding t plans and programmes and the obligatory equipment. Therefore, we find that such an approach is incomplete and that it would be adequate to form a specialized committee that would be formed by representatives of all relevant subjects related to seafaring who would, among other tasks, be responsible for determining the compliance of educational plans and programs of maritime educational institutions with the STCW regulations.

3.1. ISO 9001:2015 - Quality management systems

In Montenegro, ISO 9001:2015 is used in institutions for the training and education of seafarers. This standard is used not only as a means for quality management but as a significant framework for promoting and improving work in all segments, not only of MET institutions but also those involved in their work. This standard represents the institution's base regarding the quality management system and when it is well implemented, it represents a foundation for upgrading all other standards.

The standard ISO 9001:2015 is implemented through the Quality Assurance Manual, laying down the procedures for specific processes within the institution. In addition, the Quality Assurance Manual describes its purpose, i.e., the mission and vision of the institution define and present a quality management system and aims of the quality. Besides, the Quality Assurance Manual defines responsibilities and authorities necessary for the proper functioning of the quality system, and provides adequate quality management control.

Experience shows that using the quality system without awareness of what this system does, leads to a pure formality. Therefore, the compliance and adequate application of the Rulebook and procedures present a precondition for quality without giving a 'success formula'. In light of this, each institution lays down the method of work per se and only well-developed awareness about that will enable continual improvement in work. There are many processes within an institution to which specific procedures are related, and that comply with the regulations of the mentioned standard ISO 9001:2015. Many procedures are exclusively a result of the joint work within the institution, depending on the scope of work. A comprehensive documentation of the quality management system represents a 'live process' subject to changes that must be evidenced through relevant records.

Quality management system at the Faculty of Maritime Studies Kotor has been applied since 2001 and the first implemented standard was ISO 9001/1994. In 2004, Faculty of Maritime Studies Kotor received the certificates for standards ISO 9001:2008 and ISO 9001:2009, and starting from 2017, the ISO 9001:2015 is applied. Within quality management system, in addition to the Quality Rulebook, there are also thirteen procedures. Activities related to the education and training of seafarers are defined by the procedures Education process (PF P09) and Training of seafarers (PF P10) and corresponding documents. Regarding controls within this institution, a special procedure anticipates at least one internal control relating to control of all activities at the Faculty and the assessment of the compliance of the quality management system of the Faculty of Maritime Studies Kotor with the requirements of the standard ISO 9001-2015. Also, the report from the internal audit is always subject to control by the external auditors coming from reputable organizations. Besides, there are also external audits to which all segments of maritime affairs are subject, including the education and trading of seafarers.

4. CONCLUSION

In order to provide the necessary level of seafarers' competencies, Montenegrin educational institutions and training centres must comply with and follow international and European requirements (STCW convention, Directive 2008/106/EC on the minimum level of training of seafarers, that is a Directive 2012/35/EU amending Directive 2008/106/EC on the minimum level of training of seafarers).

An adequately implemented system of the control of maritime educational institutions and training centres that will enable the implementation of standards (requirements) and provide high-quality education for seafarers is an effective mechanism for seafarers' qualifications. In addition to the international legal framework for the education of seafarers, the role of each country in creating its legal regime in the segment of education is of the utmost importance. This, in particular, relates to the fact that each national framework represents a link to completing the global legal regime and thus contributes to raising the competence level and creating qualified and competent seafarers.

Investment in high-quality education and training is obligation of all those involved in creating a qualified seafarer.

It is necessary to find a mechanism for improving cooperation, monitoring and control of the work of MET institutions in Montenegro to achieve higher-quality education and qualifications for seafarers. One of the possible solutions for this problem is forming a committee that would represent a link between corresponding ministries, those covering education and training of seafarers and that would, among other things, have a vital role in giving an opinion in compliance with the curricula with the international and European standards. Furthermore, the committee would have a substantial role in following amendments to the STCW Convention and the rights of the EU in this segment, with the aim of their implementation into the Montenegrin legal system.

REFERENCES

[1] Bao, J., Li, Y., Duan, Z., Li, T., & Zhang, P. (2021). Key factors affecting the quality of maritime education and training: Empirical evidence from China. *The Journal of Navigation*, *74*(2), 396–408. https://doi.org/10.1017/S0373463320000740

[2] Boljević-Vuleković, V. (1974). Development of Maritime Instruction on the Montenegrin Seacoast. *Zbornik Više Pomorske Škole u Kotoru*, *1*(1).

[3] *Law on Safety of Maritime Navigation ("Official Gazette of Montenegro", Nos. 62/2013, 6/2014, 47/2015 (articles 3-6 are not included in the consolidated text), 71/2017, 34/2019 and 77/2020.* (2020). Vlada Crne Gore.

[4] Marušić, L. (2010). STCW KONVENCIJA I BOLONJSKI PROCES. *Metodički ogledi : časopis za filozofiju odgoja*, *17*(1–2), 13–22.

[5] Milošević, M. (2010). 12 skica za 12 vjekova Bokeljske mornarice. *Zbornik Radova , XII Vjekova Bokeljske Mornarice*, 11–20.

[6] Ministarstvo saobraćaja i pomorstva. (n.d.). *Strategija pametne specijalizacije Crne Gore 2019-2024*. Vlada Crne Gore. Retrieved March 20, 2022, from https://www.gov.me/dokumenta/18205a91-1afc-4eb7-a5cb-8ad5bd0b7712

[7] Nikčević G., J. (2015a). Legal regulations in the function of ensuring ship safety. *Pomorstvo*, *29(1)*, 30–39.

[8] Nikčević, J. (2015b). *Pravni aspekti pomorske sigurnosti*. Institut za uporedno pravo.

[9] Nikolić, D. (2017). *Pomorski fakultet Kotor, Monografija 2011-2017*. PRINHOUSE Podgorica.

[10] *Pravilnik o vrstama zvanja i ovlašćenja, uslovima za sticanje zvanja i idavanje ovlašćenja za članove posade broda ("Official Gazette of Montenegro", Nos. 51/2015, 44/2016, 63/2018 i 50/2020, 77/21)*. (2021).

[11] Radulović, M. (1997). The Qualifications Acquiring in Navigation. *Zbornik Fakulteta za pomorstvo- u Kotoru*, *17*, 59–70.

[12] Sharma, A., & Nazir, S. (2021). Assessing the Technology Self-Efficacy of Maritime Instructors: An Explorative Study. *Education Sciences*, *11*(7), 342. https://doi.org/10.3390/educsci11070342

[13] *Strategija razvoja pomorske privrede 2020-2030*. (2020). Vlada Crne Gore. https://www.gov.me/dokumenta/2b69a6ae-e751-4a25-8de0-48b564e2a38d

[14] Tuljak-Suban, D., & Suban, V. (2013). Quality standards implementation in maritime education and training institutions: Fuzzy assessment. *Transport Problems*, *8*, 63–72.

[15] Tusher, H. M., Sharma, A., Nazir, S., & Munim, Z. H. (2021). Exploring the Current Practices and Future Needs of Marine Engineering Education in Bangladesh. *Journal of Marine Science and Engineering*, *9*(10), 1085. https://doi.org/10.3390/jmse9101085

CRUISE SHIPS ROUTING IN THE SOUTH PART OF THE ADRIATIC EAST COAST – THE ISLAND OF LASTOVO AND THE ISLAND OF MLJET

Josip Dorigatti, Ph.D. student
Tina Perić, Ph.D.
Gorana Jelić Mrčelić, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, 21000 Split, Croatia
josipdorigatti@yahoo.com

ABSTRACT

Cruise traffic in the Mediterranean region including Adriatic region has significantly grown since 2000, as well as popularity of the Adriatic cruise destinations. The demand for competitive itineraries and exciting passenger experience brings cruise ships to navigationally restricted and environmentally sensitive areas and the pressure to make itineraries more appealing will grow in the future. The aim of this paper is to present cruise ships routing practices in South Adriatic East coast region with focus on the island of Mljet (Nationa Park) and the island of Lastovo and its archipelago (Nature Park). The paper analysed the data on cruise ships over 50 000 GT for five months (August, September and October 2014 as well as June and July 2015) obtained by Marine Traffic. Longitudinal and transversal cruise routes interaction and their tendency to pass close to the islands shore have created zones of high navigational, safety and environmental risk. The monitoring revealed high-risk zones: south shores of Lastovo island, passage between Sušac island and Lastovo island and passage between Lastovo island and Mljet island. The results of five months cruise ships traffic monitoring showed that high-risk navigational routes are planned deliberately and they have become standard navigational practice and routine. Operational demand for attractive cruising routes and rich passenger experience brings cruise ships too close to the shores on various challenging navigational situations that can compromise ship safety but also marine environment The further development of cruising industry in the South part of the East Adriatic coast has to be well planned and monitored from the aspect of navigational safety. Future expansion has to be in line with implementation and development of routing systems, efficient traffic control and maritime regulations.

Keywords: cruise ships, sustainability, navigational safety, routing, the Southern Part of the East Adriatic Coast, Lastovo island, Mljet island

1. INTRODUCTION

Since 2000, cruise traffic, passenger movement and number of cruise destination in the Mediterranean region have significant growth [12]. The growth of cruise industry is particularly evident in the areas that have not been popular cruising regions before. The Adriatic Sea have been successfully using opportunity to attract cruising industry [1], [10]. In addition to substantial cruise industry growth, the Adriatic East coast region has been recognised worldwide by unique natural beauty and picturesque indented coastline.

Cruise ships spend major part of their itineraries in coastal navigation often in restricted, environmentally sensitive protected areas. The demand for competitive itinerary and exciting passenger experience brings cruise ships to navigationally restricted and environmentally sensitive areas and the pressure to make itineraries more appealing will grow in the future. This operational practice compromise navigational safety but also environmental safety.

Existing papers analyzed maritime traffic in the Adriatic Sea from various aspects. Dorigatti *at al.* [2] analysed the impact of cruise ships routing in coastal navigation from the aspect of sustainability. The authors concluded that operational aspect of cruise industry was an important factor of sustainability but had not been well addressed.

Detailed analyses of maritime traffic and routes in the Adriatic region was given by Lušić and Kos [7] and Zec et al. [13]. The focus was on general longitudinal maritime traffic from the Otranto strait to the Northern Adriatic ports. These papers concluded that maritime traffic flow in the Central Adriatic was mostly directed through the Central Adriatic Separation Scheme. Maritime accidents were rare what was an indication of good maritime traffic coordination.

Lušić, *at al*. [8] analysed sailing routes and structure of maritime traffic in the Central part of the Adriatic Sea and focused on maritime traffic inside the Central Adriatic Separation Scheme. The authors concluded that the longitudinal sailing route stretched out mostly over the area of sufficient depth and width so there was no significant navigational risks, excluding the risk of collision with the opposite and transverse traffic and risk of grounding in the broader area of Palagruža island.

The report IMO *Routing of ships, ships reporting and related matters - Establishment of new recommended Traffic Separation Schemes and other routing measures* *in the Adriatic Sea* [5] gave consideration on environmental issues on the Adriatic East coast, with emphasis on the islands: Vis, Jabuka, Svetac, Biševo, Sv.Andrija, Palagruža and Mljet. The report stated that maritime traffic and incidents were warnings and could have very serious environmental consequences.

In the Adriatic region, strong expansion of cruise traffic and development of new cruise destinations have created new routes that have not been in use ever before, moreover, they have become standard navigational options for cruise ships. In order to determine cruise routes, analysis of cruise ships traffic movement in south part of the Adriatic East coast was carried out. As frequent longitudinal cruise routes pass in vicinity of Lastovo island and its archipelago, the paper focused on Lastovo island (Natural Park) and Mljet island (National Park).

The aim of this paper is to present cruise ships routing practices in South Adriatic East coast region with focus on the island of Mljet and the island of Lastovo and its archipelago.

2. MATERIALS AND METHODES

The paper analyzed data obtained from PhD thesis Evaluation model of sanitary wastewater pollution from cruise ships in the Adriatic Sea [11] that monitored all cruise ships movements on daily basis during one year period (from August 2014 to July 2015) using Marine Traffic software. The paper analyzed the data on cruise ships over 50 000 GT for five months (August, September and October 2014 as well as June and July 2015) in the South part of the Adriatic East coast. Data were analysed and chartered together in order to get a clear picture of cruise ship traffic.

3. RESULTS AND DISCUSSION

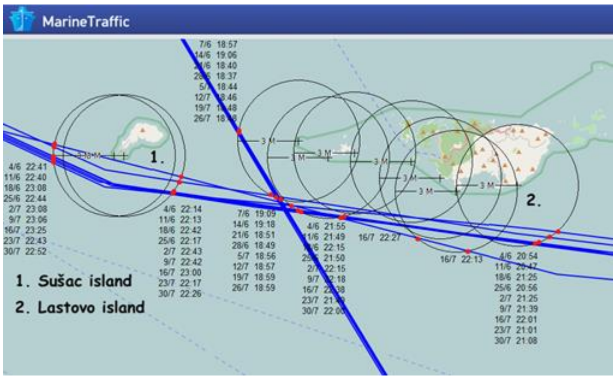
Mljet island and Lastovo island and its archipelago, are part of the outer island region of the South Adriatic East coast. Lastovo and its archipelago of 17 islets and islands is protected area as a Natural Park and west part of Mljet island is protected as a National Park. Longitudinal and transversal cruise ships traffic is dense in this region. Longitudinal routes keep north of the Central Adriatic Separation Scheme and proceed south of Sušac island and Lastovo island. Southeast longitudinal routes come from the Northern Adriatic ports and proceed to Dubrovnik, Kotor or Otranto strait. Northwest longitudinal routes proceed from Kotor, Dubrovnik or Otranto strait to the North Adriatic region using outer island costal route. Transversal routes pass west of Sušac island, between Sušac island and Lastovo island and between Lastovo island and Mljet island. Northerly transversal routes arrive from Otranto strait, Dubrovnik, Kotor or West Adriatic coast while southerly transversal routes arrive from the North Adriatic ports, Split or Korčula island.

3.1. South shores of Lastovo island

Lastovo island and its archipelago with 17 islands and islets, form the outer islands region in the South Adriatic East coast [3]. The area is protected Natural Park. Due to its unique beauty Lastovo island is a popular touristic and nautical destination. During season Lastovo region has dense sailing boat, yachts and leisure boat traffic. Coastal leisure boat traffic on many occasions interacts with cruise ships routes that pass close to the island shores.

Longitudinal northwesterly and southeasterly cruise ship routes often pass along the south coast of Lastovo island. Cruise ships on northeasterly longitudinal route from Kotor and Dubrovnik to northern Adriatic ports, do not use the Central Adriatic Separation Scheme. They proceed in east coast outer island route, heading along the south coast of Lastovo island and Sušac island until they reach the Northern Adriatic Separation Scheme. Cruise ships on southeasterly routes from the North Adriatic ports, after leaving northern Adriatic separation scheme, proceed in east coast outer island route along Lastovo south coast to Dubrovnik and Kotor.

Figure 1. shows movement of one selected cruise in Lastovo island region during two months period from June 2015 to July 2015. Blue lines represent selected cruise ship routes, while black circles are areas within 3 NM from islands shore and represent safety navigational reference: the distance cruise traffic pass from the island shores. In addition, they are environmental reference to *The International Convention for the Prevention of Pollution from Ships (MARPOL) - Annex IV regulation* [6]. Dates and time show when a cruise ship entered and departed 3 NM area. It is obvious that the routes are repetitive and have become standard navigational routine for monitored cruise ship.



Source: Marine Traffic [8]

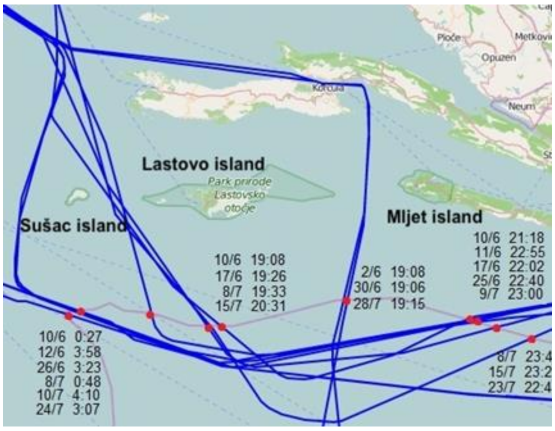
Figure 1: Routes of one selected cruise ships south of Lastovo island and between Sušac and Lastovo island during two months period from June 2015 to July 2015

Main navigational risks for cruise ships are navigation close to the island shores, head on and overtaking situation close to the island shores. High navigational risk occurs when cruise ships meet in head on situation close to the island shores. Having shallow water and land on starboard side, cruise ships in northwesterly course are in particularly demanding navigational situation [4]. Cruise ships navigation close to the Lastovo island shores present environmental, safety and navigational risk in particular risk of collision and grounding.

3.2. Passage between Sušac Lastovo island (Sušac-Lastovo passage)

Passage between Sušac island and Lastovo island is part of transversal route that cruise ship use on northerly and southerly courses. Cruise ships on southerly courses proceed through Sušac-Lastovo passage to western Adriatic coast or they join longitudinal corridor on the way to Dubrovnik, Kotor or Otranto Strait, while cruise ships on northerly courses proceed through Sušac-Lastovo passage from western Adriatic shores or from longitudinal corridor from Dubrovnik or Kotor on the way to the Central and North Adriatic ports. There is also high presence of sailing boats, yachts and touristic boats in the area during the summer season.

Figure 2. shows movement of one selected cruise ship in Sušac-Lastovo passage during two months period from June 2015 to July 2015. Blue lines represent selected cruise ship routes taken by the cruise ship, while dates and time show when the cruise ship entered and departed 12 NM area. It is obvious that the routes are repetitive and have become standard navigational routine for monitored cruise ship.



Source: Marine Traffic [8]

Figure 2: Selected cruise ships routes in Lastovo-Sušac passage and Lastovo-Mljet passage during two months period from June 2015 to July 2015

Main navigational risks for cruise ships are crossing situation between longitudinal and transversal routes south of the passage, head on and overtaking situation inside the passage and navigation close to the island's shores. Longitudinal and transversal routes often pass close to Lastovo island and Sušac island shores. Crossing and close encounter situation happen when cruise ships on transversal and longitudinal routes meet. Crossing situation is often in restricted areas, close to the island shores. Navigational risks happen when cruise ships on northwesterly longitudinal route meet in crossing situation a ship on transversal southerly route who pass through the Sušac-Lastovo passage. In this situation northwest bound ship is give a way vessel [4]. Passing close to the island shore and having shallow water and land on her starboard side cruise ship encounter demanding navigational situation. Cruise routes that pass through Sušac-Lastovo passage in southerly or northerly courses navigate close to the island shore. Navigational risk increases in overtaking or head on situation in presence of leisure crafts inside the passage.

3.3. Passage between Lastovo island and Mljet island (Lastovo-Mljet passage)

During the summer season, there is dense traffic of sailing boats, yachts and leisure boats. In passage between Lastovo island and Mljet island, leisure boats traffic interacts with cruise ships routes. The passage between Lastovo island and Mljet island, precisely between Glavat island and Mljet island, cruise ships use on northerly courses and on southerly courses when arriving/departing to/from Korčula island.

The main navigational risks for cruise ships are: crossing situation between longitudinal and transversal courses close to the island shores, navigation close to the islands shore, head on and overtaking situation in restricted area. High navigational risk occurs when cruise ships in outer island route in northwesterly courses meet in crossing situation with cruise ship in southerly courses, transiting Lastovo-Mljet passage [4]. Having shallow water and land on starboard side, cruise ship heading northwesterly is in challenging navigational situation. In transit through Lastovo-Mljet passage, challenging navigational situation occurs when cruise ship is crossing with other ship on longitudinal route on southeasterly courses. Being in restricted channel area and having giveaway vessel status, southbound ship encounters navigationally demanding situation [4].

The results show that cruise ships operate on constant circular itineraries among scheduled ports on repetitive cruise routes during the summer season. Cruise ships navigational routine does not change and probably will not change. Taking in consideration above mentioned cruise ship navigation close to the shores of Sušac island, Lastovo island, Mljet island, through Lastovo and Sušac and Lastovo and Mljet passage present environmental and navigational risk in particular risk of grounding, collision and pollution.

4. CONCLUSION

Cruise traffic in the Mediterranean region including Adriatic region has significantly grown since 2000, as well as popularity of the Adriatic cruise destinations. The demand for competitive itineraries and exciting passenger experience brings cruise ships to navigationally restricted and environmentally sensitive areas and the pressure to make itineraries more appealing will grow in the future. Longitudinal and transversal cruise routes interaction and their tendency to pass close to the islands shore have created zones of high navigational, safety and environmental risk. The monitoring revealed high-risk zones:

- South shores of Lastovo island: Cruise ships navigation close to the Lastovo island shores present environmental, safety and navigational risk in particular risk of collision and grounding.
- Passage between Sušac island and Lastovo island: Cruise routes that pass through Sušac-Lastovo passage in southerly or northerly courses navigate close to the island shore. Passing close to the island shore and having shallow water and land on her starboard side cruise ship encounter demanding navigational situation. Navigational risk increases in overtaking or head on situation in presence of leisure crafts inside the passage.
- Passage between Lastovo island and Mljet island: In Lastovo-Mljet passage, head on and overtaking situation of two cruise ships was not recorded, but dense leisure traffic put cruise ship in head on, overtaking and crossing situation with leisure boats. In transit through Lastovo-Mljet passage, challenging navigational situation occurs when cruise ship is crossing with other ship on longitudinal route on southeasterly courses. Being in restricted channel area and having giveaway vessel status, southbound ship encounters navigationally demanding situation.

The results of five months cruise ships traffic monitoring showed that high-risk navigational routes are planned deliberately and they have become standard navigational practice and routine. Operational demand for attractive cruising routes and rich passenger experience brings cruise ships too close to the shores on various challenging navigational situations that can compromise ship safety but also marine environment. The further development of cruising industry in the South part of the East Adriatic coast has to be well planned and monitored from the aspect of navigational safety. Future expansion has to be in line with implementation and development of routing systems, efficient traffic control and maritime regulations.

REFERENCES

[1] CLIA (2020) State of the cruise industry outlook, Passenger capacity table. Available at: https://cruising.org/-/media/research-updates/research/state-of-the-cruise-industry.ashx

[2] Dorigatti J., Perić T., & Jelić Mrčelić G., (2021). Sustainability in Maritime Transport: Impact of Cruise Ships' Routing in Coastal Navigation, KIMC 2021, Kotor, Montenegro

[3] Hydrographic Institute of the Republic of Croatia (2021). Adriatic Sea Pilot Volume II. Split: HHI.

[4] Lloyd's Register (2005). COLERGS - International regulations for preventing collisions at sea. Rule 8, Rule 13, Rule 14, Rule 15 Rule 16, Rule 17, London : IMO. Available at: http://www.mar.ist.utl.pt/mventura/Projecto-Navios-I/IMO-Conventions%20(copies)/COLREG-1972.pdf

[5] International Maritime Organisation Sub - Committee on safety of navigation, 49th session, Agenda 3, (2003). Routing of ships, ship reporting and related matters: Establishment of new recommended Traffic Separation Schemes and other new routing measures in the Adriatic sea. London: IMO 6

[6] International Maritime Organisation (2006), (IMO). The international convention for the prevention of the pollution (MARPOL), Annex IV, Regulation 11. London: IMO 7

[7] Lušić, Z., & Kos S. (2006). The main sailing routes in the Adriatic for Naše More, 53 (5-6), 198–205.

[8] Lušić, Z., Medić, D., & Pušić, D. (2017). Analysis of the maritime traffic in the central part of the Adriatic. In Transport Infrastructure and Systems 2017, (pp. 1013–1020, ISBN: 9781138030091). Rome, Italy: CRC Press

[9] Marine traffic application. Available at: https://www.marinetraffic.com

[10] MedCruise report (2019) Statistics and cruise activities in Med Ports. Available at: https:// www.medcruise.com/2019-statistics-cruise-activities-in-medcruise-ports

[11] Perić T. Rijeka (2016). Evaluation model of sanitary waste water pollution from cruise ships in the Adriatic Sea, Doctoral Thesis. Available at: https://doi.org/10.7307/ptt.v28i4.2087

[12] Zanne M., & Beškovnik, B., (2018). Assessing Home Port Potential of Selected Adriatic Ports for TOMS – Transactions on Maritime Science, 7(2), 143- 153.

[13] Zec D., Frančić V., Rudan I., Maglić L., Žuškin S., Bukša J., Petričić U., Tešar K. & Vukelić M., (2016). Studija Konsolidacije sustava obveznog javljanja brodova i uspostave zajedničkog Jadranskog VTS sustava - Prometno plovidbena studija. Rijeka: University of Rijeka

RESEARCH ON VESSEL DELAYS ON SWINOUJSCIE - SZCZECIN WATERWAY IN THE ASPECT OF LIMITATIONS RESULTING FROM PORT REGULATIONS

Irmina Durlik, M.Sc.
Lucjan Gucma, Ph.D.
Maritime University of Szczecin
Waly Chrobrego 1-2, 70-500 Szczecin, Poland
i.durlik@am.szczecin.pl, l.gucma@am.szczecin.pl

Tymoteusz Miller, Ph.D.
University of Szczecin
Wąska13, 71-899 Szczecin, Poland
tymoteusz.miller@usz.edu.pl

ABSTRACT

The article analyses the phenomenon of ship delays on the Świnoujście-Szczecin fairway and the research carried out on this subject. The aim of the study was to determine the impact of vessel traffic intensity on the occurrence of delays, as well as to answer the question of which of the existing Port Regulations generate the highest number of delays and how significant the associated financial losses are.
Then, based on the results obtained, the work aims to create a statistical model to estimate the expected ship delays and to determine the incurred financial losses resulting from these delays.
The research was conducted by the VTS operator in Szczecin using an empirical method through a series of observations of ship delays. Univariate and multivariate regression analysis has been carried out based on the collected data in order to examine the extent to which vessel delays depend on traffic intensity.
The research focuses on the analysis of Port Regulations and their direct impact on vessel delays. They lead to the identification of the rule responsible for the longest delay time. The results obtained in the process of analysing traffic intensity and causes of delay were subjected to statistical modelling in order to examine the correlation between the factors studied.

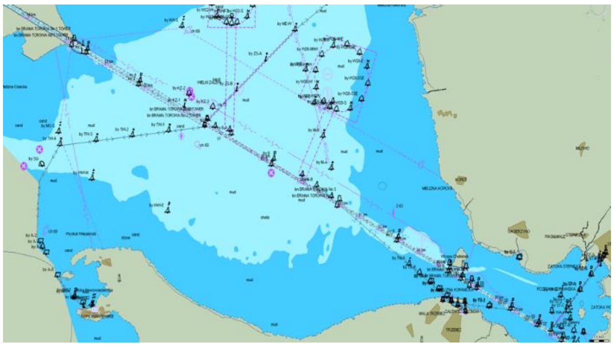
Keywords: List of keywords (vessel traffic, vessels' delays, statistical model, regression analysis)

1. INTRODUCTION AND PROBLEMATICS

According to UNCTAD[1] data, shipowners reported record profits last year and the importance of maritime transport in international trade continues to grow. Not only is the intensity of ship traffic increasing, but so are their dimensions. Maneuvering areas and port infrastructure cannot keep up with such dynamic changes, so the need to maintain waterway capacity and terminal efficiency has ports around the world looking for new solutions and tools to optimize time and costs.

1.1. Organisation of traffic on the Świnoujście-Szczecin fairway

The Świnoujście-Szczecin fairway is an artificial fairway 67.35 km long with an average width of 90 m and a depth of 10.5 m. It is a relatively long approach fairway where jurisdiction is shared between the VTS Świnoujście and VTS Szczecin. The change of area of responsibility between VTS Świnoujście and VTS Szczecin takes place at the Gate II in the Szczecin Lagoon. (Fig.1).



Source: Own elaboration based on chart system in Szczecin VTS

Figure 1: The Szczecin Lagoon

The VTS service start when the ship arrives at the roadstead in Świnoujście and reports its readiness for entry. VTS services provide information on the availability of berths, planned vessel traffic and weather

[1] https://unctad.org/news/global-trade-hits-record-high-285-trillion-2021-likely-be-subdued-2022

conditions. If the navigational situation on the fairway allows the vessel to enter the port and the vessel meets all formal requirements, it may proceed to the designated quay. However, if the conditions mentioned above are not met, the vessels must wait at the anchorage until permission is granted. Ships without pilotage exemption or tug assistance will be obliged to use these services.

On the Świnoujście-Szczecin fairway there are some rather complicated restrictions on passing ships due to their overall length and width or available water depth. These guidelines are specified in the Port Regulations. On several sections of the waterway one direction of traffic is obligatory due to safety conditions for ships with a maximum draught of nearly 9 m and a length of nearly 160 m. It is also necessary to monitor the water level at the approaches and at selected quays for ships with large drafts.

To ensure safety on the fairway, there must be close and continuous cooperation between the traffic control operators in Szczecin and Świnoujście. This is to ensure smooth, synchronised vessel traffic and to monitor compliance with regulations at area covered by the VTS.

1.2. Review of literature on ships traffic efficiency

The maritime industry worldwide uses simulation models with varying levels of efficiency and accuracy. These models have proven to be an extremely useful tool for assessing port performance. This is understandable give the diversity of port infrastructure, the complexity of the ship manoeuvring process and the many external factors affecting the ship. The same approach was taken during the research for this article focusing on the case study of the examined fairway.

The analysis of vessel traffic on waterways is also the subject of research of Almaz and Altiok [2012], Hasegawa et al. [2001], Xiao et al. [2012 and 2013] or Xu et al. [2015].

As mentioned earlier, the research conducted for this study focuses on the analysis of port regulations and the role of VTS operators in their enforcement. Xiao et al. [2013] showed that the VTS traffic control system is important and should be considered in the process of developing new models.

Groenveld et al. [2006] in their work undertook to estimate the capacity of port infrastructure using traffic flow simulation models. In their analysis of the results they also highlight the importance of traffic rules and the role of VTS operators in vessel traffic control.

Shu et al. [2012] and Xiao et al. [2012] in their studies work on using AIS database records to describe ship traffic.

In this study, AIS database records were also used to determine vessel passage times. It is believed that the use of AIS brings the results obtained closer to the actual behaviour of ships on the waterway.

There is a lack of comprehensive studies in the literature on vessel delays from the roadstead and the quays in the ports of Szczecin and Police. Gucma et al, [2016] take up the topic of ship delays on the Świnoujście-Szczecin waterway and presented the results of validation of the stochastic model of ship traffic flow by comparison with real data of delayed ships. The total waiting time was taken as the main parameter of the presented validation. The investigated delays were recorded and averaged. The time defining vessel delay was obtained from the VTS Szczecin Centre and compared with the model results. The model was then confronted and verified with actual data obtained from 25 half-day observations [Gucma et al, 2016]. The data were collected from July to September 2016. In that period, the total delay of ship traffic on the Świnoujście-Szczecin waterway was estimated at 125 ship-days.

In order to verify the obtained results, the research for this paper was carried out in a way to estimate the expected delay of ship traffic on the waterway in ships-days per year.

Zhou et al. [2019] reviewed marine vessel motion models. In this paper, basic modelling schemes are presented and an attempt is made to assess the extent to which motion models can represent the actual behaviour of ships. In the opinion of the author of the paper, none of the existing models describes in detail all the dynamic data for different types of ships and does not take into account the influence of the full range of external factors. Models without proper calibration and validation limit the possibility of their universal implementation.

2. RESEARCH MATHODOLOGY

The object of the research were ships participating in traffic on the Świnoujście-Szczecin waterway calling at the ports of Szczecin and Police. Ships using Świnoujście port were observed only in direct correlation with the ships entering or leaving Szczecin and Police ports, i.e. having direct impact on their delay. The study covered the area from the head of the breakwater in Świnoujście to the quay. Inland waterway vessels and assistance services (e.g. tugboats, firefighting units) were not included in the study. The study focused on delays resulting directly from the Port Regulations, i.e.:

1. Ships to be provided with one direction of traffic (ODT) on designated sections of the waterway or on the entire route of their passage.
2. Ships which may not pass each other because the total permissible length is exceeded.
3. Ships which may not pass each other on account of exceeding the permissible overall width of the crafts.
4. Vessels that cannot pass each other due to exceeding the draught limit.

5. Ships which could not enter or leave the port due to the prevailing hydro-meteorological conditions.

A total of 56 twelve-hour observations were carried out. During these, delays were recorded for ships that were unable to arrive or depart the port due to Port Regulations restrictions. It should be noted that the system does not provide automatic recording of vessel delays in the VTS database. All delay measurements and analysis of their causes were observed and recorded in real time while on duty. Therefore, vessel traffic studies were based on own observations and analyses, with detailed knowledge of Port Regulations and the use of database tools and an electronic charting system.

The delay occurred during 36 observations. No vessel was delayed during the remaining 20 observations. A total of 62 vessels were surveyed. Their total delay was 150.6 h.

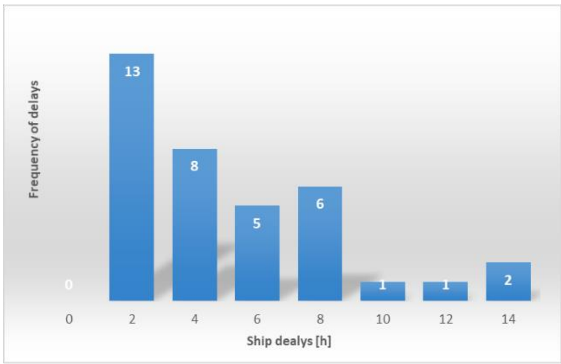
The actual time of passing the breakwater heads in Świnoujście by the surveyed vessels was used for the study. These times were used to calculate the intensity on the fairway during one observation (one service lasting 12 h). The breakwater head passage time was also used to calculate the delay of vessels entering the ports of Szczecin and Police by comparing the planned head passage time (based on ETA) with their actual passage time (AIS). The calculated intensity for each of the 56 observations was analysed to determine the correlation between the intensity of traffic on the fairway and the resulting delays.

The time of delay, the cause of delay and the number of vessels delayed during each observation were recorded. The total data of all vessels delayed during one observation, for both inbound and outbound vessels, were used for statistical analysis. Univariate and multivariate regression analysis was performed on the collected data to determine the extent to which vessel delays depend on traffic intensity. The results obtained from the analysis of the effect of traffic volume on delays showed the need for multivariate linear regression.

The next stage of the research was to identify the most frequent cause of vessel delays directly resulting from Port Regulations. The results obtained in the process of analysis of traffic intensity and causes of delays were subjected to statistical modelling in order to examine the correlation between the factors studied.

3. ANALYSIS OF OBTAINED RESULTS

The most frequent delays of the studied vessels occurred in the time interval up to 2 hours. The histogram of observed delays is shown in Fig. 2. A similar frequency of delays is observed in the time interval from 2h to 8h, while delays lasting longer are much less frequent.



Source: Own elaboration based on own data

Figure 2: The histogram of delays

Multivariate linear regression analysis was performed to determine whether the delay could be intensity-dependent. As mentioned earlier, delay occurred during the 36 observations. According to the results of our study, the average intensity on the fairway during this time was 0.59 vessels/h. During the 20 observations without the delay phenomenon, the average intensity on the fairway was 0.47 vessel/h.

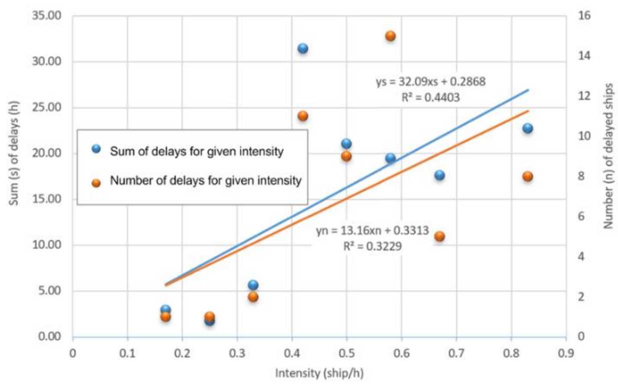
During the study period, there was an average of 1.75 delayed vessels per observation and the average delay time was 4.2 h.

When analysing the average traffic intensity during observations with delays (0.59 vessels/h) and without delays (0.47 vessels/h), it is clear that vessels were delayed at higher traffic volumes.

In conclusion, according to the results obtained, there is a strong correlation between traffic intensity and vessel delays.

In order to answer the question to what extent traffic intensity variability explains the occurrence of vessel delays, a linear regression of the sum of vessel delays as a function of traffic intensity was performed.

The results of the regression analysis showed that the model calculated on the basis of the flow rate explains 44% of the variation in total vessel delay (Figure 3). It can be assumed that 56% of the variance in delay depends on other factors.



Source: Own elaboration based on own data

Figure 3: Analysis of selected univariate regressions of sum of delays and number of delayed ships

At the same time, when analysing the effect of intensity on the number of delayed vessels, the obtained model explained only 32% of the actual variation.

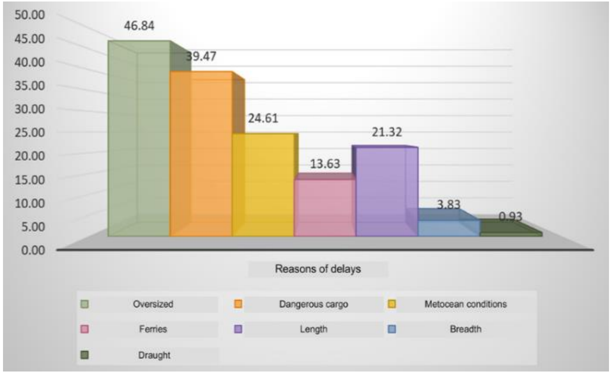
As the statistical analysis showed, intensity is not the only factor affecting vessel delays on the fairway. There is also no high correlation between intensity and the occurrence or duration of delays. Subsequent research has focused on determining how much of a role constraints play in vessel delays under the of the port regulations.

The study collected the total time ships were delayed during one observation (12 hours) and the number of ships that were delayed during that time. It was then determined which Port Regulation had a direct impact on vessel delay.

For the purpose of the study, 7 main causes of vessel delays were identified on the basis of Port Regulations:

1. Oversized vessel on the waterway.
2. Vessels carrying dangerous cargo.
3. Metocean (wind, wave and visibility) conditions.
4. Ferries at Świnoujście.
5. Due to exceeded L - length overall.
6. Due to exceeded B – ships breadth.
7. Due to exceeded T – ships draught.

The results of the survey (Figure 4) showed that the longest total time of delays was caused by the rule on the requirement to provide one-way traffic direction for oversize vessels (special conditions) or vessels carrying dangerous cargoes. The obligation to provide the surveyed vessels with a clear fairway along the entire passage route generated 46.84 h of delays. One-way traffic on designated sections of the waterway for ships with dangerous cargo is responsible for 39.47 h of delays. Meteorological conditions, i.e. poor visibility or strong wind, caused 24.61 h of delays.



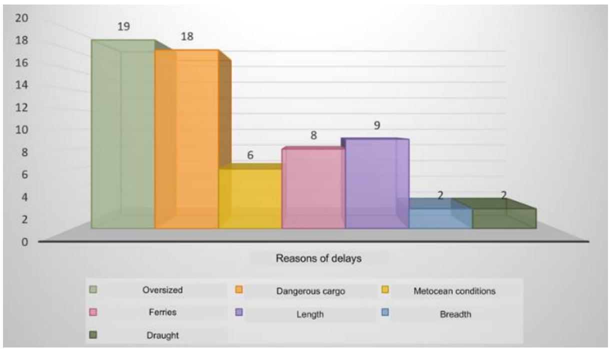
Source: Own elaboration based on own data

Figure 4: Duration of vessel delays by its cause

Exceeding the technical parameters of vessels (length/overall width or permissible draught) with ferries calling at Świnoujście resulted in 13.63 h of delay for the surveyed vessels.

Restrictions resulting from the overall length of passing vessels are responsible for 21.32 h of delays. The shortest time of delays was caused by limitations resulting from the exceeded overall width of passing vessels (3.83 h) and the mutual ratio of their draughts (0.93 h).

The obligation to provide one traffic direction for oversize ships on the whole fairway or on a given section of the fairway is also the reason for the highest number of delayed ships [Fig.5]. As many as 19 surveyed vessels were delayed for this very reason.



Source: Own elaboration based on own data

Figure 5: Number of delayed vessels by cause

Another regulation that caused vessels to be delayed is the requirement to maintain one direction of traffic for vessels carrying dangerous cargoes. This rule caused the delay of 18 surveyed vessels.

The third most common cause of delays is exceeding the total length of vessels. This restriction caused the delay of 9 vessels.

4. CONCLUSIONS

Based on the collected empirical samples, the following objectives were achieved in the process of statistical analysis:

1. The effect of traffic intensity on vessel delays was investigated and proved to be less significant for total delays than originally assumed.
2. It has been shown that the interaction between vessels resulting from Port Regulations is much more important than the number of vessels on the fairway.
3. It was determined which Port Regulation on the Świnoujście-Szczecin fairway is responsible for the greatest number of delays. It was found out that it is a port rule that requires oversize vessels and vessels carrying hazardous cargo to navigate in one direction on the entire fairway.

After reviewing the available literature on the subject, it appears that despite the growing availability of proposed simulation models, treating the discussed research problem from different perspectives, the number of available publications is still limited, and these models do not provide a comprehensive and universal solution.

The research presented in this paper is an introduction to the next projects and will be extended by own simulation model of ship motion. The research also aims at estimating the costs resulting from ship delays and stoppages.

The waterway is currently modernised to depth of 12.5m that could accommodate larger ships of draught around 11m and length exceeding 200m which will be the field of further researches of ships delays.

REFERENCES

[1] Port Regulations 2019. Directive No 3 of Head of Maritime Office in Szczecin.

[2] Gucma L., Sokołowska S. and Bąk A. (2016). Stochastic Model of Ships Traffic Capacity and Congestion - Validation by Real Ships Traffic Data on Świnoujście - Szczecin Waterway. Annual of Navigation. Vol. 24.

[3] Olba X.B., Daamen W., Vellinga T., Hoogendoorn S.P. (2018). State-of-the-art of port simulation models for risk and capacity assessment based on the vessel navigational behavior through the nautical infrastructure. Journal of Traffic and Transportation Engineering. Vol.5.

[4] Almaz, O.A., Altiok, T., (2012). Simulation modeling of the vessel traffic in Delaware River: impact of deepening on port performance. Simulation modelling practice and Theory vol. 22.

[5] Olba, X.B, Daamen, W., Vellinga, T., et al., (2015). Simulating the port wet infrastructure: review and assessment. Conference: 18th Euro Working Group on Transportation, EWGT.

[6] Groenveld, R. (2006). Ship traffic flow simulation study for port extensions, with case extension Port of Rotterdam. In: 31st PIANC Congress, Estoril, 2006.

[7] Groenveld, R. (2001). Service Systems in Ports and Inland Waterways. VSSD, Delft.

[8] Groenveld, R. (1983). Harboursim, a Generally Applicable Harbour Simulation Model. Delft University of Technology, Delft.

[9] Hasegawa, K., Tashiro, G., Kiritani, S., et al. (2001) Intelligent marine traffic simulator for congested waterways. In: 7th IEEE International Conference on Methods and Models in Automation and Robotics, Mexico City.

[10] Hassan, S.A. (1993). Port activity simulation: an overview. Simulation Digest 23 (2), 18.

[11] Shu, Y., Daamen, W., Ligteringen, H., et al. (2012). AIS data based vessel speed, course and path analysis in the Botlek area in the Port of Rotterdam, The Netherlands. In: Transportation Research Board 92nd Annual Meeting, Washington DC.

[12] Xiao, F. (2014). Ships in an Artificial Force Field: a Multi-agent System for Nautical Traffic and Safety. Delft University of Technology, Delft.

[13] Xiao, F., Ligteringen, H., Gulijk, C., et al., (2013) Nautical traffic simulation with multi-agent system for safety. In: 16th International IEEE Conference on Intelligent Transportation Systems-(ITSC), the Hague.

[14] Xiao, F., Ligteringen, H., van Gulijk, C., et al. (2012) AIS data analysis for realistic ship traffic simulation model. International Workshop on Nautical Traffic Models, Delft.

[15] Xu, W., Chu, X., Liu, X. (2015). Simulation models of vessel traffic flow in inland multi-bridge waterway. In: International IEEE Conference on Transportation Information and Safety (ICTIS), Wuhan.

RESULTS OF THE ANALYSIS OF THE EFFECTS OF LOW-SULPHUR FUEL OIL ON THE OPERATION OF THE MARINE TWO-STROKE SLOW-SPEED DIESEL ENGINE

Joško Dvornik, Ph.D.
Srđan Dvornik
University of Split, Faculty of Maritime Studies,
Ruđera Boškovića 37, 21000 Split, Croatia
josko@pfst.hr

ABSTRACT

Exhaust gas emissions are often directly related to the impurities in marine fuels. High level of sulphur oxides (SOx) and nitrogen oxides (NOx) in the exhaust gas emissions is an inevitable result of using heavy fuel oil (HFO).
The requirements introduced in some shipping for reducing SOx emissions from the marine two-stroke slow-speed diesel engines areas have resulted in using low-sulphur fuel oils in diesel engine operation or install the exhaust gas cleaning system. Using HFO with high sulphur contents has become unacceptable after the regulations brought by Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), the designation of some seas as particularly sensitive areas (Emission Control Areas – ECA) and the implementation of the ship exhaust emissions in the ECAs.
The maximum allowed fuel sulphur content in European ECAs amounts to 0.1 % for ships in ports and all inland waterways across the European Union, whereas California Air Resources Board (CARB) applies the regulation limiting the sulphur content in fuel to 0.1 % within 24 NM off the California's shoreline [1], [10], [13].
This paper discusses the results produced by the analysis of the problems occurring when using low sulphur fuel oils in the operation of marine two-stroke slow-speed diesel engines. The paper analyses the effects of the low sulphur fuel on the fuel injection system, fuel combustion and liner lubrication, as well as the measures taken to prevent possible damage to engine components [1], [12], [13].

Keywords: low-sulphur fuel, combustion, lubrication, cylinder liner, viscosity

1. INTRODUCTION

At the request of California Air Resources Board (CARB), following a series of issues that affected ships due to fuel switching after the introduction of regulations on using low-sulphur fuel oils within 24 miles off the Californian coastline, a research was conducted from 2009 to 2010, according to [3]. The research results indicated that fuel switching caused:

- Loss of propulsion and operation instability as the engine speed was reduced to dead slow or slow astern, resulting in rpm fluctuations or stopping the engine, whereas the engine operation was stable at higher rpm.
- Difficulties in starting the engine or inability to start the engine due to low pressures in fuel systems, low viscosity of fuel, problems related to high-pressure fuel pump operation, fuel injection, leakage of oil in the fuel injectors and sealing rings.
- Inability to reach maximum speed, inability to reverse the engine ahead/astern, most commonly due to low pressure of fuel injection or malfunctions in injection timing.

Based on the observation and analysis of the difficulties detected in California, American Petroleum Institute (API) published *Technical Considerations of Fuel Switching Practices* in 2009.

According to this study, possible causes of the difficulties may be recognised by the following events, according to [3]:

- Temperature of fuel during fuel switching causes sticking of the components of high-pressure fuel pumps and injectors due to thermal shock, increase in fuel viscosity and reduced lubrication of high-pressure fuel pumps.
- Non-compliance of the fuel in use and changes caused by scuffing and sticking of high-pressure pumps and fuel injectors.
- Use of inadequate oil for the lubrication of bearings and cylinder liners resulting in excessive wear of the liner and piston rings.
- Liner lacquering as a result of poor lubricating oil film.

2. RESULTS OF THE ANALYSIS OF THE EFFECTS OF LOW-SULPHUR FUEL OIL ON THE OPERATION OF THE MARINE TWO-STROKE SLOW-SPEED DIESEL ENGINE

2.1. Problems related to the high-pressure fuel pumps

Since sulphur has lubricating ability, the use of low sulphur fuel oil (LSFO) leads to concern that lubrication of fuel pumps may be inadequate.

The viscosity during fuel injection may change from that of heavy fuel oil (HFO) (10-20 mm^2/s) to that of marine gas oil (MGO) (1-3 mm^2/s), and become an issue.

Although the lubricating ability of marine fuel oil and sticking of fuel pump require particular attention, the problems are not insurmountable. The engine manufacturers have tested the use of fuel with agents added for enhancing lubricating oil during trials, according to [1], [5], [10].

When the engine is switched from heated heavy fuel oil (HFO) to unheated marine gas oil (MGO) or marine diesel oil (MDO), malfunctions in the high-pressure fuel pump may occur due to vaporisation of the fuel oil because of heat. In addition, the high-pressure fuel pump may leak, i.e. fuel with HFO specifications may end up in the oil sump tank as the engine operates in MGO mode. According to [1], this may have the following effects:

- Decreased viscosity of lubricating oil which, in severe cases, may adversely affect the lubrication of bearings.
- Drop in flash point, which may trigger an explosion in the crankcase.
- Since this fuel has low aromatic properties, it is not compatible with some kinds of rubber, and is likely to cause problems such as inadequate sealing.

Leakage of oil from the high-pressure fuel pump may have the following effects:

- Drop in fuel pump pressure.
- Reduced amount of the fuel injected.
- Poor fuel atomisation.
- Various ignition delays on engines complying with emission regulations such as NOx regulations.

2.2. Combustion problems when using LSFO

Combustion problems may occur due to any the factors listed below, but in most cases, they occur as a combination of several of these factors:

- Low sulphur level.
- Matching of low-sulphur content of fuel oil and the cylinder oil base number (BN).
- FCC catalytic fines.
- Poor combustibility of fuel oil.
- Contamination by used lubricating oil (ULO).
- Design of engine.
- Maintenance and operation of engine.

Although abnormal wear of piston rings and cylinder liners (scuffing) as well as combustion problems such as high temperature corrosion and the use of low sulphur heavy fuel oil (LSHFO) have been observed and addressed for a long time, comprehensive solutions related to the effects of sulphur content in fuel on the combustion process have not yet been found, according to [1], [8], [10].

2.3. Problem of liner lacquering when using low-sulphur fuel oil

Lacquering is a colouring effect due to black fuel oil without any effect of wear at places where the quantity of lubricating oil is normal. Since anti-polishing rings began to be used in 1990s, the oxides of the piston crown and unburnt oil have been prevented from rubbing against the cylinder liner, and the colouring effect has reduced considerably.

The problem of liner lacquering is a cause for concern when using low-sulphur fuel oil (LSFO) as it is harder to maintain the necessary lubricating oil film across the surface of the liner.

This may lead to increased oil consumption. However, the process of lacquering ceases when the engine is switched back to HFO. The use of high-quality lubricating oil with improved thermal stability at high temperatures reduces the effects of fuel and the effects of flame on the cylinder liner surface, according to [1], [6].

2.4. Scuffing effects

Scuffing, which is the cause of abnormal wear of the cylinder liner and piston rings, occurs in a relatively short time, but is a kind of precursor phenomenon that can be predicted by observing its symptoms. Before scuffing occurs, the lubricating oil film of the cylinder liner starts to break and to form again repetitively. Broken lube oil film allows metal-to-metal contact between the liner wall and piston rings, resulting in friction and increased temperature [1], [11], [10]. The temperature of the cylinder liner repetitively rises and falls to its initial temperature over the 10 to 20 min. intervals. The observed and recorded oscillation has a saw-toothed waveform. When this typical phenomenon is detected and if immediate measures such as reducing the engine load or increasing the lubricating oil quantity are taken, then the process can be postponed or prevented. In addition to temperature monitoring, the occurrence of scuffing is prevented by the newly-developed systems that emit alarm when a waveform indicates the above symptoms, according to [1].

It has been established that the damage occurs due to common factors, such as poor performance of the lubricating oil, fuel oil characteristics, torque change, adverse sea conditions, poor engine maintenance, poor choice of material, etc. The trouble is that the scuffing phenomenon occurs fast, it cannot be always accurately predicted, and the ship operator is forced to bear the costs of repair and delay.

Over the last decades, the marine low-speed two-stroke diesel engines have become more powerful and more complex. At the same time, the maintenance intervals have become longer and the maintenance quality lower. On the other hand, the shipping schedules are getting busier, the ship exploitation is maximised and the time spent in port is reduced to minimum. Under the conditions, the shippers and ship operators pay greater attention to the reliability of the vessel, its systems and components.

The cylinder liner is one of the essential components of the marine two-stroke slow-speed prime mover and its excessive wear is one of the worst threats a ship operator may address. Inability to operate a ship results in various costs and loss of credibility and image on the market, according to [1].

Excessive wear of the cylinder liner in the ring belt presents a serious problem, according to [1], [11]. It is likely to occur when using low-sulphur fuel oil together with the cylinder lubricating oil having the base number 70 or higher. These oils contain excessive calcium carbonate, i.e. its content is much higher than necessary to neutralize sulphuric acid that is created during fuel combustion. Calcium carbonate settles on the piston ring lands, scraping the oil off the liner wall and causing malfunction in the lubricating process, according to [1], [11], [13].

In order to prevent scuffing and damage to the liner and piston rings, it is possible to monitor the temperature as one of the most distinct scuffing symptoms. For instance, the Temperature Monitoring and Alarming System (T-MAS) is a dedicated system that can detect the symptoms of scuffing on the running surface of the cylinder liner in a large marine diesel engine, before the excessive wear takes place. T-MAS detects potential problems by observing the cylinder liner temperature. Under normal conditions, there is enough lubricating oil on the liner surface.

As scuffing starts to occur locally, the oil film gets thinner due to metal-to-metal contact, creating a leak for the high temperature exhaust gases. The system senses the temperature and sets off the alarm in the event of excessive temperature or excessive deviations in temperature, according to [1], [11], [13]. T-MAS consists of the temperature sensors, cables, switchboard, hybrid recording device and personal computer. The standard version features two sensors on each cylinder liner. The purpose of measurement is to read the temperatures at the running surface of the liner. The value observed by the thermopile is proportional to the temperature on the cylinder liner surface.

In addition to careful monitoring of the liner temperature, the standard measures for preventing the excessive wear of the liner include the increased supply of cylinder lube oil, lowering the cooling water temperature in the water jacket, and temporary reduction of load on the affected cylinder by adjusting the feed fuel pump, according to [1], [11], [13]. All these measures postpone or prevent scuffing phenomenon efficiently.

3. MEASURES TAKEN WHILE USING LOW-SULFUR FUELS

The reduction of the engine load is the most efficient measure. It decreases the temperature and pressure inside the cylinder, as well as the penetration of the atomised fuel, thus maintaining the adequate film of lubricating oil between the cylinder liner and piston rings.

It is necessary to reduce FCC fines as much as possible, to install fuel oil filters with mesh size below 10 microns, and thoroughly clean the fuel oil, according to [1], [2], [4].

Increasing the feed rate of the cylinder oil and lowering the temperature of the cylinder liner cooling water are the measures resulting in strengthening the lubricating oil film. In a normal engine room plan, the outlet temperature of jacket cooling water (JCW) can be made around 75°C. In this way, the cylinder lubricating oil temperature on the cylinder liner wall surface is slightly reduced and the viscosity increases. Consequently, the strength of the lubricating oil film increases and the film becomes difficult to degrade. A decrease in engine load and an increase in lubricating oil quantity are also included in the measures for reducing heat in the lubricating oil film, which leads to enhanced strength of the lubricating oil film, according to [1], [10], [13].

New cylinder oil feed systems have been developed and adapted in two-stroke diesel engines: Electronically Controlled Lubricating – ECL System, Swirl Injection Principle – SIP, developed by Mitsubishi Heavy Industries Ltd., Pulse Lubricating System – PLS (Wärtsilä) and Alpha Lubricator System (MAN). These systems directly and effectively supply lubricating oil to a wide area of the cylinder liner running surface.

The cylinder oil is supplied effectively in adequate quantity to the required locations, the reliability of the cylinder oil is improved significantly, and the margin until scuffing is increased as well, i.e. its occurrence is postponed. When this common phenomenon is detected, the processes resulting in scuffing may be prevented, provided that urgent measures, such as reduction of the cylinder load and/or increased supply of cylinder oil, are taken.

Finally, compared to the conventional cylinder oil feed systems, all of the above solutions require considerably smaller amount of lubricating oil. By introducing these systems, most of the problems related to the cylinder liner and piston rings due to LSFO effects are likely to be resolved in the near future, according to [1], [13].

4. CONCLUSION

Changing the main engine fuel type may affect the safety of navigation due to malfunction of the engine or interruption of its operation. In the emission control areas, fuel switching has to be carried out not only in the main engines, but in the auxiliary engines and steam generators as well, according to [2], [3].

If the mixture of HFO and LSGO oils remains in fuel oil pipes, clogging of strainers, sticking of fuel oil pump and other sludge problems are likely to occur. Careful monitoring is therefore necessary, according to [1].

LSGO has low kinematic viscosity so it is diffused easily when it leaks. Moreover, as its flash point is also low, there is an increased risk of fire.

The flash point of fuel oil used on board ships is regulated to a value above 60°C, in compliance with the SOLAS Convention of IMO, but the flash point of a part of LSGO may be less than 60°C.

With regard to the anti-scuffing properties, 70 BN cylinder oils perform better than the low-BN oils. The rate of neutralizing sulphur acids is to the greatest extent affected by additive composition, not the base number. High-performance 40 BN oils can substitute 70 BN oils, provided that sulphuric acid neutralisation does not result in decreased alkalinity. The 40 BN oils outperform all commercial products and could serve as models for future cylinder oils, according to [1], [11], [12], [13].

Analyses of possible causes of the encountered problems have indicated that these issues have been mainly considered from the perspective of technology and engine room plant requirements when changing the fuel type on board ships. However, the causes have to include operators' errors and have to be also studied from the viewpoint of both onboard and corporate organisation, according to [3], [10], [13].

REFERENCES

[1] Class NK. (2008). Guidance for measures to cope with degraded marine heavy fuels, Version II, Research Institute Nippon Kaiji Kyokai, Japan.

[2] Tireli E. (2005). Goriva i njihova primjena na brodu, University of Rijeka, Faculty of Maritime Studies, Rijeka.

[3] Zekić A., & Radonja R., & Berenčić D. (2012). Promjena goriva na brodu u kontekstu sigurnosti plovidbe, Naše more 59 (5-6).

[4] ABS. (2010). Fuel Switching Advisory Notice, American Bureau Survey, Houston.

[5] MAN Diesel & Turbo, (2010). Operation on Low Sulfur Fuels, MAN B&W Two–Stroke Engines, Copenhagen.

[6] Report on application of low sulpfur fuel to marine diesel engine, (2005). Fuel and Lubricant Committee, the Japan Institution of Marine Engineering, Research Report No. 369.

[7] Liddy J., & Lim K.C. (2000). Cylinder oil – positioning for the future, Motorship Amsterdam Congress.

[8] Wakatsuki Y. (2006). Fears of Low Sulpfur Fuel Oil, Mitsubishi Heavy Industries, Ltd., Journal of the Japan Institution of Marine Engineering, Vol. 41, No. 1.

[9] Wakatsuki Y., & Watanabe K., & Yamamoto T., & Takaishi T. (2000). Relation between Recent Low Grade Fuel and Reliability of Marine Diesel Engines, ISME Tokyo 2000, Paper No. TS - 66, 23-27 Oct.

[10] Djini R., & Dvornik S., & Dvornik J. (2014). Analysis of the effects of low-sulphur fuel oil on marine diesel engines operation, International Maritime Science Conference, Book of Proceedings, 6th IMSC, April 28th-29th, Solin, Croatia, ISSN 1847-1498, 11-18.

[11] Wakatsuki Y., & Watanabe K., & Yamamoto T., & Takaishi T. (2005). T-MAS, the detector of scuffing before excessive wear, Proceedings of the 7th International Symposium on Marine ngineering Tokyo, October 24th to 28th.

[12] Sasaki T., & Moriwaki T., & Noge T., & Shirahama S., & Arimoto N. (2005). The differences of commercial cylinder oils performances for marine low speed diesel engine between 70BN and 40BN for low sulfur content marine fuel oil, International Council on Combustion engines, CIMAC, paper No.:161.

[13] Dvornik J., & Dvornik S., & Radan I. (2019). Analysis of the effects of low-sulfur fuels on the cylinder liner lubrication in the marine low-speed two-stroke diesel engine, Proceedings of Naše More 1st International Conference of Maritime Science & Technology, Dubrovnik, Croatia, pp. 103-113.

KEYWORDS AND PHRASES IN TECHNICAL MANUALS ON OIL SPILLS

Zorica Đurović, Ph.D.
University of Montenegro, Faculty of Maritime Studies
Put I bokeljske brigade 44, 85330 Kotor, Montenegro
zoricag@ucg.ac.me

Christelle Nicolas
The French Maritime Academy
39 Av. du Corail, 13008 Marseille, France
christelle.nicolas@supmaritime.fr

Violeta Jurkovič, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, 6320 Portorož, Slovenia
violeta.jurkovic@fpp.uni-lj.si

ABSTRACT

Oil spills at sea have been causing serious environmental impacts due to their rapid and long-range spread and disastrous effect on ecosystems. With the increasing number of oil tankers in world fleets, this problem has been brought to a closer attention. The Blue4Seas project, a strategic partnership for supporting Blue Growth within a cooperation network on marine pollution and the environment protection field, aims to produce open-source innovative pedagogical resources to train students in the protection of the environment and prevention of marine pollution. In addition to one of the main conventions of the International Maritime Organization dealing with prevention of pollution from ships (MARPOL), there is also a series of manuals and handbooks for adequate understanding of oil spills, their environmental impact and adequate responses that more and more world professionals are required to abide by. Considering that the maritime industry generally gathers more diverse nationalities than any other human activity, adequate comprehension and proficiency in English for specific purposes can be either a great advantage or an obstacle, even threat. For this very reason, this paper aims to use corpus linguistics methods and software for focusing on the keywords and phrases in some contemporary technical manuals on oil spills that distinguish this branch of Maritime English from General English, especially in terms of (technical) vocabulary.

Keywords: oil spills, keywords, phrases, n-grams, Blue4Seas project

1. INTRODUCTION

As much as 90% of the world trade is carried by sea, about 60% of which are oil-based products [1]. Shipping is probably the most international one of all major industries in the world, but also one of the most dangerous. Marine pollution is multiple and varied. Studies explain that about 80% of marine pollution originates on land [2], in different forms of pollutants and most often as a result of various human activities. The rest is due to ships. This is generated on the one hand by their operation and on the other hand by maritime accidents. Focus is on the latter leading to accidental oil spills and the strategies to prevent them or clean them up. They can occur in various circumstances, most often during activities such as bunkering, storage, handling, transportation (large or small), offshore drilling, routine maintenance and cleaning activities, etc.

Severe marine accidents occurring as a result of collisions, contact, grounding, structural failure, fire and explosions affect aquatic and coastal ecosystems and onshore human social activities, crew's life and the ship itself. The consequences and likelihood of each risk determine the level of the risk. On this basis, risk management adopts control and reduction measures, so that they become as low as reasonably practical (ALARP).

Despite the fact that oil spills have decreased over the past decades thanks to tighter regulation and improvement in safety [3], an evaluation of the risks for Pollution Preparedness and Response (PPR) at different levels of depth and detail ensures a clean marine environment [4]. Preparedness and coordination at national and regional levels are of prime importance in order to control and limit oil from propagating and endangering public health and devastating natural resources. At the level of the global maritime domain, the IMO structure in charge of this subject is the Sub-Committee on Pollution Prevention and Response (PPR) which deals with all matters relating to pollution prevention and response that falls within IMO's remit.

In addition to official requirements and regulations, a series of projects has been developed and implemented for the purpose of a safer and cleaner marine environment. Active involvement in one of such projects, the Blue4Seas project, has been an immediate inspiration for the paper.

1.1. The Blue4Seas Project

The Blue4Seas project is an Erasmus+ European project which establishes a strategic partnership for supporting Blue Growth in marine pollution and environment protection. It gathers five institutions: Mircea cel Bătrân Naval Academy, Ecole Nationale Supérieure Maritime, Pîrî Reis Universoitesi, Univerza v Ljubljani, and Lietuvos Aukstoji Jureivystes Mokykla, located in the countries (Romania, France, Turkey, Slovenia and Lithuania) bordering three of the four European seas.

The project, in terms of marine pollution and environment protection, aims at: producing innovative pedagogical resources accessible online, training students about the environment attracting their attention to urgent needs in terms of environmental and marine pollution, and sharing good practices among the partners. The project is organized around intellectual outputs, namely Learning, Teaching and Training, as well as events and transnational meetings which enable the partnership to reach the targeted objectives. The consortium as well as a panel of expert lecturers and students meet at regular intervals in the partner countries in order to carry out this project in an effective manner.

What has proved as a necessity through the project and general education and training on oil spill response is the need for a harmonized approach to the matter in decision making [4]. This also implies the harmonization of terminology and proficiency therein, especially when having in mind the numerous members of the global maritime community who are non-native speakers of English. This brings us to our research objective of exploring the key terminology and phrases most frequently found in manuals for oil spill coverage.

2. CORPUS AND METHODOLOGY

The corpus of oil spill recovery manuals (COSRM) has been compiled out of five manuals deemed relevant and sufficient to the target users, as per the Blue4Seas Project findings and expert advice. The composition in terms of the manuals included and their general lexical count is as follows (Table 1):

Table 1: Corpus of oil spill response manuals

File title	Number of tokens[1]	Number of types[2]
Manual on the Applicability of Oil Spill Dispersants [5]	26,729	2,885
Understanding Oil Spills and Oil Spill Response (EPA) [6]	18,953	2,747
Oil in the Sea: Inputs, Fates, and Effects [7]	161,908	10,978
Oil Spill Monitoring Handbook [8]	18,738	2,587
Training Marine Oil Spill Response Workers Under OSHA's Hazardous Waste Operations and Emergency Response Standard [9]	4,208	1,193
Corpus of Oil Spill Response Manuals (COSRM)	230,536	13,001

In order to investigate the lexical profile and demand of the target corpus, we have used the freeware tool AntWordProfiler [10]. To accommodate the software requirements, the pdf files were converted to the .txt format (plain text). The referent General English (GE) word lists used for the process are Nation's word lists produced from the British National Corpus and Corpus of Contemporary American English (BNC/COCA). These 25 lists contain about 1,000 word families each, and they are accompanied by additional lists of most frequent proper names, abbreviations, transparent compounds and marginal words [11][12].

Another software solution – AntConc [13], will provide us with the opportunity to obtain the list of corpus keywords, comprised of the words unusually frequent as compared to a referent corpus of general English (GE). As such, these words are worth paying special attention to since they are considered to be the specificity and (statistically) characteristic of the target corpus. They reflect the nature of a text or genre and enable its better comprehension [14]. As for the referent GE corpus, we used the Freiburg-Lancaster-Oslo/Bergen Corpus (FLOB). This referent GE corpus was developed aiming to produce a contemporary referent corpus following the methodology of the Brown University Standard Corpus of Present-Day American English [15].

In addition, we have used the same software to examine the most frequent n-grams or multi-word units occurring in this specific professional genre and therefore worth being familiar with.

[1] Running words, the total number of words in a corpus.

[2] All the different words in the text, no repeated words are counted.

3. LEXICAL PROFILING OF THE CORPUS

In order to investigate the lexical profile of the corpus and its demand vocabulary-wise, we tested it against the BNC/COCA General English word lists [11][12] (Table 2).

Table 2: Coverage of GE word lists in COSRM

BNC/COCA Word Lists	Coverage (%)
2,000 + proper names, abbreviations, compounds and marginal words	74.33
3,000 + proper names, abbreviations, compounds and marginal words	84.93
4,000 + proper names, abbreviations, compounds and marginal words	88.25
5,000 + proper names, abbreviations, compounds and marginal words	90.5
6,000 + proper names, abbreviations, compounds and marginal words	91.59
15,000 + proper names, abbreviations, compounds and marginal words	95.08
25,000 + proper names, abbreviations, compounds and marginal words	95.71

Considering that the adequate reading comprehension is expected at the level of 95% of known vocabulary [16], we can see that in our target corpus it is reached not sooner than at the level of 15,000 General English words[3], which is a hardly attainable task for a non-native speaker. The ideal threshold for reading comprehension of 98% known vocabulary [17] is not reachable even with the cumulative coverage of all the 25 available GE words list (Table 2), which clearly calls for the focus on specific or technical vocabulary. Taking into account the recommendation for early specialization when it comes to ESP [18], our aim here is to explore the most frequent keywords and phrases found in technical manuals on how to handle oil spills.

4. KEYWORDS IN COSRM

Contrary to the frequency counts, the keyness of a word does not necessarily mean a high but rather unusual frequency of that word as compared to a referent corpus, which is usually a GE one. As such, the keywords are those with a "special status" [19] in a genre, reflecting its specificity as compared to other types of texts. The tools enabling us to relatively easily extract the keywords of a text type especially come in handy, providing us with meticulously organized lexical and syntactical material.

From the initial keyword list produced by the software (1,769 lemmas), we first opted for the cut-off point of +500 (keyness) according to the analysis conducted in view of the length and composition of the list. The keyness in our approach, however, does not refer to an individual lemma, as presented by the software. Taking into consideration the principle of learning burden or effort put in mastering a word [20], we put and counted together word family members, as well as referent (transparent) compounds (e.g. water(s), seawater, wastewater etc.). We also excluded the most frequent English words from the table such as: *of*, *and*, *or*, *are*, *in*, which mostly belong to the 10 most frequent words of the English Language [21][22]. Also, regardless our best efforts to remove proper names, single letters, symbols and abbreviations, some still occurred in the list, so we removed those as well. Finally, we came up with a list of 41 keywords in COSRM, arranged by their cumulative frequency, as per the previously explained process (Table 3).

Table 3: Keywords in COSRM

No.	Word	Keyness	Frequency
1	oil(s) oiled, oily, oiling, unoiled	+ 15,794.57	5,544
2	spill, spills, spilled	+ 5,535.60	1,549
3	hydrocarbon(s)	+ 4,485. 44	1,306
4	dispersant(s), disperse(d)	+ 4,210.35	1,176
5	petroleum	+ 4,118.42	1,138
6	water(s), seawater, freshwater, wastewater(s), waterborne	+ 3,210.34	1,306
7	marine	+ 2,601	774
8	biological, biodegradation, biodegrade(d), biodegradable, bioassay(s), biochemical, bioremediation, biomass, biogenic, bioaccumulation, biostimulation, biotic, bioaugmentation	+ 2,586.89	754
9	effect(s), effective, effectiveness	+ 2,300.84	1,060
10	sample(s), sampled, sampling, sampler	+ 2,087.66	728
11	chemical(s), biochemical, photochemical, chemistry, chemically, chemoreception	+ 1,501.1	525
12	use(d), using, useful	+ 1,185.09	1,138
13	environment, environmental	+ 1,223.08	530
14	pollution, pollutant(s), polluted, unpolluted	+ 1,216.98	399
15	sediment(s)	+ 1,863.01	673
16	sea, seawater	+ 1,764.42	664
17	organism(s), microorganisms, macroorganisms	+ 1,482.28	445

[3] A word here denotes a word family, which includes the head or base word with all its inflected and derived forms.

No.	Word	Keyness	Frequency
18	method, methodologies	+ 1,476.31	509
19	exposure(s), exposed, exposing	+ 1,320.22	454
20	concentrations	+ 1,309.84	375
21	toxic, toxicity, toxicant, toxicol, toxicities, detoxification	+ 1,289.43	361
22	crude	+ 1,187.94	360
23	response(s)	+ 1,146.24	491
24	studies	+ 1,123.24	462
25	contaminate(d), contamination contaminant(s), decontamination, uncontaminated	+ 1,117.92	327
26	fish(es), fishery, shellfish	+ 1,106.38	423
27	compounds	+ 1,068.8	304
28	slick(s)	+ 1,059.95	273
29	monitor, monitoring, monitored	+ 963.45	359
30	cleanup clean(ed), uncleaned, cleaning	+ 953.49	338
31	species	+ 934.06	413
32	surface(s), subsurface	+ 933.48	370
33	ocean(s), oceanic, oceanography, oceanographic	+ 862.39	268
34	data	+ 833.12	417
35	aromatic, monoaromatic, napthenoaromatic	+ 829.8	240
36	area(s)	+ 824.12	565
37	(inter)laboratory, laboratories	+ 797.61	268
38	coastal, coast(s), coastline(s)	+ 753.5	293
39	impact(s), impacted	+ 725.91	288
40	fuel	+ 684.69	245
41	column(s)	+ 642.19	221

As we look at the composition of the COSRM keywords, we can see that they belong to various registers. For example, we have the unusually frequent use of some GE words such as oil, water, use, area and similar, but also more specific terms such as those of maritime (*marine, sea, coast, ocean*), chemical (*hydrocarbon, laboratory, compound*) environmental (*pollution, contamination*), biology (*micro-* and *macroorganisms*) and various other academic or more or less specific and most frequently overlapping areas. This speaks in favour of multidisciplinarity of any contemporary and global human endeavour, especially having in mind the *lingua franca* character of the English language, as is especially the case in the world of shipping-related activities.

5. MOST FREQUENT N-GRAMS IN COSRM

Bearing in mind that individual words do not carry stand-alone meaning, but their semantics is context-dependent, our further interest would be driven towards the most common combinations of words we can come across in this specific type of manuals. For the purpose, we sought to detect the most frequent n-grams consisting of 2–5 members (words). The search was adjusted to the minimum range of 4 (out of 5 files under scrutiny). The examples presented in Table 4 are the most frequent ones with each cluster including either (at least) two nouns, an adjective and a noun or a verb and a noun, in order to avoid the most frequent n-grams in general language, such as *of the*, *to the*, etc. and also to pursue the examples of the most frequent collocations in the corpus. Again, since the software provides lemmatized results, we put together similar expressions with the same keywords such as *of crude oil* and *crude oil and* in 3-gram combinations (Table 4).

Table 4: Most frequent n-grams in COSRM

No	N-grams	Freq.	Range
	2-grams		
1	oil spill(s)	578	4
2	crude oil	251	4
3	water column	176	4
4	marine environment	144	5
5	aromatic hydrocarbons	110	4
6	long term	83	4
7	spill response	77	5
	3-grams		
1	the water column	150	4
2	the marine environment	131	5
3	(of) crude oil (and)	71	4
4	an oil spill	89	5
5	wide range (of)	53	4
6	oil spill response	52	4
7	environmental protection agency	34	4
8	the oil slick	25	5
9	the water surface	14	4
	4-grams		
1	in the water column	77	4
2	into the water column	35	4
3	oil in the water	26	4
4	of an oil spill	25	4
5	a wide range of	22	4
6	the amount of oil	15	4
7	area of the oil	4	4
8	characteristics of the oil	4	4
9	the potential effects of	4	4
	5-grams		
1	oil in the water column	20	4

From the n-gram examples, we can see that this kind of analysis explores beyond the lexical level and can be used for the analysis of various syntactic patterns. It also challenges the notion of keyword, which needs to be carefully addressed and defined in research. In our and, we dare say, in this type of research in general, a keyword and its role cannot be deduced to single-word units, regardless of their counts as lemmas or families. Looking at the results given in Tables 3 and 4, we can make an easy inference about the keyness of the n-grams. For example, it would not serve any practical purpose to look at "oil" and "spill" as two separate units, regardless of their statistical keyness, whereas "oil spill", as well as a series of other n-grams presented, is a true key notion of the manuals. Therefore a comprehensive approach and expert and logic intervention are indispensable in these kinds of computational analysis, bearing in mind the practical needs of target readers, who are most often also language learners, as in the case of the maritime industry.

The AntConc software also enables further examination into single words in collocations or clusters of desired and set numbers of words that come across together in the target corpus. This kind of examination can be done for each of the keywords or phrases, which, for practical reasons, are not going to be presented in this paper. We hope, though, that the produced lists, as well as the methodology applied and implied, will readily serve the manual users and (language) instructors in focusing and harmonizing the key language points widely occurring in this type of technical manuals and other genres pertaining to prospective oil spills and recovery thereof.

6. ACRONYMS

As in shipping-related manuals in general, acronyms are very frequent in this specific genre dedicated to oil-spill responses. Generally, they are explained either when first mentioned in the text and/or are given as a separate table. Due to their frequency, they directly and negatively influence the frequency of full terms and phrases, therefore implying the limitations of the analysis. Considering that the acronyms are mostly used instead of frequent noun phrases (e.g. oil spill response – OSR, International Maritime Organization – IMO etc.), we can say that n-grams provide a wider analytical approach to most frequent word clusters in a corpus, although our target groups should be familiar also with the most frequently occurring abbreviations such as those given under certain general frameworks dealing with the matter [4], e.g.:

FSA Formal Safety Assessment

IMO International Maritime Organization

PPR pollution preparedness and response

RBDM risk-based decision-making

RIDM risk-informed decision-making

RP risk perspective

SRA Society for Risk Analysis

7. CONCLUSION

Having in mind the topicality of environmental issues, especially those related to the marine environment, our aim was to provide a modest contribution to an adequate and prompt response to prospective sea pollution. In that regard, the target corpus of our research was compiled of oil spill response manuals and aimed at their proper comprehension and harmonized use of terminology. Applying some contemporary software solutions, we analysed the lexical profile of the manuals and tried to provide a meaningful selection of the most frequent keywords and n-grams occurring in at least 4 out of 5 examined files. In total, we provided a list of 41 head-keywords (word families with (transparent) compounds), as well as a set of n-grams composed of 2, 3, 4 and 5 members, avoiding the most frequent sequences of prepositions, conjunctions and similar. In addition, we also provided some further implications for lexical examination and statistical counts that could be applied both in our target genre, and any other type of text and in any similar research. We hope that the lists produced can be of use to anybody involved in oil spill response activities interested in the most common and harmonized language units. In addition, we hope that other linguistic researchers can benefit from the methodology presented in terms of their further research, as well as effective teaching material design.

REFERENCES

[1] U.S. Energy Information Agency (2017). https://www.eia.gov/.

[2] Chassignet, E. P., Xu, X. & Romero O. Z. (2021). Tracking marine litter with a global ocean model: Where does it go? Where does it come from?. Frontiers in Marine Science, Vol. 8. DOI=10.3389/fmars.2021.667591.

[3] ITOPF (2020/21) International Tanker Owners Pollution Federation (ITOPF) Handbook – second edition.

[4] Laine, V., Goerlnadt, F, Valdez Banda, O. A. & Baldauf, M. (2021). A risk management framework for maritime Pollution Preparedness and Response: Concepts, process and tools, Marine Pollution Bulletin, 171, 1–23. DOI: 10.1016/j.marpolbul.2021.112724.

[5] Lewis, A. et al. (2009). Manual on the applicability of oil spill dispersants. 2nd edition. EMSA, Lisbon, Portugal.

[6] EPA (1999). Understanding oil spills and oil spill response. US Environmental Protection Agency, Washington D.C.: EPA Oil Program Center.

[7] Steering Committee for the Petroleum in the Marine Environment Update, Board on Ocean Science and Policy, Ocean Sciences Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council (1985). Oil in the sea, inputs, fates and effects. Washington, D.C.: National Academy Press.

[8] Baxter, T, Gilbert, T, Wilde, S.& Roberts, J. (2006). Oil spill monitoring handbook, Australian Maritime Safety Authority (AMSA) and the Marine Safety Authority of New Zealand (MSA).

[9] OSHA (2001). Training marine oil spill response workers under OSHA's hazardous waste operations and emergency response standards. US Department of Labor, Occupational Safety and Health Administration.

[10] Anthony, L. (2021). AntWordProfiler (Version 1.5.1) [Computer Software]. Tokyo, Japan: Waseda University. Available from https://www.laurenceanthony.net/software.

[11] Nation, I. S. P. (2004). A Study of the most frequent word families in the British National Corpus. In P. Bogaards and B. Laufer (Eds.) Vocabulary in a second language, Selection, acquisition and testing, Amsterdam, John Benjamins, pp. 3–13.

[12] Nation, I. S. P. (2006). How large a vocabulary is needed for reading and listening? Canadian Modern Language Review, 63 (1), pp. 59–82.

[13] Anthony, L. (2022). AntConc (Version 4.0.4) [Computer Software]. Tokyo, Japan: Waseda University. Available from https://www.laurenceanthony.net/software.

[14] Culpeper, J. & Demmen, J. (2015). Keywords. In Biber, D. & Reppen, R. (eds.) The Cambridge Handbook of English Corpus Linguistics. Cambridge: Cambridge University Press. DOI: 10.1007/9781139764377.006.

[15] Kucera, H. & Francis, W. N. (1967). Computational analysis of present-day American English, Providence, R. I. , Brown University Press.

[16] Laufer, B. (1989). What percentage of text-lexis is essential for comprehension? In Special language, from humans thinking to thinking machines, Ed. Lauren, C. and Nordman, M. Multilingual Matters, pp. 316–323.

[17] Hu, M. & Nation, I. S. P. (2000). Vocabulary density and reading comprehension. Reading in a foreign language, 23, pp. 403–430.

[18] Coxhead, A. & Hirsch, D. (2007). A pilot science-specific word list. Revue Française de Linguistique Appliqueé 12 (2): 65–78.

[19] Stubbs, M. (2010). Three concepts of keyness. In M. Bondi, and M. Scott, (Eds.) Keyness in texts, Amsterdam: John Benjamins.

[20] Nation, I. S. P. (2000). Review of what's in a word? Vocabulary development in multilingual classrooms by N. McWilliam, Studies in Second Language Acquisition, 22 (1), pp. 126–127.

[21] Nation, I. S. P. (2013). Learning vocabulary in another language (second edition), Cambridge, Cambridge University Press.

[22] Nation, I. S. P. (2016). Making and using word lists for language tearning and testing, Amsterdam, John Benjamins.

ANALYSIS OF THE SOUND LEVEL REACHING THE MOTORCYCLIST'S AUDITORY SYSTEM

Tomasz Figlus, Ph.D.
Piotr Szafraniec, Ph.D.
Silesian University of Technology, Faculty of Transport and Aviation Engineering,
Department of Road Transport
8 Krasinskiego Street, Katowice 40-019, Poland
tomasz.figlus@polsl.pl

Tomáš Skrúcaný, Ph.D.
Jaroslav Mašek, Ph.D.
Juraj Čamaj, Ph.D.
University of Žilina, Faculty of Operation and Economics of Transport and Communications
1 Univerzitna Street, Žilina 010-26, Slovakia
tomas.skrucany@fpedas.uniza.sk, jaroslav.masek@fpedas.uniza.sk, juraj.camaj@fpedas.uniza.sk

ABSTRACT

Means of transport pose a significant threat to the natural environment. Noise and vibration emitted by transport are among the most negative impacts on the surrounding environment, including people. Vehicle users are also exposed to noise and vibrations emitted by means of transport. They contribute to the deterioration of the vibroacoustic climate in the means of transport, which is treated by users as a subjective symptom of low quality of the means of transport or poor comfort of vehicle operation. Motorcyclists belong to a group of transport users who are only marginally protected from the vibroacoustic impact reaching them. As a result, often underestimated impacts on the motorcyclist's body may cause deterioration of their health. In this study, examination aimed at assessment of risks related to the noise reaching the motorcyclist's ear directly was carried out. Sound level measurements were taken at the beginning of the motorcyclist's ear canal. Noise reaching the motorcyclist's hearing organ was recorded while the motorcyclist was riding his vehicle under different traffic conditions at both constant and variable speeds. The research carried out has made it possible to assess the sound level which reaches the motorcyclist's auditory organ under real traffic conditions, as well as to carry out an analysis of the possible health risk to the motorcyclist.

Keywords: Environmental hazard, Human, Motorcycle, Noise, Transport

1. INTRODUCTION

Noise and vibration are among the main environmental risks caused by transport. Traffic noise negatively affects the environment in the vicinity of the road, while often significantly reducing the comfort of living in human habitats [9, 18, 23, 27]. Its level is influenced by many factors, the most important of which are speed and traffic volume, typology of traffic flows, type and condition of road surface, type of vehicle tyres, type of engine and vehicle exhaust system [4, 10, 12, 17, 20].

Noise emissions have been subject to controls and restrictions for many years through the introduction of various types of legislation [21, 22]. This includes interventions to reduce industrial noise, environmental noise and noise directly generated by means of transport.

Motorcycles are among the means of transport whose noise has a negative impact on the environment [13,19, 25]. The paper [6], which addressed the future of transport, states that motorcycles are alternative means of transport which have lower fuel consumption and contribute less to congestion, but are much noisier. The studies presented in [23, 25] indicate that although motorcycles are mostly used in spring and summer, their noise emissions cause considerable annoyance among residents in Sweden. The studies presented in [1] also indicate that noise generated by motorcycles is one of the most annoying noises out of all means of transport. Considering the short exposure time compared to other means of transport, motorcycle noise induces similar levels of irritation as lorry noise (much longer exposure time).

Motorcyclists are exposed to noise levels that can impair their hearing and health. The studies presented in [3] indicate that motorcycle users are very likely to lose their hearing even when using very noisy motorcycles only once. The problem of hearing loss and/or tinnitus is present in many motorcycle users [23].

The noise that reaches a motorcyclist is generated mainly by the motorcycle engine and exhaust system, as well as the turbulence of the air surrounding the motorcycle and the motorcyclist. Both of these types of noise are of a transient nature. Sound levels for sports motorcycles exceed 80 dB and in extreme cases even 100 dB [11, 16].

Such a high level of sound is particularly dangerous, as the motorcyclist is in some cases exposed to noise for a longer period of time, like in the case of people practising the so-called "motorcycle tourism", or professional riders, e.g. police officers riding motorcycles. In addition to the negative effect on hearing, noise also affects response time and concentration, which can in turn contribute to collisions or accidents [7, 8].

Currently, motorcycle helmets are designed with a focus on providing maximum head protection, ergonomics of use and low weight. Only some manufacturers take into account the aspects of lowering the sound level reaching the ears of the motorcycle rider. Commercial data also do not offer comparative information on which helmet and to what extent suppresses sounds.

In their attempts to reduce the noise reaching their hearing organs, motorcycle users take advantage of additional hearing protection, such as earplugs. Using such a solution entails the risk of not hearing alarm sounds or other warning sounds.

Research into reducing the nuisance the motorbike noise causes for its users is also being carried out at various scientific research centres. The paper [7, 8] presents research on human perception of sound levels and nuisance caused by them. The contribution of the type of the motorcycle exhaust system to the change in the sound level is presented in [11]. Exploratory studies on the assessment of the nuisance of noise in motorcycle helmets are presented in [2, 14, 24]. These studies, conducted on different helmets, made it possible to determine the sound levels that reach the motorcyclist while riding a motorcycle. The paper [6] investigated which methods to reduce motorcycle noise are expected by users: earplugs or better quality motorcycles helmets. Exploratory studies on sound attenuation of helmets using methods similar to those used for testing earmuffs are presented in [19, 26]. The studies conducted thus far do not solve the problem of noise reaching the motorcyclists. At present, there are no established standards for the measurements of noise inside helmets.

A moving motorcycle emits noise caused by:

- operation of the engine and the drive train,
- aerodynamic drag from air turbulence during motorcycle motion and resonant vibration of body and chassis components,
- the rolling of wheels on the road surface.

The main sources of motorcycle engine vibration and noise are:

- combustion process and engine clearances,
- intake and exhaust system (exhaust gas discharge),
- radiator fan,
- vibration arising in the power transmission system,
- vibration arising in the gearbox.

The motorcycle noise level also depends on:

- motorcycle type (sport, touring, chopper, off-road), which is related to the power as well as engine's cylinder capacity and rotational speed range,
- ride type (idling, acceleration, riding at constant speed),
- travelling speed.

In this paper, research was carried out to assess the risks of noise reaching the motorcyclist's ear directly. Sound level measurements were made at the beginning of the motorcyclist's ear canal. The noise reaching the motorcyclist's hearing organ was recorded while riding the motorcycle under different traffic conditions and at constant and variable speeds.

2. RESEARCH METHOD

A touring motorbike in a good technical condition was used for the research (Fig. 1).

Figure 1: Motorcycle used for the research:

*** cylinder capacity: 599 cm^3**

*** maximum power: 57 kW (76 KM) / 10500 rpm**

*** torque: 58 Nm / 8000 rpm**

When planning the experiments, it was assumed that the tests would take place under real traffic conditions. This influenced the choice of the method used to carry out the measurement of sound reaching the motorcyclist's hearing organ. It was assumed that, in order to record the actual noise reaching the motorcyclist's hearing organ, measurements would take place under the helmet, at the beginning of the motorcyclist's ear canal.

Figure 2 shows the diagram of the measuring system and Figure 3 shows the distribution locations of the measuring system elements during the experiments.

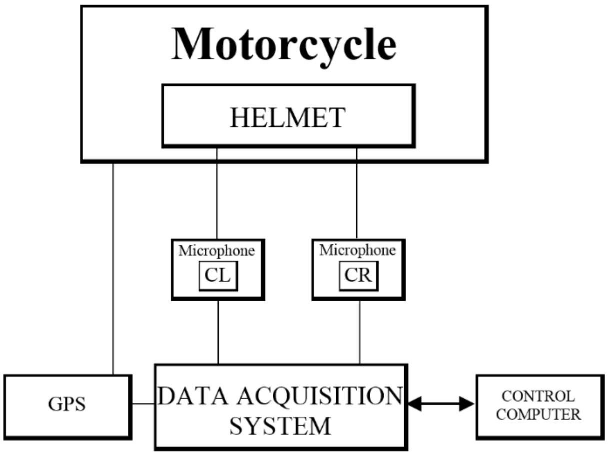


Figure 2: Measuring system diagram

The tests were carried outs using a measurement system consisting of:

- two OKM II Rock-Klassik Studio Version binaural microphones made by Soundman,
- LMS Scadas XS recording system from Siemens, which enables simultaneous recording of the motorcycle's GPS position together with the dedicated measurement control software installed on a tablet type portable computer.

a)

b)

Figure.3: Arrangement of the measuring system elements: a) signal recording system; b) binaural microphone placed in the motorcyclist's ear (covered by the motorcycle helmet during the tests)

Matlab-Simulink software was used for further signal processing.

3. RESEARCH RESULTS AND ANALYSIS

An analysis of the actual noise levels that occur during motorcycle operation in road conditions and to which the motorcyclist is exposed was carried out. Since the impact of noise on people is one of the constantly recognised methods of research in the field of occupational health and safety, as well as medical research, it was assumed that analyses of measurement results would be carried out for signals subjected to A-weighting frequency correction. This is in accordance with recommendations presented in appropriate national and European standards [21, 22].

In the first stage of the research, acoustic signals recorded at various quasi-stationary values of motorcycle travelling speeds of 50, 70, 90 and 110 km/h were analysed.

Figure 4 shows the values recorded and calculated with the application of correction curves A.

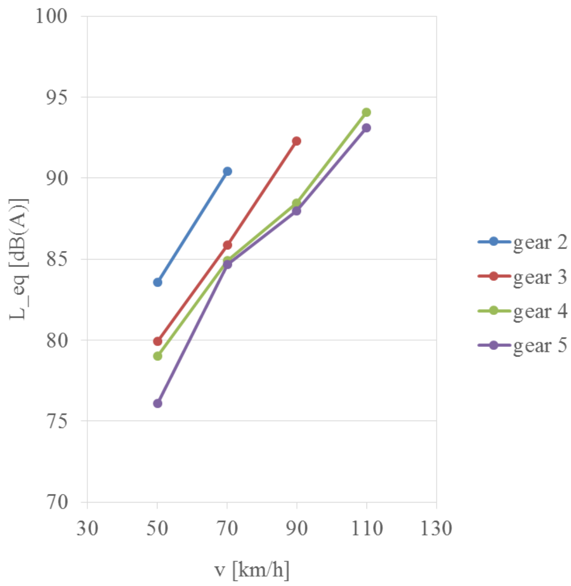


Figure 4: Change in noise as a function of travelling speed and the selected gear (quasi-stationary values of motorcycle travelling speeds)

Measurements of the sound level in the helmet - measurement using A-weighted curve - indicate that the value of noise increases non-linearly with the increase in motorcycle travelling speed and ranges from ca. 76 dB(A) to nearly 94 dB(A). When analysing the test results, it can be observed that in order to reduce the negative impact of the motorcycle on the driver the highest operationally viable gear ratio of the motorcycle gearbox should be used for propulsion as quickly as possible.

In subsequent phases of the research, noise affecting the motorcyclist under varying non-stationary traffic conditions was assessed. Two types of motorcycle traffic were considered:

- urban traffic,
- extra-urban traffic.

In the case of noise tests recorded in urban traffic, a 14-section motorcycle ride was analysed. A test route located in a city was selected that allowed the motorcycle to travel under normal traffic conditions at different speeds. Figure 5 show the values of noise inside the motorcycle helmet, calculated on these sections and applying corrective A-frequency-weighting.

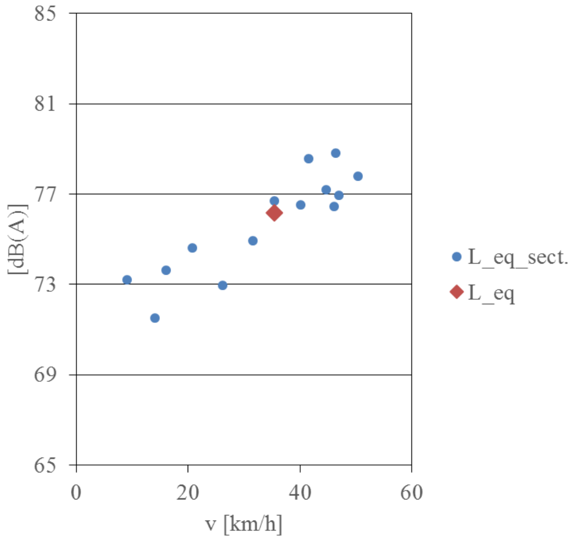


Figure 5: Momentary noise – measurements in urban traffic - L_eq_sect. - section motorcycle ride - L_eq - the entire test

In the case of the acoustic signals analysed, it can be seen that the noise values change accordingly – the sound level is 71.49-78.81 dB(A) and the equivalent value is 76.18 dB(A).

In subsequent phases of the research, vibroacoustic impact on a motorcyclist riding a motorcycle in extra-urban traffic was analysed. The aim of this research was to assess what levels of vibroacoustic impact a motorcyclist is subjected to during longer-distance motorcycle rides. In this experiment, measurements were made for a motorcycle travelling on an expressway that allowed higher travelling speeds to be maintained.

As in the case of tests in urban traffic, in extra-urban traffic noise recorded during the movement of the motorcycle on 14 measuring sections were also analysed. Figure 6 show the values of noise inside the motorcycle helmet, calculated on these sections and applying corrective A-frequency-weighting.

The results of these experiments show that noise changes accordingly: the sound level in the range 79.72-91.4 dB(A) and the equivalent value 87.86 dB(A).

By relating the frequency-corrected noise results to the limit values presented in the standards [15], it can be concluded that its equivalent level during the whole experiment is 87.86 dB(A), which is higher than the limit value of 85 dB(A).

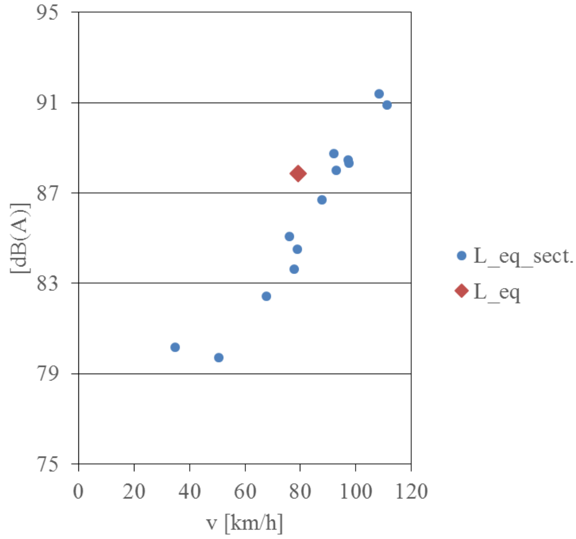


Figure 6: Momentary noise– measurements in extra-urban traffic - L_eq_sect. - section motorcycle ride - L_eq - the entire test

4. CONCLUSIONS

One of the significant impacts of means of transport on the environment and their users is the emission of vibration and noise. In vehicles, this problem can be considered as an aspect of ensuring a sufficiently high level of comfort of use, and also as a factor contributing to health deterioration. It was found in the paper that motorcycles belong to the group of means of transport which have a negative impact on their users. The main problem here is the exposure of motorcyclists to vibroacoustic signals penetrating the human body through the upper limbs, lower limbs, trunk and hearing organs.

The detailed research on the impact of noise on the motorcyclist, recorded at the beginning of the ear canal, indicate a significant exposure of the motorcyclist to the possibility of hearing loss. These studies indicate that the actual sound level to which a motorcyclist is exposed is significant, reaching momentary values of over 90 dB at higher motorcycle speeds. By relating the recorded and calculated values after the application of the A-curve correction, it can be seen that the sound levels to which a motorcyclist is exposed in urban traffic range from 71,49 to 78,81 dB(A), and in extra-urban traffic from 79.72 to 91,4 dB(A). These are values which, with intensive use of the motorcycle, can, according to literature guidelines, impair the hearing of motorcyclists.

The results of the experiments showed that motorcyclists are significantly exposed to health risks from high-level noise affecting their hearing organ. This impact can be reduced by using motorcycle helmets with greater attenuation of sound reaching motorcyclists as well as by using additional elements in the helmet body that reduce the direct flow of noise to the motorcyclist's auricle (reducing air turbulence).

REFERENCES

[1] Berglund, B., & Nilsson M.E. (2000). Total annoyance and perceptually discernible noise sources. Proc. of Inter-Noise 2000, Nice, France.

[2] Brown, Ch. H., & Gordon, M, S. (2011). Motorcycle Helmet Noise and Active Noise Reduction. The Open Acoustics Journal, 4, 14-24.

[3] Carlsson, I., (2002). Personal communication with statistician Mrs Inge Carlsson at SCB in Oerebro.

[4] Caban, J., (2021). Traffic congestion level in 10 selected cities of Poland. Scientific Journal of Silesian University of Technology. Series Transport, 112, 17-31.

[5] Czech, P., Warczek, J., Stanik, Z., Witaszek, M., & Witaszek K., (2015). The influence of noise on the car ride comfort. Logistyka, 4, (CD-ROM), 2871-2878.

[6] DFT [Department for Transport], (1998). A New Deal for Transport: Better for Everyone. Departmentfor Transport.

[7] Engel, Z., & Wiktor, M.Z., (2010). Hałas i drgania w procesach pracy. Źródła, ocena, zagrożenia. Warszawa: Wydawnictwo Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy.

[8] Engel, Z., (2012). Człowiek a hałas. Kielce, Wydawnictwo Politechniki Świętokrzyskiej.

[9] Engel, Z., (2001). Ochrona środowiska przed drganiami i hałasem, wyd. 2. Warszawa: Wydawnictwo Naukowe PWN.

[10] Figlus, T., Gnap, J., Skrúcaný, T., & Szafraniec, P., (2017). Analysis of the influence of different means of transport on the level of traffic noise. Scientific Journal of Silesian University of Technology. Series Transport, 97, 27-38.

[11] Figlus, T., Wilk, A., Liscak, S., & Kalafarski, M., (2013). The influence of muffler type of the exhaust system in the sports motorcycle on the level of the emitted noise. Acta Tech. Corviniensis - Bull. Eng., 6, 4, 59-62.

[12] Gardziejczyk, W., (2016). The effect of time on acoustic durability of low noise pavements – The case studies in Poland. Transportation Research Part D: Transport and Environment, 44, 93-104.

[13] Harold, D., Hetherington, H., & Oliver, J., (2002). Noise induced hearing loss in motorcyclists. Environment Health Protection and Safety Centre, University of Ulster.

[14] Kennedy, J., Carley, M, Walker, I., & Holt, N. (2013). On-road and wind-tunnel measurement of motorcycle helmet noise. Acoustical Society of America, 2004–2010.

[15] Kowalski, P. (2006). Pomiar i ocena drgań w środowisku pracy według nowych przepisów prawa. Bezpieczeństwo Pracy, 24-26, 9.

[16] Liang, S., M., & Wang. C., J. (2011). Experimental and Numerical Study on a Straight Exhaust Pipe. Journal of Mechanics, 27, 4, 597-605.

[17] Makarewicz, R., & Kokowski, P., (2007). Prediction of noise changes due to traffic speed control. Journal of the Acoustical Society of America, 122, 4, 2074-2081.

[18] Młyński, R., Kozłowski, R., & Żera J. (2009). Attenuation of Noise by Motorcycle Safety Helmets. International Journal of Occupational Safety and Ergonomics, 15, 3, 287–293.

[19] Michta, A., Haniszewski, T., (2018). Traffic noise experienced on buses, trams and cars in the urban agglomeration of the city of Katowice. Scientific Journal of Silesian University of Technology. Series Transport, 98, 101-109.

[20] Nader, M., (2016). Drgania i hałas w transporcie. Wybrane zagadnienia. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej

[21] Regulation (EU) No 540/2014; dated 16 April 2014

[22] Regulation of the Minister of Transport No. 51 of August 22, 2013

[23] Sandberg, U., (2002). Noise Emission from Powered Two-Wheeled Vehicles – Position Paper. National Road and Transport Research Institute (VTI).

[24] Skale, S., R., Sharp, B., H., (1974). Control of motorcycle noise volume: technology and cost information. The University of Michigan.

[25] Skanberg, A., & Ohrstrom, E. (2002). Adverse health effects in relation to urban residential soundscapes. Journal of Sound and Vibration, 250, 1, 151–155.

[26] Toivonen, M., Pääkkönen, R., Savolainen, S., & Lehtomäki K. (2002). Noise Attenuation and Proper Insertion of Earplugs into Ear Canals. British Occupational Hygiene Society, 46, 6, 527–530.

[27] Vogiatzis, K., E., (2011). Strategic Environmental Noise Mapping & Action Plans in Athens Ring Road (ATIIKI ODOS) - GREECE. WSEAS Transtactions on Environment and Development, 10, 7, 315-324.

OVERVIEW OF THE TRENDS IN ELECTRIC PROPULSION ON RO-PAX FERRIES IN EUROPE

Roko Glavinović, Ph.D. student
Luka Vukić, Ph.D.
Ivan Peronja, Ph.D.
University of Split, Faculty of Maritime Studies, Ruđera Boškovića 37, 21000 Split, Croatia,
roko.glavinovic@pfst.hr, luka.vukic@pfst.hr, ivan.peronja@pfst.hr

ABSTRACT

Considering the extensive initiatives intended towards sustainable transport development and the latest adoption of the European Green Deal, more shipping companies are investing in alternative propulsion on Ro-Pax ferries. This paper provides an overview of the alternative electric propulsion systems on Ro-Pax ferries indicating the industry's best practices in Europe. A viable model of the electric Ro-Pax ferries has already been utilized in Norway and Denmark exploiting the specific shape of the coastline and adequate, short shipping routes. The application and use of electric propulsion on Ro-Pax ferries correspond to the significant decline in emissions of harmful exhaust gases and particles and overall cost-savings compared to the standard diesel propulsion. Based on the qualitative and quantitative data on specific Ro-Pax electric ferry examples, an overview of the sector trends considering the fundamental characteristics of the route and technology is presented. These components comprise the data on route length, passenger and cargo capacities, battery capacity, charging options, speed of the ferries, and other performance features.

Keywords: Electric propulsion, sustainability, Ro-Pax ferry, Europe

1. INTRODUCTION

Ferry transportation plays a vital role in short sea shipping connecting the coast and islands. With the indented coastline in several European countries, ferry routes and transportation represent a vital line in socio-economic relations. Currently, there are hundreds of Ro-Pax ferries operating in Europe and thousands of other types of vessels. By carrying over 80% of global freight, the maritime industry is burdened with high pollution levels [2]. Marine industry and shipping have a considerable impact on climate change with hazardous gases emissions such as SO_X, NO_X, CO_2, and particulate matter. These emissions directly impact the human health and quality of life in the adjacent areas of vessels operations such as ports. Many incentives are provided by the International Maritime Organization to reduce emissions from the vessels and to promote greener and sustainable shipping. European Union also encouraged limitations in the use of fossil fuels with several directives and legislative decisions which aim to reduce the pollution from vessels. The most contemporary one is the Green Deal promoting drastic changes in the maritime industry and shipping, further introduction of alternative fuels, and sustainable renewable energy sources [15].

The ferry industry is quite significant for the European economy, and most ferries are still using fossil fuels for their propulsion systems, so the optimization of the industry is obliged. It should include renewing the outdated ferries with inadequate propulsion systems emitting substantial quantities of greenhouse gases and building new modern ships [2].

Several initiatives of alternative propulsion systems in Ro-Pax ferries have been realized already, especially in Northern Europe. Denmark and Norway are leading in implementing fully electric ferries into their fleet. Ferries usually operate on short routes connecting islands and the mainland, where the battery-powered electric propulsion implementation is feasible. With the technology innovation, the batteries became more powerful and more durable. Their implementation on short ferry routes is the first step in introducing electric propulsion in the commercial shipping industry [21]. Fully electric ferries charged with an onshore battery facility need enough power from the electrical grid to make charging operations efficient. If the charging station provides electricity generated from renewable sources thus further contributes to the reduction of pollution [32].

Even though the electrification of the ferry's propulsion systems is a big step toward sustainable technologies, issues are emerging from the implementation of e-ferries. Challenges and barriers that need discussion are technical, operational, legislative, and human nature [21, 2].

2. EUROPEAN FERRY MARKET

Maritime ferry transport plays an essential role in the integration and connectivity of the European Union, making it the most suitable passenger and freight transport system on short-sea routes [21]. Although ferry connections are significant for the European Union, their outdated propulsion systems represent a growing threat to the current environmental challenges.

2.1. Current state

In the European Union, the ferries run among ports of the same country or connect two or more European countries. Approximately 58% of the passengers travel by the ferry routes of the same country [3]. Europe is a notably ferry-intensive area due to the specific shape of the coastline and islands [21]. The European coast is 68,000 km long [19] and has around 2,400 islands [22]. The principal regions of the ferry transport routes are the Baltic, Northern Europe, and Mediterranean [21]. The Mediterranean area has the highest number of passengers transported by ferries compared to the other ones (around 450,000 passengers). The Baltic region has the highest share in vehicles regarding ferry transportation (approximately 93,000). More than half of the routes are managed in the Mediterranean area [3].

2.2. Environmental determinations and incentives

Considering the transportation of goods and people, the ferry market in the European Union plays a significant role. The European ferry fleet remained outdated. Most ferries are more than 20 years old [21]. Due to the vessels' age, the modernization of the European ferry fleet is necessary to install sustainable technologies available on the market. It is also important to note that European vessels and ferries do not have adequate specifications to reduce the growing environmental concerns [2]. According to the research by [18], Europe has around 900 ferries for cargo/cars and passengers, while the authors in [3] state that 671 ferries operate in Europe. Additionally, the authors in [3] state that 206 ferries operate in the Baltic area, 121 in the North Sea area, and 344 in the Mediterranean area. Furthermore, Clarksons Research Services Ltd. claims there are 117 Ro-Pax ferries and 3,029 ferries of other types in Europe[1].

Over the past few decades, the concernment regarding the environmental issues associated with the maritime sector and pollutions from the vessels gained significant attention worldwide. Maritime transport emits around 940 million tons of CO_2 annually and is responsible for about 2,5% of global greenhouse gas emissions. Shipping emissions are a cause of around 13% of the overall EU greenhouse gas emission from the transport sector [14]. Fossil fuels are mostly used in ferries. Vessels using fossil fuels generate a range of pollutants such as [31]:

- greenhouse gas emitted by the vessels is carbon dioxide (CO_2), which is one of the main factors associated with global warming,
- sulfur oxide (SO_X) and nitrogen oxide (NO_X) are highly dangerous due to their effects on human health and nature,
- particulate matter (PM) also has a toxic impact on human health.

These emissions have a severe impact on health while ship is in the port. The emission of hazardous gases due to the ferry's operation in the port area is significantly higher compared to other types of vessels [2]. European Commission predicted that the growth of hazardous gases will exceed the total emission due to the fossil fuels being used in the shipping industry by 2030 if no further action is taken [28].

Due to the significant number of vessels operating in Europe, measures are introduced to eliminate hazardous environmental pollution. The shipping industry is moving towards totally eradicating greenhouse gases emissions. Several global and European directives have already been implemented in the past few years to tackle pollution from the maritime industry, especially shipping. International Maritime Organization (IMO) introduced new legislation to reduce CO_2, NO_X, SO_X, and particulate matter pollution within the MARPOL Annex VI on the Prevention of Air pollution from Ships [23]. The New IMO strategy set a target to reduce greenhouse gases emission from international shipping by at least 50% by 2050 with the encouragement to fully decarbonize the industry by the end of the century [10]. The strategy can be realized by the already available methods with short and mid-term measures. Measures include lower speeds of the vessels, improvements in operational efficiency using data analytics, limited use of low-carbon fuels, energy-efficient designs, and other provisions [17]. In 2013, European Commission already implemented a strategy with the principal goal to reduce greenhouse gas emissions from the shipping industry within the three main steps [14]:

- monitoring, reporting, and verification of the CO_2 emissions from vessels using EU ports,
- greenhouse gas reduction targets for the maritime transport sector,
- market-based measures in the medium and long term period.

EU Sulphur Directive 2012/33/EU was introduced in 2015 with the incentive to reduce sulfur emissions from all vessels that operate in the English Channel, Baltic Sea, and North Sea (Figure 1) [21]. In 2019, European Commission presented the European Green Deal, a strategy for the sustainability achievement of the European economy by turning climate and environmental challenges into opportunities in all policy areas and ensuring a fair and inclusive transition. For these goals, the EU plans to make significant investments with more than 260 billion euros [15]. The initiative of implementing the decarbonization process mentioned in the Green Deal requires drastic changes in the maritime industry and shipping, which has to undergo a global transition to alternative fuels and energy sources [17].

[1] Data provided via e-mail correspondence with Clarksons Research Services Limited

Source: [3]

Figure 1: SO_X emission control areas

New technologies in propulsion systems and alternative fuels should become available globally to reduce the carbon footprint of the maritime industry. It needs to incentivize the industry stakeholders to transition to new technologies, propulsion systems, and alternative fuels [10]. European institutions and stakeholders point to the significant role of synergy to fully facilitate the goals set to achieve in the Green Deal. Thus, institutions could not discuss the Green Deal without consultation with the stakeholders or shift to alternative fuels without significant cooperation with the European and governmental institutions. Arguably, stakeholders have to make substantial efforts to implement new technologies and fuels. Many ship owners could face potential issues to finance new technologies in propulsion systems and alternative fuels because of the unpredictability of the necessary infrastructure still being constructed, the availability of alternative fuels in the future, and legislative support. Their motivation for green transition is mainly growing competitiveness due to fuel efficiency and cost-benefit effectiveness, branding, and innovation. The main potential barriers are the installation cost of new equipment, day-to-day cost operations, the complexity of operations, the reliability of new facilities (being installed onboard or onshore/berth - charging station), lack of market incentives, crew and ship safety, and maintenance [21].

3. ELECTRIC FERRY – ALTERNATIVE FUEL MARKET IN EUROPE

Recently, the academic community has focused its research on the technical aspect of the ship system, which should strive to modify the conventional diesel propulsion with more environmentally friendly fuels. The objective is to meet the latest regulations and directives of the European Union and the International Maritime Organization to tackle greenhouse gas emissions from vessels. One of the technologies that have gained increasing attention over the past decade in promoting alternative fuels and environmentally friendly technologies is utilizing electrical energy as the primary source of propulsion on ships. Usage of battery-operated electric propulsion on ferries has become available with the transition to green technology bearing in mind the objective of reducing the emissions from vessels [32]. An alternative electric propulsion system has been adapted for some vessel types. Numerous researchers also studied the effect of applying electric propulsion to commercial, naval, and cruise vessels, which provides more efficient operation at a low speed [1].

The electrical propulsion system has already been in use by some companies which integrated this type of alternative fuel in their ferries [3] while at the same time battling the environmental issues with battery innovations which finally led to designing and building fully electric ferries. Installing the alternative electric propulsion system into ferries is possible by either integrating the electric propulsion completely or combining the diesel-electric propulsion. Compared to the ocean-going vessels, the ferries are potentially more feasible for introducing the electric concept [21] in line with routes determined in advance and relatively short voyages [9]. The experience with electric ferries is precious for the further introduction and development of electric propulsion technology in shipping.

Several Ro-Pax ferries were designed and built with fully electric propulsion, and they have already been in commercial use in the Scandinavian countries. Table 1 shows the fully electric Ro-Pax ferries currently in use in Europe. It also shows the routes of the ferries and the beginning year of operations. The ferries considered in the research were exclusively designed and built for battery-powered electric propulsion and capable of carrying passengers, cargo, and vehicles (Ro-Pax ferries).

Table 1: Fully electric Ro-Pax ferries in the EU

Ro-Pax ferry	Routes operated	Year
Ampere	Lavik-Oppedal (Norway)	2015
Kommandøren	Halhjem – Våge (Norway)	2018
Ellen	Soby - Fynshav (Denmark)	2019
Bastø Electric	Moss – Horten (Norway)	2021
Grotte	Esbjerg – Fanø (Denmark)	2021

Source: [5,6,7,25,27]

The first emission-free Ro-Pax ferry Ampere (Figure 2) was built by a consortium of Ferry Company Norled AS, shipyard Fjellstrand and Siemens [4]. Ampere's route is six kilometers long across the Sognefjord between Lavik and Oppedal. It crosses the distance in 20 minutes, 34 times per day, and operates 365 days a year. Ferry's dimensions are 80 meters long by 20 meters wide. Ampere was constructed in aluminum with two electric engines of a maximum total power of 900 kW. The lithium-ion batteries facility fuels the engine with a total capacity of 1,000 kWh giving the ferry enough energy to make up to two round trips across the Sognefjord. The estimated lifetime of the batteries is ten years [32]. At each dock, Siemens installed a 260-kWh battery plant to recharge the vessel's battery where the ferry can recharge in ten minutes during unloading and boarding operations. Ampere consumes approximately 200 kWh on each crossing [30]. If the electrical energy for charging is obtained from a fossil-free power plant, the ferry runs on fossil-free energy, which is still cheaper than diesel. A diesel-powered ferry of the same capacity and size would consume about 1 million liters of diesel and emit 2,680 tons of CO_2 and 37 tons of NO_X per year [25]. Research has shown that the electric ferry reduces carbon emissions by 95% and costs by 80% compared to oil-powered ferries [24]. Ampere Ro-Pax ferry can take 120 vehicles and 360 passengers and has a maximum speed of 14 knots [30].

Source: [25]

Figure 2: Ferry Ampere

A larger and more advanced version of the e-ferry Ampere is the Kommandøren (Figure 3) fully electric ferry delivered in 2018. The ferry designed and built by Fjellstrand operates the route between Halhjem and Våge in Norway. Compared to the Ampere's voyage, the Kommandøren route is more than two times longer (12.5 kilometers), with a crossing time of 35 minutes and a battery capacity of 2,938 kWh. The annual savings in diesel fuel are estimated at more than 2.5 million liters and a reduction of more than 7,197 tons of CO_2 emission [6]. This ferry is 87.5 meters long and 20.8 wide, and it can carry 120 cars, 12 trucks, and 350 passengers. Like the Ampere, Kommandøren was also built of aluminum with a catamaran hull [20].

Source: [6]

Figure 3: Ferry Kommandøren

The e-ferry Ellen (Figure 4) has been in operation since 2019 crossing the route between Soby and Fynshav in Denmark three to five times a day during weekdays. Ellen was designed to meet the needs for transportation between islands and coastal zones. Dimensions of the vessel are as follows: length 59.4 meters and width 13.4 meters. Ellen is charged up to 3.8 MWh over the night in Soby. In a one-way trip, the Ellen propulsion system needs the energy of 1,400 to 1,700 kWh, depending on various variables such as weather conditions, route length, and the vessel load. The route is 22 nautical miles long (or more than 40 kilometers), which the ferry crosses in two hours. The charging point is harbor Soby where the ferry connects to the charger of 4 MW. Lithium-ion Nickel Manganese Cobalt Oxide (Li-NMC) battery system [11] has a capacity of about 4.3 MWh, and the recharge operation is between 15 to 40 minutes long [12]. The ferry is built from new lightweight materials being different kinds of carbon composites besides the more traditional aluminum lightweight composition of the superstructure, thus allowing the maximum speed of the ferry up to 14.5 knots. Ellen can also operate in ice conditions up to ice thickness of 15 to 20 centimeters. The capacity is 31 cars or five trucks on the open deck, 147 passengers in the winter and 198 passengers in the summer [13]. By introducing fully electric battery-powered e-ferry Ellen, the annual emissions will be lowered by 2,520 tons of CO_2, 14.3 tons of NO_X, 1.5 tons of SO_2, 1.8 tons of CO, and half a ton of particulate matter compared to those of traditional diesel propulsion ferries [29]. The E-ferry project that had the task of designing and building ferry Ellen was an EU-supported development project within the EU's Horizon 2020 program which successfully covered more than 15 million euros of the total costs of about 21.3 million euros [5, 16].

Source: [5]

Figure 4: Ferry Ellen

In 2021, the fully electric ferry Bastø Electric (Figure 5) was delivered to the company Bastø Fosen. The operating route is 10 kilometers long between Moss and Horten, and it takes about 30 minutes to reach another coast [9]. This electric ferry is 139.2 meters long with 21-meter width [27] and can carry 200 cars and 600 passengers [9]. The high voltage charging systems situated both in Moss and Horten have the capability of charging with a power of up to 9,000 kW. The ferry's battery system has a capacity of 4,000 kWh. The predicted reduction of greenhouse gases emissions will be about 80% compared to diesel ferries emissions [26].

Source: [27]

Figure 5: Ferry Bastø Electric

In 2021, Danish company Molslinjen introduced a fully electric ferry Grotte (Figure 6) on the ferry's route between Esbjerg and Fanø in Denmark [8]. The sailing distance is 3.5 kilometers long, which the ferry crosses in 12 minutes [7]. The batteries drive two 375 kW electric motors with an output speed of 11.5 knots. The Grotte recharges the batteries from a dual shore supply facility having 1,250 kW of power each. The charging operations take place in the port of Esbjerg during an eight-minute stay in port. The energy provided is enough for the purely electric round trip [8]. The fully-electric ferry Grotte saves annually more than 800,000 liters of diesel fuel lowering CO_2 emissions by 2,214 tons. It has a capacity of 396 passengers and 35 cars [7].

Source: [7]

Figure 6: Ferry Grotte

4. CHALLENGES OF IMPLEMENTATION OF FULLY ELECTRIC FERRIES

Introducing electric propulsion in the maritime industry and shipping is a significant step in line with the EU transport policy. Some companies have already adopted this form of green and sustainable technology. However, some possible challenges and barriers need additional explanation and research. They include technical, operational, and legislative issues, and they are related to the sailing range covered by the fully electric ferries, charging stations, and electricity, the composition from which the vessels are built [21], and the human factor [2]. Beneficial to the electric ferry's total cost reduction are the electric energy price and charging stations. Charging stations are expected to be implemented in many ports as common infrastructure and thus the application of the economy of scale with further adoption [12]. However, possible port electric energy charging fees are still to be discussed if the e-ferry technology is implemented on a larger scale. The electric energy price issue for the charging of the e-ferries depends on the spot prices of the electricity for each country and electric energy taxes.

4.1. Technical issues

Technical issues emerge from the daily use of the fully electric ferry. The vessel consumes electrical energy stored in the batteries for propulsion and other purposes. The ferry consumption depends on several factors as weather conditions, e.g., wind and currents, speed, load, and possible formation of an ice layer on the sea in harsh cold conditions in Scandinavian countries [2]. With the external effects defined, fully electric ferries are designed and built to have a surplus of energy stored in case of challenging situations that could potentially emerge in day-to-day operations. The technical challenge is the onshore charging stations and the electrical grid, which needs to provide enough power to charge the vessel's battery station in a reasonable time until the next scheduled trip. Preferably, the charging speed should enable the ferry to make a round trip [32] with surplus energy.

Somewhere, filling the batteries in poor conditions, e.g., bad weather, is also a point of concern. [21]. To optimize the sustainability of electric ferries, the electricity from the grid used to charge the onshore battery systems should origin from renewable sources that also provide appropriately more energy than was used to build the ferries [32]. Materials from which the green ferry has been built are also delicate issues bearing in mind that the additional weight requires more power that burdens the batteries. Designing and building ferries with lightweight materials such as aluminum is a good solution for new ferries but limits the possibility of building-in electric propulsion on the existing ones [21].

4.2. Operational issues

The battery technology that enabled the transformation from conventional fuels to green energy is accomplished by using various types of lithium batteries. The materials used to build batteries are available, but their inherent toxicity, the possibility of sudden shortages of starting materials, and limited lifespan depending on the charge cycles are of concern. Another important factor is the battery's energy density, although battery technology has improved over the last few years. Increasing the number of battery units onboard the ferry deems unpractical due to the size and weight issues. Furthermore, efficient transmission charging cable is compulsory to deliver high voltages without problems of overheating either the charging infrastructure or batteries themselves [2]. Operational cost savings derive from notably lower energy costs due to the improved energy efficiency of the fully electric ferry when average energy prices of electricity and bunker fuel are compared [12].

4.3. Legislative issues

The legislative and advisory bodies haven't yet recognized considerable electric energy application in the maritime industry. Present regulations from the International Maritime Organization increases the complexity of the active implementation of electric energy in the maritime and shipping industry [2]. An example is in the case of tax-free hydrocarbon fuels, while electricity, which represents a greener energy source, is taxed. Furthermore, the payback period of electric ferry investment would be much shorter if new legislation gave the electricity the same tax privilege as fossil fuels [21].

5. CONCLUSION

The sustainable development policy in the maritime industry of the European Union and International Maritime Organization and the contemporary Green Deal resulted in the introduction of fully electric battery-powered ferries. It presents a first step in reducing air pollution from vessels in commercial maritime transport. It should be followed by introducing a new propulsion system in the marine industry on a much larger scale. New battery technologies are becoming increasingly popular with the efficient design and affordable price, thus encouraging the ship owners and companies to built-in them into their new builds. However, some potential barriers and challenges have to be addressed before optimizing the electric ferry industry on a larger scale. Barriers discussed in this paper are related to technical, operational, and legislative issues. Also, current innovations limit the ferries only to short route operations. Incentive from the European Commission with the E-ferry project seems successful, and several companies follow it with advanced designs and capabilities of the ferries. Although investments for the electric ferry propulsion are much higher than for the diesel ones, calculations show that the costs are compensated after 5 to 8 years, even including the costs of charging facilities and the potential replacement of batteries [29]. It means that higher investments in fully electric ferries would pay off if the prices of electric energy wouldn't change drastically. Introducing the battery-powered electric ferries, estimated savings in both commercial activity and environmental pollution are growing, thus encouraging enough to promote electric ferries even more. Besides, the electrification of the propulsion systems in the maritime industry is solely one of the ways to tackle environmental pollution from the vessels. Other incentives related to alternative propulsion like hydrogen, biofuels, methanol, and other environmentally friendly alternatives, are also gaining worldly attention. Their advantages and disadvantages need to be further discussed.

REFERENCES

[1] Ammar, N. R., & Seddiek, I. S. (2021). Evaluation of the environmental and economic impacts of electric propulsion systems onboard ships: case study passenger vessel. Springer. https://doi.org/10.1007/s11356-021-13271-4/Published

[2] Anwar, S., Yousuf, M., Zia, I., Rashid, M., Zarazua De Rubens, G., & Enevoldsen, P. (2020). Towards Ferry Electrification in the Maritime Sector. https://doi.org/10.3390/en13246506

[3] Brambilla, M., & Martino, A. (2016). The EU Maritime Transport System: Focus on Ferries. Retrieved January 11, 2022, from https://www.europarl.europa.eu/RegData/etudes/STUD/2016/573423/IPOL_STU(2016)573423_EN.pdf

[4] Case study: Norled AS, MF Ampere, Ferry. (2015). Retrieved February 20, 2022, http://files7.webydo.com/42/421998/UploadedFiles/a4465574-14ff-4689-a033-08ac32adada1.pdf

[5] Cerny, P. (2021). "All aboard!" E-Ferry Ellen and the future of electric shipping | Heinrich Böll Stiftung | Brussels office - European Union. Retrieved January 10, 2022, from https://eu.boell.org/en/2021/07/07/all-aboard-e-ferry-ellen-and-future-electric-shipping

[6] Corvus Energy. (2018). MF Kommandøren - Corvus Energy. Retrieved January 10, 2022, from https://corvusenergy.com/projects/kommandoren/

[7] Corvus energy. (2021). MF Grotte - Corvus Energy. Retrieved January 10, 2022, from https://corvusenergy.com/projects/grotte/

[8] DEIF. (2021). Electric ferry gets off to a great start with DEIF solution. Retrieved January 10, 2022, from https://www.deif.com/marine-offshore/cases/electric-ferry-gets-off-to-a-great-start-with-deif-solution/

[9] DNV. (2021). Charging into tomorrow today - DNV. Retrieved February 16, 2022, from https://www.dnv.com/expert-story/maritime-impact/Charging-into-tomorrow-today.html

[10] ECSA. (2020). A Green Deal for the European shipping industry. Retrieved February 15, 2022, from https://www.ecsa.eu/sites/default/files/publications/2020%20ECSA%20Position%20Paper%20-%20A%20Green%20Deal%20for%20the%20European%20shipping%20industry.pdf

[11] E-ferry Ellen. (2020). Retrieved December 10, 2021, from https://En.Wikipedia.Org/Wiki/E-Ferry_Ellen.

[12] E-Ferry Final Conference. (2020). Retrieved December 10, 2021, from http://www.conf.eferry.eu/

[13] E-ferry - Impact. (2020). Retrieved February 5, 2022, from http://e-ferryproject.eu/Home/Impact#horizontalTab2

[14] European Commission. (2022). Reducing emissions from the shipping sector. Retrieved February 18, 2022, from https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en

[15] European Commission. (2019). Europski zeleni plan. Retrieved February 8, 2022, from https://ec.europa.eu/commission/presscorner/detail/hr/ip_19_6691

[16] European Commission. (2020). E-ferry | Innovation and Networks Executive Agency. Retrieved January 5, 2022, from https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/waterborne/e-ferry

[17] European Parliament. (2020). European Green Deal - Fuel EU Maritime - Sustainable maritime fuels. Retrieved January 5, 2022, from https://www.europarl.europa.eu/legislative-train/api/stages/report/04-2020/theme/a-european-green-deal/file/fuel-eu-maritime

[18] European Sea Ports Organisation. (2007). ESPO Annual Report for 2006—2007. Retrieved February 17, 2022, from https://www.espo.be/media/espopublications/annualreport2007.pdf

[19] Europe's seas and coasts — European Environment Agency. (2022). Retrieved February 8, 2022, from https://www.eea.europa.eu/themes/water/europes-seas-and-coasts

[20] Fjellstrand. (2018). Fjellstrand AS - New ferry "Kommandøren" delivered. Fjellstrand. Retrieved January 8, 2022, from https://www.fjellstrand.no/index.php/home/news-media/193-new-ferry-kommandoren-delivered

[21] Gagatsi, E., Estrup, T., & Halatsis, A. (2016). Exploring the Potentials of Electrical Waterborne Transport in Europe: The E-ferry Concept. Transportation Research Procedia, 14, 1571–1580. https://doi.org/10.1016/J.TRPRO.2016.05.122

[22] Haase, D., & Maier, A. (2021). Executive summary - Policy Department for Structural and Cohesion Policies Directorate - General for Internal Policies. Retrieved January 8, 2022, from https://www.europarl.europa.eu/RegData/etudes/STUD/2021/652239/IPOL_STU(2021)652239_EN.pdf

[23] IMO, Prevention of Air Pollution from Ships. (2021). Retrieved February 18, 2022, from https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx

[24] Lambert, F. (2018). All-electric ferry cuts emission by 95% and costs by 80%, brings in 53 additional orders, Elektrek, Feb 3rd, 2018, https://electrek.co/author/fredericclambert/

[25] Mikkola, N., Randall, L., & Hagberg, A. (2016). Green growth in nordic regions. Retrieved February 1, 2022, from http://norden.diva-portal.org/smash/get/diva2:957463/FULLTEXT01.pdf

[26] Norwegian ship design. (2020). The world's largest electric ferry delivered — The Norwegian Ship Design Company. Retrieved February 3, 2022, from https://www.norwegianshipdesign.no/archive/basto-electric-has-been-delivered

[27] Randall, C. (2021). World's largest electric ferry launches in Norway - electrive.com. Retrieved February 19, 2022, from https://www.electrive.com/2021/03/02/worlds-largest-electric-ferry-yet-goes-into-service-in-norway/

[28] Register of Commission Documents – SEC 1133. (2005). Retrieved February 17, 2022, from https://ec.europa.eu/transparency/documents-register/detail?ref=SEC(2005)1133&lang=en

[29] The e-ferry Ellen information package. (2020). Retrieved December 2, 2021, from http://www.conf.eferry.eu/InfoPackage/eFerry_Information_Package.pdf

[30] The Explorer. (2016). The world's first electric car and passenger ferry - The Explorer. Retrieved February 2, 2022, from https://www.theexplorer.no/solutions/ampere--the-worlds-first-electric-car-and-passenger-ferry/

[31] Vidas, S., Cukrov, M., Šutalo, V., & Rudan, S. (2021). CO2 Emissions Reduction Measures for RO-RO Vessels on Non-Profitable Coastal Liner Passenger Transport. Sustainability, 13(12), 6909. https://doi.org/10.3390/su13126909

[32] Vukić, L., Guidi, G., Jugović, T. P., & Oblak, R. (2021). Comparison of External Costs of Diesel, LNG, and Electric Drive on a Ro-Ro Ferry Route. Promet - Traffic&Transportation, 33(3), 463–477. https://doi.org/10.7307/PTT.V33I3.3690

INTERMODAL TRANSPORT INDICATORS FOR SELECTION OF TRANSPORT CARRIERS

Marko Golnar, B.Sc.
Bojan Beškovnik, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, Portorož, Slovenia
marko.golnar@fpp.uni-lj.si, bojan.beskovnik@fpp.uni-lj.si

ABSTRACT

With the globalization of production in recent decades and the growing environmental pressure from EU legal obligations to reduce emissions from transport, intermodal transport chains are becoming increasingly complex. Given the commercial and regulatory conditions which directly or indirectly affect their efficiency; competitiveness is measured by a wider range of indicators of successful transport chain operation. The in-depth literature review examines the most common indicators that describe the competitiveness of the individual operator's selected transport chain. Knowledge of the indicators enables more efficient comparison processes of intermodal transport chains and at the same time sheds light on the different priorities in the selection of indicators from the perspective of freight owners and transport or logistics company organizers. The case study with the selected set of criteria has been made presenting two ways of transporting a container on the maritime silk road and land silk road to central Europe destination. In addition to the traditional elements of price and time, they also include environmental and sustainable elements, which are more difficult to identify and elaborate in the complex intermodal chain.

Keywords: supply chain, green, intermodal transport, indicators

1. INTRODUCTION

Transport and logistics processes must follow the sustainable development of the economy. This goal must be pursued by all stakeholders along with transport and logistics chains. This is particularly evident in the operation of complex intermodal chains, bringing together stakeholders from different transport sectors and cargo owners from different parts of the world. Regardless of the decisions in the formation of transport chains, the transport activity will continue to generate negative effects on the environment, namely the growth of greenhouse gas emissions, rising temperatures and changes in weather phenomena. According to a report on international freight (OECD, 2016) greenhouse gas emissions from transport are expected to increase by as much as 60% by 2050 unless appropriate measures are taken to limit emissions, as world trade is expected to triple over the same period.

Governments around the world are working to adopt new regulations to limit the negative effects of transport. Internationally harmonized protocols and commitments are being adopted. In the Paris Agreement in 2015 (COP, 2016) has been “revealed” that shipping hasn’t been included in global efforts on minimizing emissions in any other international climate agreement before. Consequently, International Maritime Organization (IMO) has committed itself to reduce emissions from international shipping by at least 50% by 2050 with the year 2008 representing a reference year. The European Union seeks to limit emissions from transport and logistics, but most often measures are considered separately by transport industry and very rarely from the user’s point of view. The countries of European Union have a common commitment to reduce the GHG by 60-80% by 2050, depending on the 1990 emissions situation (European commission, 2016).

With all the pressures from the economical perspective of globalization of supply chain to regionalization and environmentalization of intermodal transport, the chain becomes harder to design (complicated). Most of the time, intermodal transport chain optimization is assigned either to find the optimal transport route and modes based on the customer’s demand or to find the right transport time slots to gain some financial advantages. Consequently, the decision-making process of shippers is mostly reliant on two aforementioned criteria consisting of several components. Consequently, demands for cargo transport have risen significantly in spite of meeting the requirements of customers. The container transport industry cannot meet today’s global intermodal transport chain management when using only one transport mode. Thus multimodal transport has become widely recognized for creating an efficient and convenient transport with optimization problems waiting to be resolved.

Green transport corridors can be an appropriate solution in ensuring sustainable transport and efficient operation of intermodal transport chains. In addition to green operation, such corridors are also a safer and more productive solution to individual solutions developed by individual logistics companies. Green transport corridors promote multimodality in the pre-coordinated construction of infrastructure elements and communication protocols and the adopted regulations (Batarliene et.al., 2016; Hunke K. & Prause G., 2013; Prause G. & Hunke K., 2014; Hunke K., & Prause G., 2014). Concepts of green transport corridors were politically defined, consequently, some different implementations were performed such as the, Baltic Sea Region (BSR), the EWTC - East-West Transport Corridor connecting the southern Baltic with the Black Sea, was established; Scandria, which connects Scandinavia and the Adriatic, RBGC-Rail Baltica Growth Corridor connecting the countries of the Baltic Peninsula with the Central Railway System; NECL North East Cargo Link-Nordic green transport corridor between Norway, Sweden, Finland, and Russia. (Golnar & Beškovnik, 2020).

In addition to national or European regulations, decision-making patterns of decision-makers in the organization of intermodal transport need to be encouraged. It is necessary to pursue the most standardized approaches in the design of multimodal transport and, above all, the evaluation of it. In this way, comparability of performance and appropriate ranking of already established multimodal transport can be achieved.

On the basis of summarizing the relevant literature in the field of the mentioned corridors, numerous studies were carried out on how to green the corridors, which differed from each other as they addressed the problem from different aspects (powertrains, fuels, transshipment machinery, vehicles, navigation technologies). Nevertheless, in all studies, they formulated common goals such as co-modality, efficient transshipment infrastructure, innovative transport units and vehicles, and innovative Information and Communication Technologies.

On the basis of summarizing the relevant literature, the article takes further research and study on the defining the relevant factors when making a decision-making a decision with which intermodal transport chain goods will be shipped. The comparison of the values of individual factors of intermodal transport is performed on a case study of container transport from Asia to Central Europe. The results of the study emphasize the need to design and unify indicators that would equally include environmental components in the evaluation and selection of intermodal transport.

2. LITERATURE REVIEW

In the literature, the first articles with various principles of "greening" of individual operations or types of transport and methodology began to appear in the late 90s at the turn of the new millennium. Due to the nature of the field in question, the review of the existing literature revealed the fragmentation of research into individual subsystems of the transport chain. Thus, for example, in maritime transport, research is focused primarily on the field of minimizing the cost of transport and transport emissions, by adapting or determining the optimal sailing speed, where Wang and Xu (2015) and Norlund et al. (2015) discussed the possibilities of using the Mixed Integer Linear Programming model as a tool to minimize costs. It is important to note that the reduction in the ship's speed is mainly due to economic reasons (lower fuel consumption, oversupply of cargo capacity) and not so much for environmental reasons as competitive advantages, but from the point of view of regulatory measures entering emission zones. emission control area). In road transport, research is mostly focused on solving the classic logistics problem by modelling emissions and finding minimum emission routes. Thus, Darvish et al. (2019) found with the help of extended models that it is an important factor in reducing emissions: reducing empty runs, transporting lighter loads, and the balance between vehicle load and transport distance. Calculation of simulations verifies that in order to minimize emissions not only the distance travelled but also the load on the vehicle must be taken into account. Some studies have focused on reducing greenhouse gases emissions with optimizing vehicle routing. Depending on how many factors are being optimized literature uses simple vehicle routing problem (VRP) as Braekers et al. (2015) used in the study or complicated where Bektas and Laporte (2011) used more factors such as speed, vehicle load and travel costs which have been simulated with Pollution Routing Probem (PRP). Compared to road transport, rail transport is more "green", but it does not reach full utilization due to technical and administrative barriers. Thus, Aditjandra et al. (2016) in her work highlights the main areas towards the development of green rail transport. Although a fairly large part of the literature is devoted to rail transport planning, there are not many studies that would address environmental aspects. Bauer et al. (2010) in the study focuses on the design of the railway service within the broader operation of intermodal transport, where environmental costs are already included in the planning of the service and a computer algorithm for minimizing emissions is presented as a solution. The algorithm was later further developed by Qu et al. (2016) in a study to design a network model of intermodal transport. In the research, we also encountered different models where we found study of Wang et al. (2011) where they optimize two criteria in the whole transport chain or Mallidis et al. (2010) where they minimize CO_2 emissions and costs when planning supply chains. We also found a study by Quariguasi Frota Neto et al. (2009) that look for the right relationship between profit and the environment. Furthermore, studies have been published that focus on effective freight transport planning where modeling and optimizing, two aspects: price and environment were considered in the study by Demir et al., (2019). Based on a review of the scientific literature, it can be concluded that future development should be to develop an algorithm which would consider price, environment and profitability. Moreover, as can be observed there is a great fragmentation of research and consequently the lack of comprehensive organization and clear standardized structure in the operation of intermodal transport chains and an approach that would provide transparent information for users.

3. MATERIALS AND METHODS

The research is based on identifying the key-criteria when organizing and implementing the intermodal transport chain in sustainable way. Therefore, research is based on the following research questions:

- What should be the key criteria for end-users in the decision-making process choosing intermodal transport chain?
- What is the role of rail intermodal transport chain on land Silk road from operational and environmental perspective?

The analysis is considering destinations of main hinterland Asia to Europe; from loading port Shanghai (China) through Port of Koper to Budapest (Hungary) that are not so often used in the research but represent important business point in central Europe. Consequently, two services with various transport modes (Rail vs. Maritime+rail) are analyzed from different perspectives considering previously defined indicators. For the origin of all trips have been chosen Shanghai (China) which represent market with a lot of industry which is producing semi-finished products and finished products-components for other products manufactured in Europe. In addition to that China market is qualified with preferential customs duty on imports. Preferential tariff measures derive from agreements concluded by the EU with certain countries or groups of countries or are unilaterally adopted by some countries. When designing an intermodal transport chain it is deemed that the most efficient and biggest ships will be utilized by comparing two direct services from China to Port of Koper and continuing with rail transport.

The criteria for evaluating intermodal transport chains were obtained from the literature review; some of the criteria were provided and studied in previous studies. In this study, the nine important criteria have been chosen as cost (C1), transport time (C2), pollution-GHG as CO_2 (C3), energy consumption (C4), Reliability (C5), reduction in fuel consumption (C6), equipment availability (C7), distance (C8) and the ratio of all transport modes used in transport chain (C9). Presented criteria could have a detrimental impact on the evaluation and selection process of the “right” intermodal transport chain. The **cost** criteria is one of the easiest to obtain and is directly dependent on another factor which involves route and operational time of individual transport time. **Transport time** as criteria differentiate transport carriers on efficient an inefficient. For the buyers of transport services information on the longevity of transport is crucial information for planning subsequent operations. The transport time also depends on the negotiating skills of the transport organizer to obtain the best time slot for transporting. **Pollution** or green issues when purchasing transport services is becoming tremendously important. Shippers nowadays during decision-making process express green demands in requesting proposals and in negotiations phase. Though the green criteria is by importance still after traditional cost and transport time which occupy the shippers priorities when selecting transport service. In addition to that, the demand for green practices from buyers seems to be uneven. That means that shippers request green practices in requesting proposal but they don’t follow them later in the execution phase. Nevertheless, logistic service providers became self-initiated with providing green services and modified operating practices. **Energy consumption** is indirectly connected with green criteria of transport provider and it represents how efficient means of transport are used. **Reliability** in the traditional transport operations and their estimation of time of arrival COVID-19 introduced major change in leading times mostly because all of the transport chain has broken. It opened a new way of conducting business, where reliability is much lower than pre pandemic periods. Reliability presents important information for transport chain operator to organize timely all of the means of transport. **Reduction in fuel consumption** can be achieved through different measures. Most effective without and financial input is speed reduction which has been widely used in maritime sector. Other measures for reducing fuel consumption is connected with technical solutions as exhaust gas recirculation. **Equipment availability** represents transport service providers’ ability to provide enough empty containers to fulfil buyers ‘needs. **The ratio of all transport modes used in transport chain** is a measure to show how much each of transport mode in intermodal transport chain is used. It is good criterion to asses which transport leg is contributing the most to the overall cost, time and environmental performance.

3.1. Case study

Based on the defined indicators, a study of their influences in the choice of intermodal transport route was performed. As it is difficult for logistics companies to evaluate a large set of indicators, the set was narrowed down to five key indicators that best summarize the interdependence between indicators.

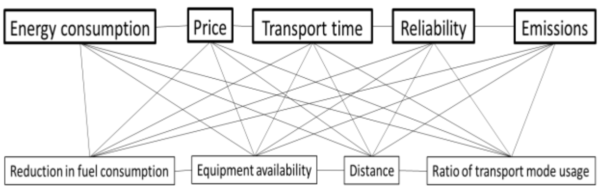


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Figure 1: Interconnectivity among the most important decision criteria.

In the case-study two intermodal transport chains from Shanghai (China) to Budapest (Hungary) were analyzed. The first intermodal transport chain relies on the shipping of a 40’ container on the Shanghai direct line to Koper and the continued use of rail transport from Koper to the intermodal terminal in Budapest.

The second intermodal transport chain is implemented using only rail transport from Shanghai via Xi'An Alashankou-Dostyk terminals and Batyev/Eperjeska on the Hungarian-Ukrainian border. In the process of forming train set and limit of it, the 40' container weighing up to 23 tons are mainly used for the transport. To compare the parameters of intermodal chains, the following parameters are used: sea and rail prices valid for March and April 2022, the average transport time of different transport carriers and the service reliability of the first quarter of 2022.

At the calculation of environmental data, the following input variables are used: 40' container (2 TEU) with 12 tons gross weight, container ships with a capacity of over 14.500 TEU (ULCV-Ultra large container vessel) and 20 % reduced voyage speed and 90% occupancy of the ship's cargo. For the calculation of rail emissions parameters for 1.000t container train was chosen while for the electricity used by such a train we chose a class EU UIC 1. Considering the load factor a full capacity of 100% was chosen with 0% of empty trip. All environmental calculations from transport activities and energy efficiency of the intermodal chain have been carried out with EcoTransIT World calculator (EcoTransIT), although there are also other environmental calculators on the market (NTMCalc, DHL Carbon calculator). The basis for the calculation of emissions in EcoTransIT calculator is standard guideline EN 16528 (Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services, 2012), which gives a very good foundation for transport industries evaluating their emissions.

Table 1: Comparison of parameters between Shanghai-Budapest intermodal transport chains

Source: own source

Shanghai-Budapest	SEA& RAIL	ALL RAIL
Price [USD]	15.300	11.500
Travel time [Day]	35 (32-38)	19 (17-22)
Reliability	Extremely low	High
Energy consumption [MJ]	28118	66885
GHG emissions as CO2e [T]	1.96	4.15

The analysis of the price parameter shows a significantly higher transport price of the first intermodal chain using maritime transport. The FOB (Free On Board) price of transportation in March and April 2022 is about 15.300$.

The transport time if the space on the container ship is acquired in time is about 35 days, but the reliability of transport is extremely low. According to Sea-Intelligence (2022), ship-owners on direct container connections from Asia to Europe achieved between 30% and 40% reliability of transport accuracy. In Shanghai, however, there are also huge problems with reaching empty containers and gaining space on ships. Thus, transport reliability is marked as very low (Table 1).

The intermodal transport chain by land and rail is 25% cheaper, with a transport price of 11.500 USD for a 40' container. Travel time is between 17 and 22 days, which is 45% shorter travel time. The availability of containers and the availability of space on trains is high, as logistics companies in the 1st quarter of 2022 did not have major problems with shipments.

Further comparison (figure 1) shows that intermodal transport on the Silk Road by rail emits more emissions per container and uses more energy than intermodal transport chain on the Maritime Silk Road in combination with maritime and rail. Such a difference could be possible because ULVC can carry a lot of containers and consequently yields smaller emission rates per container than rail with train set.

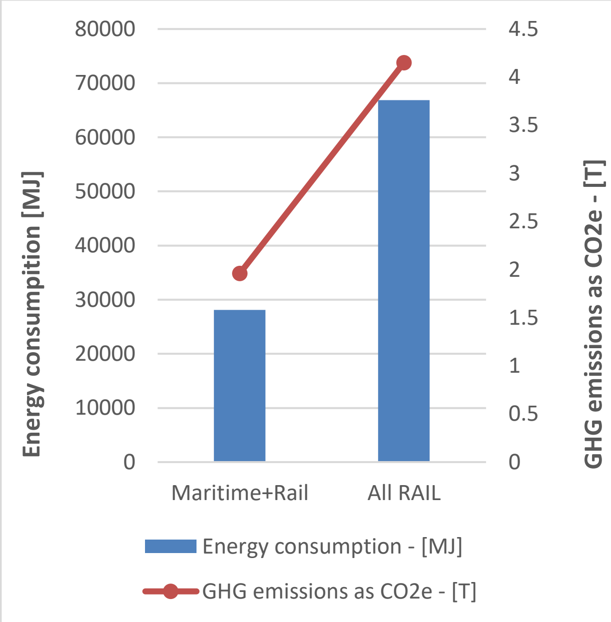

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Figure 2: Comparison of energy consumption and GHG emissions for Maritime+rail and all rail

4. CONCLUSION

Intermodal transport chains are changing a lot. The current situation on the market is such that it is extremely difficult to get shipping space, and at the same time, space on the railway is available immediately. Due to the current geopolitical and COVID-19 situation, market prices have risen several times. In the current situation, the railway is more favourable because of shorter transport time and at the moment more reliable transport space, although their energy efficiency and greenhouse gas emissions are worser in comparison to maritime transport. Nevertheless, maritime transport could become more competitive if ship-owners manage to provide sufficient cargo space and at the same time reduce the price and install cleaner powertrains, which in turn would improve energy efficiency. It follows from the described situation that frequent multi-criteria evaluation of intermodal transport chains is necessary as market conditions are changing and we can still evaluate a non-competitive intermodal transport chain as competitive tomorrow. It follows from the described issues that in the future it will be necessary to dedicate a study that will deal more precisely with the evaluation on the intermodal transport chain.

REFERENCES

[1] Aditjandra PT., Zunder TH., Islam DMZ., Palacin R., (2016) Green Rail Transportation: Improving Rail Freight to Support Green Corridors. In: Psaraftis HN (ed) Green Transportation Logistics: The Quest for Win-Win Solutions. Springer International Publishing, Cham, pp 413–454

[2] Batarlienė N., & Jarašūnienė A., (2016) Development of Advanced Technologies (AT) in Green Transport Corridors. Procedia Engineering 134:481–489

[3] Bauer J., Bektaş T., Crainic TG., (2010) Minimizing greenhouse gas emissions in intermodal freight transport: an application to rail service design. Journal of the Operational Research Society 61:530–542

[4] Bektaş T., & Laporte G., (2011) The Pollution-Routing Problem. Transportation Research Part B: Methodological 45:1232–1250

[5] COP 2016, Conference of Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015, United Nations 2016

[6] Darvish M., Archetti C., Coelho LC., (2019) Trade-offs between environmental and economic performance in production and inventory-routing problems. International Journal of Production Economics 217:269–280

[7] Demir E., Hrušovský M., Jammernegg W., Van Woensel T., (2019) Green intermodal freight transportation: bi-objective modelling and analysis. International Journal of Production Research 57:6162–6180

[8] EcoTransIT World. https://www.ecotransit.org/.

[9] EN 16258:2012 Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).

[10] Golnar, M., & Beškovnik, B., (2020). Comparison of environmental pollution of land transport modes in green suppy chains through port of Koper, International conference on transport science 2020: 91-97

[11] Hunke K., & Prause G., (2013) Management of Green Corridor Performance. Transport and Telecommunication Journal 14:292–299

[12] Hunke K., Prause G., (2014) Sustainable supply chain management in german automotive industry: experiences and success factors. JSSI 3:15–22

[13] Mallidis I., Vlachos D., Dekker R., (2010) Greening Supply Chains: Impact on Cost and Design. Erasmus University Rotterdam, Econometric Institute, Econometric Institute Report

[14] Norlund EK., Gribkovskaia I., Laporte G., (2015) Supply vessel planning under cost, environment and robustness considerations. Omega 57:271–281

[15] OECD (2017) International freight. ITF Transport Outlook 2017. European commission

[16] Prause G., & Hunke K., (2014) Sustainable entrepreneurship along green corridor. JESI 1:124–133

[17] Report of European strategy for low-emission mobility (2016) European commission

[18] Quariguasi Frota Neto J., Walther G., Bloemhof J., van Nunen JAEE, Spengler T (2009) A methodology for assessing eco-efficiency in logistics networks. European Journal of Operational Research 193:670–682

[19] Qu Y., Bektaş T., Bennell J., (2016) Sustainability SI: Multimode Multicommodity Network Design Model for Intermodal Freight Transportation with Transfer and Emission Costs. Netw Spat Econ 16:303–329

[20] Wang F., Lai X., Shi N., (2011) A multi-objective optimization for green supply chain network design. Decision Support Systems 51:262–269

[21] Wang C., & Xu C., (2015) Sailing speed optimization in voyage chartering ship considering different carbon emissions taxation. Computers & Industrial Engineering 89:108–115

ON THE SIMPLIFIED MATHEMATICAL MODELS FOR OIL SPILL SIMULATIONS

(INVITED SESSION PAPER)

Aleksander Grm
Marko Perkovič
University of Ljubljana, Faculty of Maritime Technology and Transport
Pot pomorščakov 4, Portorož, Slovenia
aleksander.grm@fpp.uni-lj.si, marko.perkovic@fpp.uni-lj.si

Dinu Atodiresei
Andrei Pocora
Naval Academy Mircea cel Batran Constanta, Romania
dinu.atodiresei@anmb.ro, andrei.pocora@anmb.ro

ABSTRACT

The most principal issues today are the environment, green energy and food. One branch is also Blue Seas, the protection of the marine environment. UL-FPP is linked to the Blue for Seas (B4S) project, which deals with oil pollution in the oceans and where we are looking at all possible aspects to protect the marine environment. One of the topics is also oil pollution simulations. This article presents some models that can quickly calculate oil spills' dynamics. If simulation needs to be fast, preferably in real-time, you need a simplified model. How much to simplify the model is an open dilemma. Most important is the ability of the model to predict the motion almost correctly under basic parameters. The word "almost correct" here means a balance between speed and accuracy. The simplest model is the diffusion equation solution for the source type with simple advection coupling. In addition to describing the simplified models, some examples of source diffusion models with simplified advection are also presented.

Keywords: Oil pollution, Numerical simulations, Advection-diffusion equations, Model approximations, B4S

1. INTRODUCTION

A severe accident could have catastrophic effects on the fragile environment, the natural resources of the enclosed seas, and their important uses, such as for tourism and local fisheries. Environmental hazards in the marine environment can arise from a variety of natural and anthropogenic sources. One of the biggest sources of danger, which has been a problem for decades, is oil. As oil pollution can have multiple environmental and socio-economic impacts, the risk of oil pollution from human activities needs to be minimised. The main sources of oil pollution in marine waters are natural seepage, industrial and urban runoff from land, offshore extraction and shipping. On average, 1,250,000 tonnes of oil from the sea enter the marine environment annually GESAMP, 2007. Another source of oil pollution is leaking shipwrecks. The number of shipwrecks (non-tankers of at least 400 GRT and tankers of at least 150 GRT) in global marine waters is estimated at > 8600, and some of these wrecks still contain significant amounts of oil. However, many other sources of low-level pollution are of concern, including leakage from wrecks, fishing activities, operational discharges, and low-level leaks of lubricants (like damaged stern tube seal). The amount of petroleum products in the wrecks is estimated at 2.5-20.4 million tonnes [1,2]. On the other hand, operational pollution from seagoing vessels includes various types of discharges of oil and oily mixtures, including chemicals, resulting from routine daily operations. A calculated amount of illegally discharged oil in the Adriatic Sea per year would be about 3,000 m^3 annually [3].

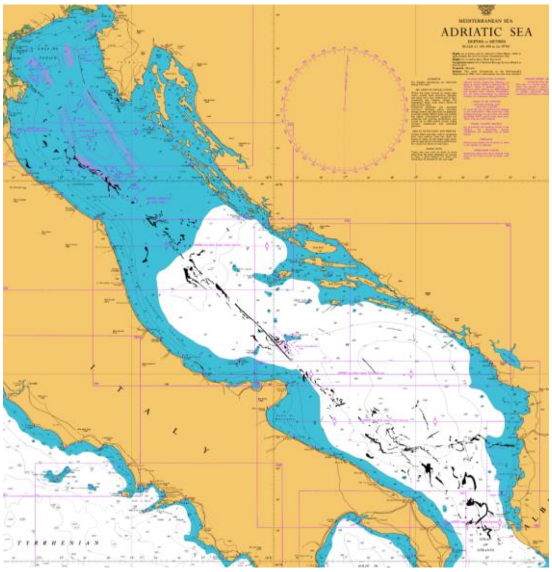


Figure 1: Probable oil spills in the Adriatic Sea [3]

In general, oil spills can be divided into large (macro) and small (micro) spills. Large oil spills from marine disasters and offshore oil drilling affect biota differently than small but frequent discharges from shipping and urban/industrial runoff. Impacts can range from acutely toxic to sublethal. Large oil spills, for example, can cause narcotic effects, oxygen depletion, obstruction of the transmission of sunlight to the water and hypothermia of seabirds. In addition to acute effects, they can also have long-term consequences for marine ecosystems. Unlike large oil spills, small oil spills usually only lead to chronic and long-term impacts. Therefore, both large and small oil spills can be of ecological importance [2].

Risk is usually defined as a combination of the probability of a negative event, its consequences and the uncertainty associated with both. In the context of oil spill risk assessment, it can be expressed as a combination of the probability of a particular pollution event occurring and the magnitude of the consequences of that pollution. Both the probability and the consequences of an oil spill are subject to a degree of uncertainty, which leads to uncertainty in the final risk value of an oil spill.

The probability of an oil spill scenario is usually estimated from historical data and/or expert surveys. In the case of a sunken vessel, the oil spill is assumed to be caused by activities that may damage the wreck. The wreck and the site-specific conditions have an influence on the degree of impact of the hazardous activities. In addition, the wreck must still contain oil. Taking these uncertain factors into account, a PDF can be derived to describe the uncertainty of the probability of an oil spill. The uncertainty of the consequences/impacts of oil spills can be quantified through simulations. Trajectory models can be used to predict the behavior of oil in the environment and the relative spatial and temporal extent of the potential consequences.

The circumstances of an oil spill, such as the source, the cause, the type of oil, the amount and speed of the spill, the location of the spill, and the time of year in which the spill occurs are examples of factors that influence the impact of an oil spill. To account for the uncertainties of these factors, the calculation of impacts should be based on trajectory modeling of the expected total of a wide range of accident scenarios [2].

The research presented in the current discussion deals with the comparison between a professional oil spill simulation tool PISCES II (Potential Incident Simulation, Control and Evaluation System) [4], and a simple advection-diffusion model.

As we will see, one of the main effects is hidden in the diffusion and advection of the oil spill. The comparison shows that the advection in the simple model is exaggerated because it does not consider the shear force exerted on the oil slick by the forced flow of the surrounding fluid.

2. MODEL

A fully developed oil model should consider changes that occur to oil as it spends time in the environment. Main weathering processes are spreading, evaporation, dispersion, emulsification, viscosity variations, combustion, and shore interactions. Additional factors such as shoreline description, current field representation, water temperature, wind speed, and directions, and finally oil properties should be considered in the modeling.

The PISCES model uses a Lagrangian approach to describe the oil slick, i.e., the oil is represented by an ensemble of particles moving independently under the influence of wind and current. The trajectories of the oil particles are two-dimensional and are calculated by a two-dimensional flow field.

It is assumed that the particles have the same properties and do not interact with each other. The water parameters and weather conditions are the same for the entire oil spill. These parameters are used to simulate the weathering processes.

The flow field is determined using constant basis vectors with a specific rate of change over time. The flow velocity at a given point is calculated by interpolating the basis vectors and considering the sliding resistance of the shoreline. Delaunay triangulation is used for the above procedure.

At the beginning, one should determine the information about the source of the oil slick: Time, location, quantity and type of oil slick such as:

- Point source – with given mass and position of the oil slick
- Area source – with specified mass, position and area of the oil spill
- Source of the oil spill – where the amount of spilled oil depending on the position and time is specified.

In this part, we focus only on the comparison of oil dispersion between the models PISCES and FE. The theoretical background of the advection-diffusion problem in oil spill modeling is based on the solution of a one-dimensional advection-diffusion equation in a plane

$$\frac{\partial u}{\partial t} + \boldsymbol{v} \cdot \nabla u = \frac{1}{Pe} \Delta u, \quad \text{in } \Omega \tag{1}$$

where u is the height of the oil spill, $\boldsymbol{v}$ is the velocity vector field in the plane, Pe is a dimensionless number and $\Omega$is a computational domain in our case $\mathbb{R}^2 \times \mathbb{R}^+$ To solve (1) we need to specify the initial and boundary conditions

$$\begin{aligned} u &= u_0, \quad \text{in } \Omega \\ u &= u_D, \quad \text{on } \partial\Omega \end{aligned} \tag{2}$$

Initial condition in (2) is defined with a bump function

$$\Psi(x) = \begin{cases} exp\left(-\frac{1}{a^2 - x \cdot x}\right), & x \in [-a, a]^2 \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

The characteristic of the bump function is that its value is positive inside the region bounded by the radius *a*, and zero otherwise. Boundary condition is of Dirichlet type and is initially set to zero.

System (1)-(2) is solved with FE (Finite Element) method, where the stabilization of advection nature of Eq. (1) is stabilized by SUPG method [5]. Implementation of the problem was realized in Fenics/Dolfin FEM environment [6].

The results of the solution FEM are compared with the software Spill Management Simulator PISCES II This software was originally developed by Transas Marine as an exercise management tool for the U.S. Coast Guard. Today, PISCES II is used to train students and professionals on how to respond to major oil spills and minimize the impact on the environment and local economies.

It's also used to test and/or develop appropriate response plans and improve teamwork and decision-making.

3. RESULTS

Using a PISCES II software we have first simulated a point-source spill (at 45° 31'N latitude and 013° 32'E longitude) of 100 m^3 of fuel oil (IFO 180) with a viscosity of 180 cSt, the surface tension of 30.7 dyn/cm (mN/m), and a density of 967.9 kg/m^3 (14.7 API). The oil pour point is -10 °C and the oil flashpoint is 91 °C.

The sea temperature was 15 °C and the air temperature 20 °C, without waves, the density of the sea was 1027 kg/m^3 and 5 tenths of clouds.

Two scenarios were analyzed and compared. In the first case, only the wind is used for the movement of the oil slick, and in the second case, only the current is used for the movement of the oil slick.

Wind external force

The wind blows from the direction 315°, with a speed of 10 m/s. Fig. 1 and 2 show the results from PISCES and FEM for a time interval of 1 hour.

The first difference when comparing the results in Fig. 2 and Fig. 3 is the length of the overflow path, which is related to the advection term in (1). In the case of PISCES, it's about 4700 m and in the case of FEM, it's 33500 m. It's obvious that the solution of FEM doesn't take into account the stress and friction forces between the oil slick and the air/water surface. The introduction of an empirical shear force friction coefficient or some kind of transport coefficient would improve the results of FEM.

The comparison of the final shapes shows some differences, which are probably also due to the different stress/friction coefficients.

The diffusion in (1) is associated with the Peclet number *Pe*. In all simulation cases it was set to 100. The results of PISCES and FEM for the diffusion are shown in Figs. 2 and 4.

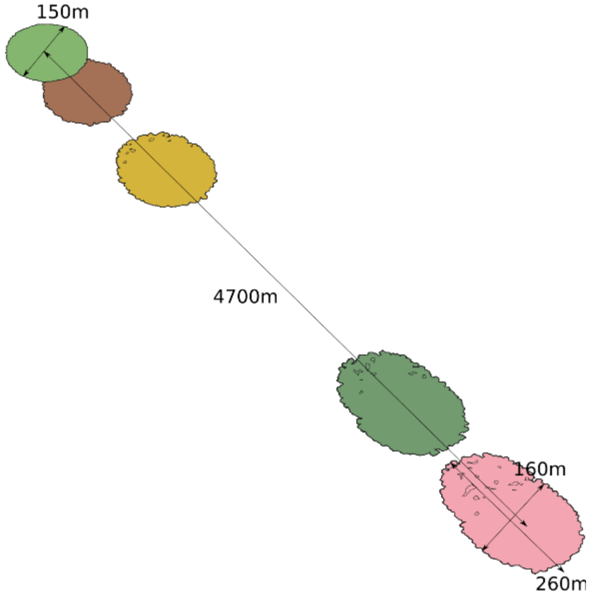


Figure 2: PISCES solution of wind forced oil spill motion

The differences in the size of the oil slick also show the effect of non-constant diffusion in the model PISCES. A constant diffusion coefficient as in the model FE (1) clearly doesn't do justice to the real conditions.

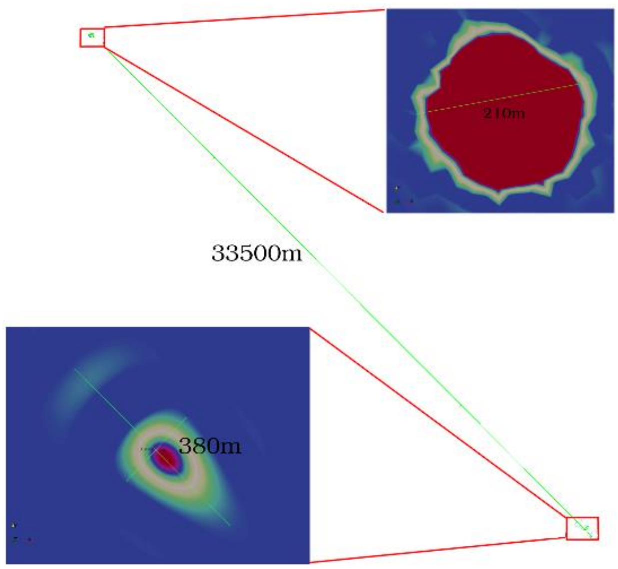


Figure 3: FEMS solution of wind forced oil spill motion

Current external force

The current flow acts in direction 135° with a speed of 0.2 m/s in a time window of 3 hours. The results are similar to the wind-driven situation.

In this case, the diffusion is very isotropic, probably due to the small advection velocity term. Nevertheless, the growth of the silk area can be observed well.

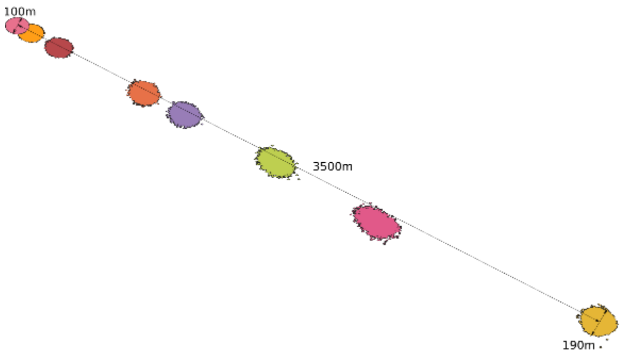


Figure 4: PISCES solution of current-driven oil spill motion.

The spread of the slick in conjunction with the change in thickness of the stain over time is shown in the figure below (Fig. 5). Note that other processes such as dissolution of the slick in the water column, emulsification, and even evaporation are virtually absent during the first few hours. When viscous fuel is spilled, it evaporates barely 0.1 percent of its mass in three hours.

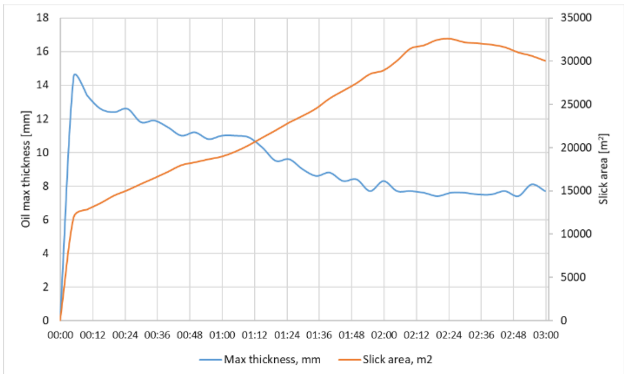


Figure 5: PISCES solution of current-driven oil spill motion

4. DISCUSSION AND CONCLUSIONS

This paper compares the movement of the oil spill between two different mathematical models. In the first model of the linear advection-diffusion model, the solution is calculated using the FEM approach. It clearly shows all the basic motion phenomena, but lacks the complexity of the coupling between the external force, friction and the oil slick, which is probably introduced by the transport coefficient. Also the diffusion doesn't seem to be constant, probably a non-linear relationship, when comparing the results of FEM and PISCES. PISCES is known as a good simulation tool for oil spills and the comparison between these two models shows the main differences between the very simple model and a model that includes many oil spill motion effects.

The results show that the simple linear advection-diffusion model cannot predict the movement of the oil spill, but with some basic extensions such as the introduction of a transport coefficient and a non-constant diffusion coefficient, the results could be improved.

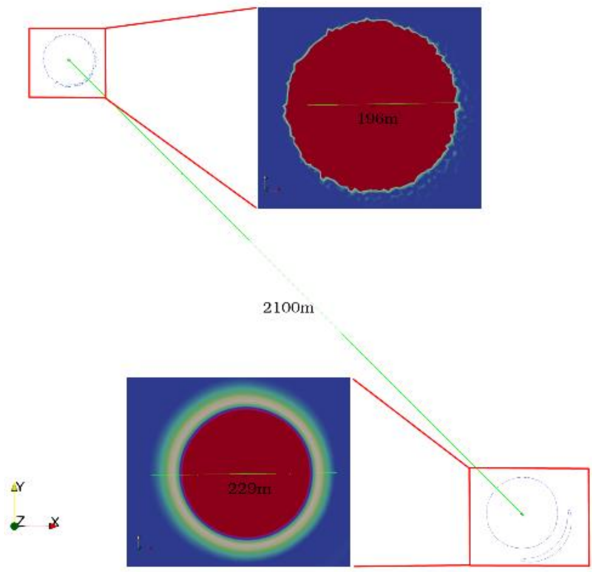


Figure 6: FEM solution of current-driven oil spill motion.

REFERENCES

[1] Landquist H., Norrman J., Lindhe A., Norberg T., Hassellöv I.M., Lindgren J.F., Rosén, L. (2017), Expert elicitation for deriving input data for probabilistic risk assessment of shipwrecks. Mar. Pollut. Bull. 125 (1-2), p.p. 399–415.

[2] Heidari P.A., Arneborg L., Lindgren J.F., Lindhe A., Rosén L., Raie M., Axell L., Hassellöv I.M. (2019), A state-of-the-art model for spatial and stochastic oil spill risk assessment: A case study of oil spill from a shipwreck, Environment International, Volume 126, p.p. 309-320

[3] Perkovic M., Harsch, R., Ferraro ,G. (2018), Oil Spills in the Adriatic Sea, Oil Pollution in the Mediterranean Sea: Part II, A. Carpenter and A. G. Kostianoy (ed). Cham, Springer International Publishing, Volume 84, p.p 97-131

[4] PISCES2 - Potential Incident Simulation, Control & Evaluation System, Transas Marine International

[5] Bochev P.B., Gunzburger M.D., Shadid J.N. (2004), Stability of the SUPG finite element method for transient advection-diffusion problems, Computer methods in applied mechanics and engineering, vol. 193, num. 22-26, pp. 2301-2323

[6] Logg A., Wells G.N., Hake J., (2012), DOLFIN: a C++/Python Finite Element Library, in: A. Logg, K.-A. Mardal and G. N. Wells (eds) Automated Solution of Differential Equations by the Finite Element Method (chapter 10), volume 84 of Lecture Notes in Computational Science and Engineering, Springer

METHODOLOGY OF OFFLINE VIBRATION DIAGNOSTIC TESTING OF MARINE PROPULSION SYSTEMS

Andrzej Grządziela
Marcin Kluczyk
Polish Naval Academy, Smidowicza 69, Gdynia, Poland
a.grzadziela@amw.gdynia.pl

ABSTRACT

Diagnostic multisymptoms tests are commonly used in shipbuilding and ships operations. We divide the methods into online and offline. Most of the ships built today are equipped with modern diagnostic systems called Health Monitoring System. However, a significant operational problem is the technical diagnostics of the older marine propulsion systems that were not equipped with diagnostic devices. This work was devoted to one of the elements of such a system as vibration diagnostics. The paper presents research methodologies, the method of selection of measurement points and directions, and the issues of analysis of the obtained test results. The research analyses were divided into the steady-state mode and nonstationary states. Exemplary results of the research are presented, and potential sources of errors in making diagnostic decisions are indicated.

Keywords: Naval ships, technical diagnostics, vibration, propulsion systems

1. INTRODUCTION

Today's merchant vessels are equipped with several automation systems, including Health Monitoring Systems. Automation results from economic needs by reducing the cost factor and safety requirements set by the IMO. Any disaster or accident at sea will lead to a significant start in the marine ecosystem and endanger people working for the maritime industry. Similar requirements are also imposed on warships, with the scope of requirements not defined by the IMO or ship classification societies, but mainly by defense standards and the shipyard's rules and experience.

The main difference between merchant ships and warships is the broader range of threats that warships can potentially face. In addition to the typical influences of the marine environment and the action of mechanisms inside the ship, naval vessels are exposed to the fighting means of a potential enemy in the form of underwater and surface explosions, direct hits by an artillery shell, torpedo or rocket. Technical diagnostics systems are therefore differently defined and have a broader scope.

The ships operating in the Navies are most often used for around 40 years and are modernized throughout their lives. Such activities concern not only armaments but also technical diagnostics systems. However, the primary problem is the susceptibility of the drive system components to the possibility of adapting modern online monitoring systems. These problems defined the need to adjust off-line technical diagnostics to naval vessels that are not very susceptible to modernization, or the scope of activities would be economically unjustified. This paper shows the methodology of vibration tests within the off-line multi-symptom system for older naval vessels. The paper presents typical failures in the drive system, the methodology of identifying the symptoms of failures, and the measurement apparatus using non-invasive vibration parameters tests.

2. METHODS OF DIAGNOSTIC TESTS ON SHIPS

The naval vessels built at the end of the 20th century had quite common systems for monitoring operational parameters, but only a few were equipped with advanced diagnostic techniques. The situation led to the use of the ships according to the scheduled replacement of spare parts. Failure of the propulsion system was detected due to significant wear of its components or even destruction. The high cost of repairs and the necessity to exclude the ship from service resulted in the development of non-invasive diagnostic methods using multi-symptom, non-invasive diagnostic procedures supported by expert interviews with the ship's crew. The basic non-invasive methods were tests of thermodynamic parameters of machines in the drive system (pressure, temperature), vibration parameters (free run and triggering), X-ray, ultrasound methods, tests of lubricating oil contamination, endoscopic procedures and analysis of electrical parameters characterizing the start-up processes of turbine engines, etc. (Vizentin G., 2020).

2.1. Regulations and standards

To some extent, tests of vibration parameters on warships correspond to the standards specified in the regulations of classification societies. The guidelines provide practical guidance on avoiding excessive vibration in the design phase and refer to the finite element analysis (FEA) vibration analysis procedure to calculate the vibration response. In addition, the standards present the methods for measuring vibrations during sea trials and indicate acceptance criteria for vibration limit values based on international standards. The most frequently used standards in the vibration diagnostics of propulsion system elements in Poland are: ISO-10816-1:1998, Mechanical vibration — evaluation of machine, ISO 10816-6:1995, Mechanical vibration — evaluation of machine vibration by measurements on non-rotating parts, Part 6, Reciprocating machines with power ratings above 100 kW vibration by measurements on non-rotating parts, ISO 20283-2: 2008, Mechanical vibration — measurement of vibration on ships, Part 2, Measurement of structural vibration and Polish Defense Standard NO-20-A500-3:1999.

For warships, such requirements are not enough. In addition to harmonic and stochastic vibrations from machines and the marine environment, we should expect loads from shocks and explosions characteristic of the maritime theatre of combat operations. The ships should also be immune to shock impulses.

2.2. On-line vs off-line diagnostics

The performance of the operating parameters monitoring system most often allows the execution of a bypass to obtain measurement data; lots of them can be used for online and offline diagnostics. Therefore, it is necessary to identify which of the operational parameters and symptoms of non-invasive diagnostics can be qualified for particular types of diagnostics (Kluczyk M. Grzadziela A., 2021). Diagnostics online type concerns vibration and thermal diagnostics of bearing systems, analysis of thermodynamic parameters, lubricating oil pressure in all bearing, and electrical parameters describing stationary and non-stationary processes. An essential element of online diagnostic procedures is the multi-state of parameters and the generation of warnings and alarms. More advanced techniques are also equipped with technical condition forecasting functions. Forecasting is performed using the server onboard the ship or by radio data transmission at coastal diagnostic stations.

As mentioned earlier, many drive systems with measuring equipment are not amenable to modernization to the level of online monitoring. Typically, an offline system will then be introduced to assist technical staff in making rational operational decisions. Such techniques are, in principle, non-invasive, and we divide them into two groups. The first group are diagnostic systems that can perform measurements in the outage power mode. Examples are visual endoscopic inspections, surge tests, dc and ac high potential, impedance tests or ultrasnic examinations. Unfortunately, those types of tests sometimes require partial disassembling. The second group consists of tests of operating parameters in the form of a bypass from the marine sensors of operating parameters and measurements of external parameters such as vibrations. This work focuses only on those parameters that are vibration parameters measured in the form of free run and synchronous in the stationary and non-stationary states.

2.3. Objectives and scope of vibration tests

The purpose of offline vibration diagnostic tests is to determine the technical condition of the drive system or the quality of the process being carried out at the moment considered necessary. The state of the technical elements of the ship's propulsion depends on the design and technological factors, including the operating time. In addition, various external factors, independent of the operator, depending on the quality of operation and random, operate in the operation process. It follows that twin marine propulsion systems that worked simultaneously may be in entirely different technical conditions.

The analysis of the dynamics of the naval propulsion system consists of the following stages:

- Stage I - a detailed description of the tested elements of the system, its essential features and the construction of the physical model dynamic properties will be acceptably consistent with the properties of the object.
- Stage II - analytical description of dynamic phenomena reflected by a physical model, i.e. a mathematical model (a system of differential equations describing the physical model).
- Stage III - simulation of dynamic properties based on the solution of differential equations of motion, determination of the predicted movement of the system for a technically efficient system with simulated deviations.
- Stage IV - making design or modernization decisions, i.e. adopting the physical parameters of the system with modernization adapted to the expectations; synthesis and optimization leading to the achievement of the required dynamic properties of the structure.
- Stage V - measurements of vibration parameters and validation of models as well as evaluation of the current technical condition of the facility.

The presented algorithm of research stages seems logical and relatively simple; however, naval propulsion systems operate in specific hydrometeorological conditions. The flow of water around the hull, variable draft and wave action may cause self-excited vibrations, which will result in errors in the diagnosis. Hence, knowing the fingerprint vibration attributes for a new or fully technically efficient ship is essential. Comparing the measurement results of a fully operational system and advanced wear can give a correct picture of the current technical condition. This methodology is used when the user and diagnostician do not have access to the design documentation, making it impossible to build mathematical, physical models. The comparison of the test results of a technically efficient unit and the results of the current technical condition allows for an accurate diagnosis only in the case of knowledge of the kinematics of the drive system and the use of vibration measurement as an element of multi-symptom diagnostics.

Many navies operate vessels over 30 years old and whose propulsion systems have not been calculated using numerical methods. Often the problem is also the lack of access to project documentation. Such cases indicate the need to perform diagnostic inverse models. Therefore, the diagnostic task consists of measuring the vibration parameters of a technically efficient unit and making physical and mathematical models that should be adjusted so that the results correspond to the measurement results. Such an operation is a simplification because it is identified the deviations of the vibrating shaft but the inputs to the model are the measurements are carried out on the bearings in the model, far away from shaft deflection. Therefore, a transition function is assumed, which must be monotonic in terms of all operating rotational speeds, simplifying the model. Such a model allows the simulation of fundamental failures such as misalignment, unbalancing or bearing failure.

3. METHODOLOGY FOR TESTING OF PROPULSION SYSTEM COMPONENTS

Direct drive propulsion systems and combined propulsion systems are purposes of the diagnostic research. The investigation assessed the quality of work of combustion engines and gas turbines. Combustion engines were usually turbocharged, high-speed diesel engines. The basic tests performed using the vibration method were the identification of the quality of the combustion process in the cylinders.

Diagnostic vibration tests of gas turbines were focused to identify the rotor systems' unbalancing. The research was conducted in the signal synchronization mode and using the order tracking and auto-tracking functions. The test results concerned stationary processes under operating loads and during the coasting/stoppage of rotors from cold and hot conditions.

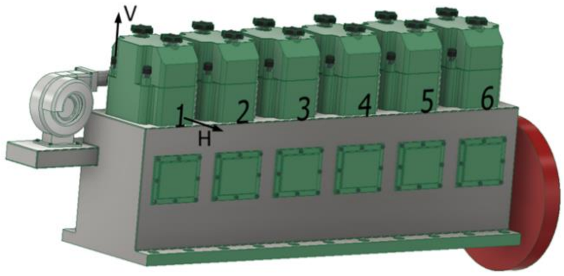
A significant part of the research concerned the quality of the transmission of the driving torque through the shaft lines. The fundamental operational problems were the identification of misalignment and unbalancing parameters. The torsional vibration was not recorded and analyzed regarding multi-cylinder, high-speed engines and gas turbines. A decision was due to many excitation and application of flexible couplings. The test results were most often verified by laser measurements of the refraction parameters and displacement of the shaft axis.

3.1. Combustion engine quality testing

There are no injection pump test stands on small warships, and it is impossible to indicate the pressure in individual cylinders. Deterioration of the technical condition of the engine fuel system may result in drive torque imbalance and faster wear of the piston-cylinder liner system. Other elements that will wear out are turbochargers, flexible couplings or torsional shock absorbers. Identification of degradation the technical condition of injection pumps can also prevent secondary damage to other engine components. Although the best method to indicate pressure changes inside the cylinder is the indication procedure, most small, high-speed engines cannot do this due to the lack of indicator valves (Polanowski S., 2011).

Using the vibration method as a qualitative and not a quantitative tool is the optimal method for identifying changes in gas pressure inside the cylinder. In addition, it allows determining the technical condition of injection pumps of marine engines.

Pulsation of gas pressure in the cylinders will change the force acting on the crank-piston mechanism and the closing surfaces of the combustion chamber. These assumptions assume that the vibration parameters recorded in the vicinity of the cylinder working with the defective injection system will differ from the reference one. As a result of theoretical analyzes, it was confirmed two measuring points of measurement: V (vertical) and H (horizontal), are susceptible to changes in pressure inside the cylinder concerning the measured vibrations recorded along the vertical axis - see Figure 1. Therefore, accelerometers are placed on the heads of subsequent cylinders. The measuring points were on the cylinder head tightening bolts. The symptom was the acceleration signals filtered by a high-pass filter with a frequency of 0.7 Hz.



Source: (own research results)

Figure 1: Virtual model of the 6 AL 20/24 engine with measurement axes (V, H)

In the research, a simplified model of the dynamics of the combustion process in the engine cylinder was developed. The primary source of vibration excitation, apart from the force of inertia, is the gas forces occurring during the ignition event and the power stroke. The model mathematically describes the course of pressure changes in individual engine strokes according to the theoretical Sabathe cycle. The models use one of the non-parametric regression methods, i.e. weighted locally weighted scatterplot smoothing. This function allows obtaining a course much closer to that recorded during the measurement of the indicated pressure (Kluczyk M., 2019). The analysis of the natural curves obtained from the model and obtained from the model using the loess function is presented in Figure 2 (Kluczyk M, 2020).

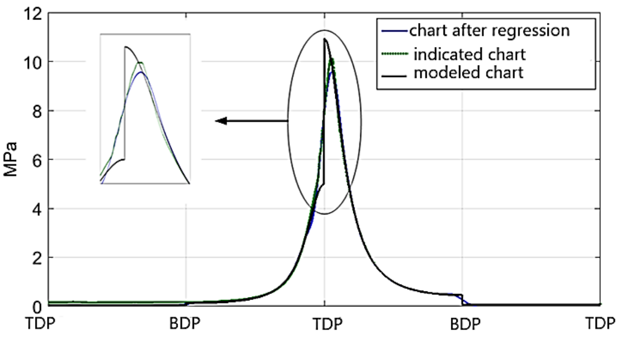


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Figure 2: Comparison of the course of pressure changes obtained by three different methods

The simulation assumes that the gas force acting on the piston is constant and its value can be determined by the equation:

$$F_g = \frac{\pi D^2}{4}(p_d - p_0) \tag{1}$$

where: p_0 - ambient air pressure.

Following compression stroke, the change in gaseous force might be described by the formula:

$$F_g = \frac{\pi D^2}{4} \cdot \cdot \left\{p_d \left[\frac{2\varepsilon}{(\varepsilon - 1)(1 - cos\varphi + 0{,}5\lambda sin^2\varphi) + 2}\right]^{n_1}\right\} \tag{2}$$

The performance of gas force is changed according to the dependence in the power stroke as follow:

$$F_g = \frac{\pi D^2}{4} \cdot \cdot \left\{p_d \varphi_c \varepsilon^{n_1} \left[\frac{2\rho}{(\varepsilon - 1)\left(1 - cos\varphi + 0{,}5\lambda sin^2\varphi\right) + 2}\right]^{n_2}\right\} \tag{3}$$

The value of the gas force in the exhaust stroke can be accepted as constant and described by the formula:

$$F_g = \frac{\pi D^2}{4}(p_w - p_0) \tag{4}$$

The stroke of the expansion at an initial phase is an isobaric increase in volume. According to the literature and own research, the formula can be used. Replacing the gaseous forces more significant than those induced by the theoretical maximum pressure p with the forces corresponding to this pressure is only one condition. Then, the maximum pressure is expressed by:

$$p_z = p_d \varphi \varepsilon^{n_1} \tag{5}$$

The gas forces coming from this pressure are expressed by the equation:

$$F_g = \frac{\pi D^2}{4}(p_z) \tag{6}$$

The presented equations indicate the need for adaptation for the simulation model of the fuel system. Presented in Figures 3 - 6 results confirm an evident relationship between the measured pressure course and the course obtained in the simulation model. The developed models of engine dynamics take into account the specificity of the tested engines in terms of the mechanics of the crank-piston system and auxiliary coupled mechanisms.

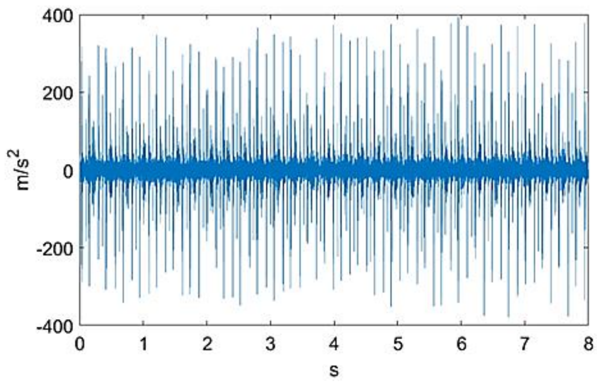

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Figure 3: Time waveform of the acceleration measured on working engine

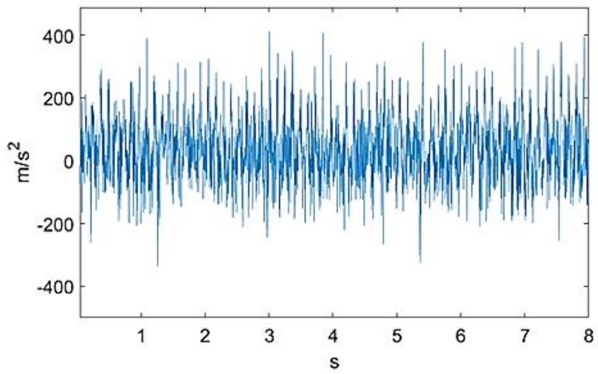

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Figure 4: Time history of the acceleration generated from simulation model

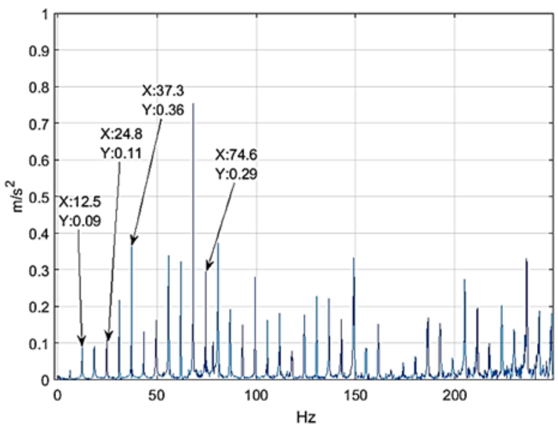

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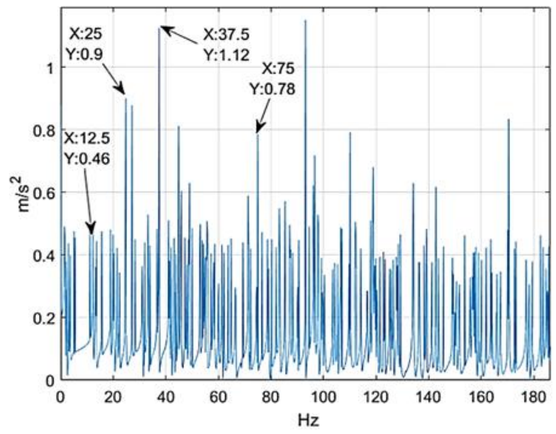
Figure 5: Acceleration spectra of the measured on working engine



Source: (own research results)

Figure 6: Acceleration spectra generated from simulation model

An example is the comparison of the model diagram with the diagram recorded on the engine's cylinder, as shown in Figures 3 and 4. The FFT analysis of both Time waveforms indicates the compliance of the characteristic harmonics resulting from the engine's principle of operation and construction, which are presented in Figures 5 and 6. In addition, the amplitude values obtained during the measurements and as a result of modelling the engine vibrations were identified and confirmed. Therefore, the obtained results are slightly different from changes resulting from an improperly-working fuel system. It means that it is possible to prognoses damage to the model's fuel system and forecast changes in the technical condition by determining the limit value of vibration symptoms in terms of acceptable simulations errors.

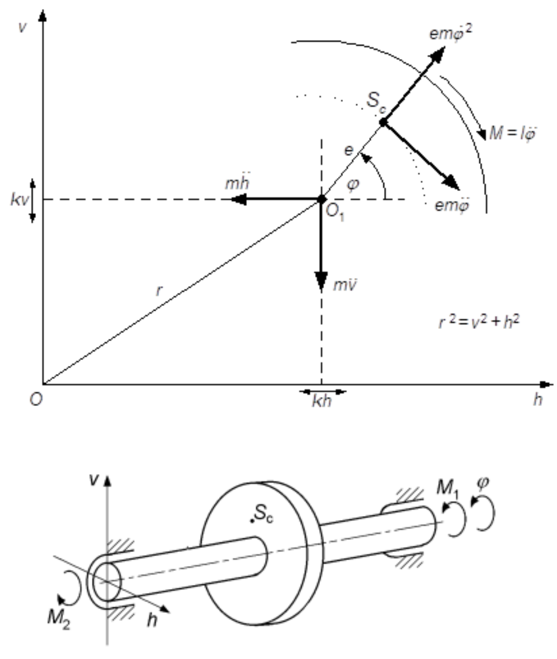
3.2. Diagnosing unbalance of rotors in gas turbines

Diagnosing such machines like gas turbine engines depends on the measurement and processing of many symptoms, including the vibration signals. Marine gas turbine engines mustn't work with a constant rotational speed of compressors and power turbines rotors. That is why synchronizes the processing method with selected reference magnitude, the rotational frequency of one of the rotors. It allows recognizing most of the typical multifunction of rotors systems. Basic, operational inefficiency of gas turbine engines include the following reasons:

- In the result of damage or crushing of the compressors' blade (s) or power turbines blade (s).
- Emerged unbalancing coming from the carbon deposit or the salinity.
- As the result of seizing of rotors sealing system and leaking the lubrication oil inside the rotor.
- Aero-dynamical misalignment between the gas generator and power turbine.
- Thermal damages of combustion chambers - torsional vibration of the power turbine.
- As the result of damage auxiliary mechanisms of the engine.

The numerical methods for diagnosing the rotor systems of the gas turbine are implemented at the design stage, which is most often the case now. However, the problem begins when the manufacturer does not include his knowledge of the object for the user. Currently, a comparative analysis of the rotor model made using FEM or the simulation method of differential equations with vibration measurements performed on a real object is used as a universal system for identifying damage (Downham, 1971). For initial simulations, a linear model is sufficient, in which the expected effect is the displacement of the bearing support as a function of time (Musiał, 2015). However, the change of geometric parameters influences the adopted rotor model and, therefore, the adopted coefficients and values in the equations of motion. Consequently, it implies a change in displacement. By applying the fast Fourier transform FFT to the obtained time course of the displacement, one can get the effect in the form of the expected spectrum of displacements, velocities or accelerations, depending on the expected vibration symptoms (Charchalis, 2011).

In the diagnostics of gas turbines, the rotor system shown, for example, in Figure 7, is analyzed, assuming that the static deflection caused by gravity is negligibly slight. The system transmits the torque M, which is generally a function of time and rotational speed (Rządkowski, 2009).



Source: (own research results)

Figure 7: Scheme of the rotor system

According to the designations given in Figure 7, it is possible to obtain equations of motion in the form of:

$$m\ddot{h} + kh = me(\ddot{\varphi}\sin\varphi + \dot{\varphi}^2\cos\varphi) \qquad (7)$$

$$m\ddot{v} + kv = me(-\ddot{\varphi}\cos\varphi + \dot{\varphi}^2 \sin s\varphi) \quad (8)$$

$$(I + me^2)\ddot{\varphi} = me(\ddot{h}\sin\varphi + \ddot{v}\cos\varphi) + +M_1(\omega) - M_2(t) \quad (9)$$

Equations (7-9) are interconnected, which means that bending vibrations affect torsional vibrations and vice versa, i.e. a disturbance in one of these areas must respond to both. It implies that such effects cannot be ignored in considerations. The damping turns out to be necessary when the model is to be used for a classic diagnostic task. The continuous mapping of symptom ↔ state in a quantitative and not only qualitative manner, and when in the identification process, it compares the values of vibration amplitudes and not only locate the occurring frequencies. On the other hand, considering the elasticity of support is not always necessary, contrary to appearances. For example, when observing an object, we most often register vibrations of fasteners or housings in an exciting direction. Moreover, the stiffness of these elements is usually many times greater (sometimes by several orders of magnitude) than that of the rotating components, and the internal damping is so tiny that the vibrations are transferred without a significant change in frequency. Thus, the problem of mapping observations comes down to finding the transition function (or, most often, spectral transmittance in the frequency domain) (Pająk M., 2016). In this case, therefore, the model from Figure 7 should be expanded, at least to the form shown in Figure 8.

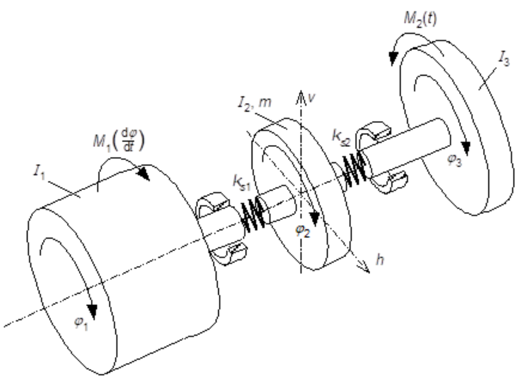


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Figure 8: Dynamic model of an exemplary rotor system: *I_1* - reduced moment of inertia of the drive; *I_2* - transmission system moment of inertia; *I_3* - reduced moment of inertia of the power receiver; *m* - mass of the unbalanced transmission system; *k_{s1}*, *k_{s2}* - coupling stiffness; *$\varphi_{1,2,3}$* - rotation angles; *$M_{1,2}$* - drive and resistance torque

It is the simplest case of modeling the entire power transmission system from the compressor to the low pressure turbine of the exhaust gas generator. The equations of motion of the system can be presented in the form:

$$m\ddot{h} + kh = me(\ddot{\varphi}\sin\varphi + \dot{\varphi}^2\cos\varphi) \quad (10)$$

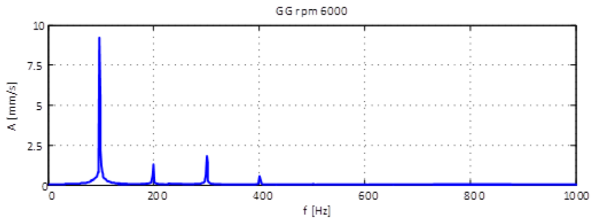
$$m\ddot{v} + kv = me(-\ddot{\varphi}\cos\varphi + \dot{\varphi}^2 \sin s\varphi) \quad (11)$$

$$I_1\ddot{\varphi}_1 + k_{31}(\varphi_1 - \varphi_2) = M_1(\omega) \quad (12)$$

$$I_2\ddot{\varphi}_2 + k_{31}(\varphi_1 - \varphi_2) + k_{32}(\varphi_2 - \varphi_3) = ke(v\cos\varphi_2 - h\sin\varphi_2) \quad (13)$$

$$I_3\ddot{\varphi}_3 + k_{32}(\varphi_3 - \varphi_2) = M_2(t) \quad (14)$$

The equations can be extended by the damping, the matrix which has the same form as the elasticity matrix, and by relations illustrating the deflection of supports, etc. It is easy to see that the adoption reduces the system to a simple model of one member, taking into account its torsional susceptibility. The analysis of the presented model allows to obtain a dynamic response in the form of vibration velocity spectrum of the gas generator rotor - see Figure 9.



Source: (own research results)

Figure 9: Velocity spectrum of the GG rotor at 6000 rpm – simulation model

The obtained simulation results correspond to the measurements on a technically efficient engine directly after the overhaul. For example, the spectra of the vibration measurement on the Gas Generator front bearing is shown in Figure 10.

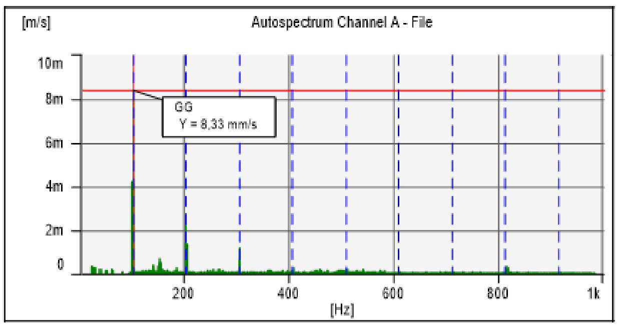


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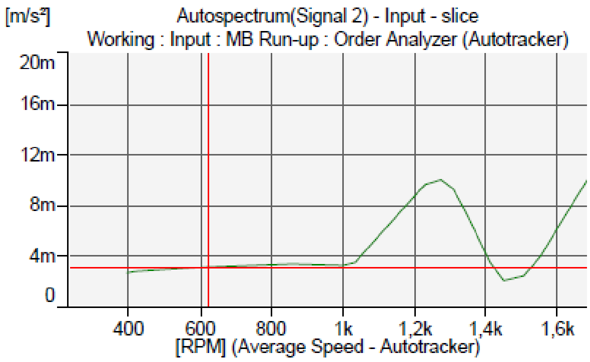
Figure 10: Velocity spectrum of the GG rotor at 6000 rpm, result of measurement

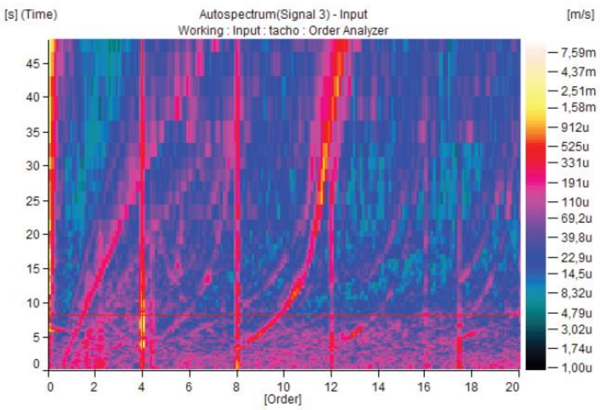
Research in non-stationary states aims to identify local resonances and primary fatigue failures revealed in the rotor's acceleration and deceleration. The time of the cold gas turbine start-up process (without the fuel ignition) and the overrun takes about 110 seconds. Therefore, it enables full data recording by any analytical and recording system. However, recording vibration signals in the free-run mode does not meet the diagnostic requirements due to the variable input parameters, i.e. air pressure and temperature, oil temperature etc. Moreover, during the measurements in the free-run mode, the harmonics do not line up in parallel, and therefore their identification is difficult. The problem is solved by using the Ordertrackig or Autotracking procedures. During the start-up and shut-down process tests, the relations of successive harmonics values are analyzed, which characterizes rotor unbalance (Grzadziela, 2012). Another symptom is the increase in the instantaneous vibration acceleration values, which can be considered both in terms of the speed increase of the rotor being started - see Figure 11, and in the field of start-up time – see Figure 12 (Grzadziela, 2011).



Source: (own research results)

Figure 11: Characteristics of vibration acceleration (1st harmonic) with the use of the AUTO TRACKING procedure in the gas turbine start-up process

The use of both procedures makes it possible to identify the impact of the combustion process on changes in vibration diagnostic symptoms and local resonances. Simultaneous observation of vibration parameters and rotational speed makes it possible to find the relationship between the selected vibration signal and the processes occurring during the start-up and shut-down.



Source: (own research results)

Figure 12: Autospectrum of velocity of vibration in the shut-down process with the use of order tracking procedure

The results obtained from the engine tests make it possible to perform model AUTOTRACKING characteristics for the entire population of the tested objects.

3.3. Vibration tests of shaft line alignment

Shaft line torsional vibrations analyzes began in the second half of the 19th century and concerned the determination of the causes of fatigue damage to long shaft lines. Such tests are standard until today, but their application is mainly in the direct drive type systems with low-speed engines (Murawski, 2004). Warship propulsion systems, especially those with long shaft lines, as is the case, for example, in combined systems, are mainly exposed to bending vibrations resulting from typical marine environment influences. Vibration tests of the propulsion system are carried out in many ways, and some aspects of the measurements have even been standardized. The primary analytical and measurement tools currently used in the propulsion system vibration diagnostics are (Musiał, 2015):

- Measurements using free-run triggering.
- Measurements with the use of synchronous tripping.
- Tracking analysis, ORDERTRACKING.
- Analysis with self-tracking rows, the so-called AUTOTRACKING.

Measurements using free-run triggering should be ad hoc. Most often, this method is used to general evaluate the vibroactivity of drive system components without the use of advanced analytical tools. The widespread use of triggering free-run measurements is due to the following advantages:

- inexpensive and straightforward apparatus,
- low computing power required to obtain the analysis result,
- real-time analysis (online).

Measurements with the use of synchronous triggering are much more widely used. The FFT spectra are presented as a function of the rotational speed measured by the tachometer and the function of the time. Marine propulsion systems with fixed pitch propellers operate over a wide range of rotational speeds. For this reason, the most commonly used analyzes are ORDER TRACKING and AUTOTRACKING (Pedersen, 2006).

Order tracking changes the frequency range corresponds to changes in the rotational speed of the propeller shaft or intermediate shaft. As a result of the analysis, single orders remain in the same place on the frequency axis in transients, thus preventing their blurring. This measurement technique enables the identification and analysis of closely spaced rows and higher orders. The analysis of orders in the measurement of marine propulsion systems has some limitations, the most important of which are (Grzadziela A, 2017):

- Necessity to use the speed probes.
- Dependence of the tachometer and the number of triggers of the synchronizing signal per one shaft revolution.

A reasonably common measurement problem is the inability to access the drive shafts. An example is marine propulsion systems with gas turbine engines. The solution to the problem is auto-tracking, which enables the synchronization of signals, even in multi-shaft systems.

The study of the vibration processes of the propulsion system should be guided by the individual adjustment of the measurement and analytical methods. The fundamental factors influencing the decision to choose a form and the correctness of the analyzes performed are (Acanfora M, 2022):

- Knowledge of the design and principles of using of the propulsion system.
- The history of the propulsion system maintenance processes and the opinions and operational notes of the ship's technical staff.
- Analysis of the possibility of accessing rotating parts and speed probes dedicated to measuring rotational speed.
- The ability to stop and restart the drive system.
- Minimization of research time.
- Possibility of mounting the transmitters (some devices are unavailable, enclosed, exposed to high temperature, presence of water or moisture).

The presented methods are used for measurements identifying the basic malfunctions occurring in the operation of the shaft line. The possibility of using non-invasive measurement tools significantly increases the safety of use and eliminates random shipyard inspections. It is of particular importance in the case of warships, as the methods used do not impose the necessity to exclude units from the service.

The primary external influences on the shaft lines include:

- Driving torque of the main drive motor.
- Thrust moment of a screw propeller.
- Longitudinal thrust force.
- Interactions caused by changes in the mutual position of the shaft line support and thrust bearings.
- Impact of the hydrodynamic pressure of an underwater explosion.
- The effect of hydrodynamic pressure of a sea wave - slamming - see Figure 13.

Source: (own research results)

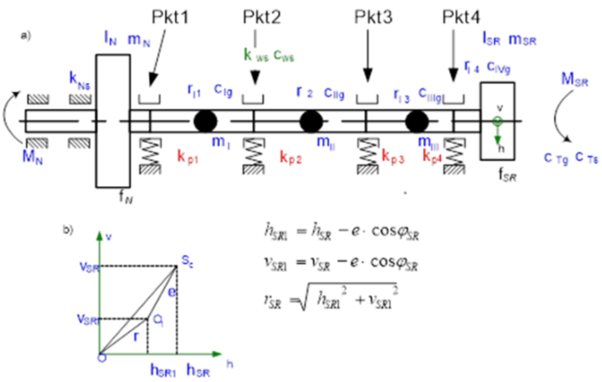
Figure 13: A photo showing the slamming effect

A significant threat to the safe operation of the propeller shaft is the possibility of resonance in the operating speed range. In addition, although propeller shafts are usually designed as subcritical, there is a potential for a calculation error, mainly due to incorrect calculation of longitudinal forces and the effect of water damping on the hull.

As in the imbalance of gas turbine rotors, the most common method is to prepare a mathematical model based on the knowledge of the geometry and kinematics of the shaft lines. Simulation models allow for a relatively precise determination of the symptoms of breakdown and/or displacement of the shaft lines. However, attention should be paid to the fact that in the drive system, the torque pulsation expressed by the sum of the Fourier series is more complex and additionally includes components related to the number of propeller blades. The structure of the reduction gear and the effects of disturbances in adjacent mechanisms, primarily the main drive engine, should be analysed as well. An example of a physical model of a shaft line is shown in Figure 14.

The example shows a model where the driving torque is transmitted from the engine through the reduction gear to the propeller. A model was proposed that meets the following requirements:

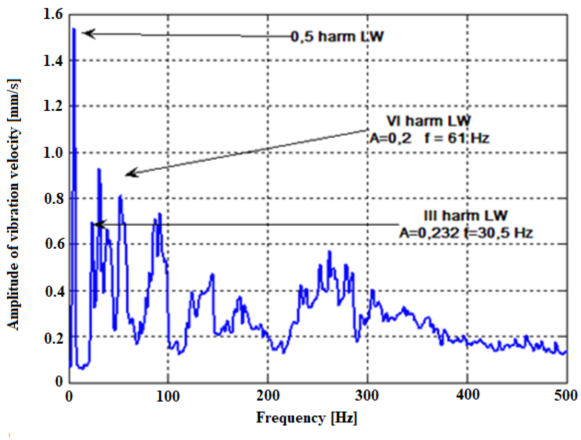
- Enables the introduction of external influences.
- Shows sensitivity to the introduced variable parameters of the propeller shaft motion.
- Shows sensitivity to the introduced displacement of the propeller shaft axis.
- Shows the lack of sensitivity of the concentricity symptom to disturbances resulting from environmental influences.
- Maintains the compliance of the spectral structure in the frequency domain with the measurement results of the real object.



Source: (own research results)

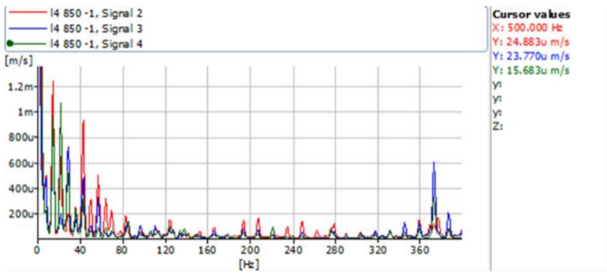
Figure 14: Model of shaft line, where Pkt means bearing

The proposed model is non-linear, an attempt to describe using linearization of interactions is unacceptable due to erroneous conclusions that would arise with applying the principle of superposition of effects applied in linear systems. Since time is explicit in the adopted model, it is a non-autonomous system. Therefore, it is necessary to describe kinetic energy, potential energy, and dissipated energy. It should be assumed that the external influences of the drive are understood as the difference between the driving torque and the resistance torque. Calculations of the stiffness k require a statically indeterminate system, which can be performed using the influence factor method (Acanfora M, 2022). Using the Lagrange equations of the second type and introducing the discussed dependencies on the influence coefficients, one can obtain equations describing the vibration of the propeller shaft. An example of a simulation solution is shown in Figure 15 and results of measurement on the Figure 16.



Source: (own research results)

Figure 15: Shaft line vibration velocity spectrum - the effect of the mathematical model



Source: (own research results)

Figure 16: Shaft line vibration velocity spectrum - the effect measurement

4. CONCLUSIONS

For marine propulsion system diagnostics, complex health monitoring systems are now widely used; however, they are limited on older ships due to their high cost. The use of multi-symptom diagnostics systems offline type can significantly reduce the number of failures and operating costs. The presented vibration diagnostics module is only one of the elements of a broader multi-symptom diagnostic system. In the case of ships with many years of service at sea, the economic factor blocks the implementation of modern diagnostic techniques, especially on small vessels. The use of ad hoc tests using diagnostic models significantly reduces the risk of unexpected failures of the primary drive system components. Lack of information about the construction of the propulsion system's structure, geometry, and kinematics makes the only solution to perform fingerprints of the tested parameters on a technically efficient unit. The analysis of vibration parameters changes as a trend and their interconnection with other symptoms increases the chance of detecting failures at low maintenance costs. However, it should be noted that the essential tool of vibration diagnostics is the construction of simulation models that facilitate virtual identification of changes in the technical condition in the range of damage from acceptable to use to destructive (Yan, Liu, Zhang i Shi, 2016).

REFERENCES

[1] Charchalis, G. (2011, Nr 18). Vibration diagnostics of marine gas turbine engines. *Journal of KONES*, pp. 157-162.

[2] Downham, E. W. (1971). The rationale of monitoring vibration on rotating machinery. *ASME Vibration Conference*, (pp. Paper 71 - Vib 96).

[3] Grzadziela. (2011, Nr. 3). Diagnostics gas turbine rotors in non stationary states. *Diagnostyka*, pp. 41 - 46.

[4] Grzadziela. (2012). Diagnosing of Rotor Systems of Marine Gas Turbine Engines in Nonstationary States. *Condition Monitoring of Machinery in Non-Stationary Operations*, pp. 439 - 450.

[5] Grzadziela A, Batur. T. (2017, Issue 4). Dynamics of shaft lines of the landing ships. *Journal of Marine Engineering & Technology*, pp. 238 - 247.

[6] Grzadziela A., Kluczyk. M. (2021, Vol. 817). Diagnostic Model of the Marine Propulsion System. *Applied Mechanics and Materials*, pp. 57 - 63.

[7] Grządziela, A. M. (2015, Nr. 1). A method for identification of non-coaxiality in engine shaft lines of a selected type of naval ships . *Polish Maritime Research*, pp. 65 - 71.

[8] Kluczyk M, Grzadziela. A. (2020). Detection of Changes in the Opening Pressure of Marine Engine Injectors Using Vibration Methods. *Nase More*, pp. 1 - 8.

[9] Kluczyk M., Grzadziela. A. (2019). Detection of Changes in the Opening Pressure of Marine Engine Injectors Using Vibration Methods. *Diagnostyka*, pp. 1 - 8.

[10] M Acanfora, M. A. (2022). Simulation Modeling of a Ship Propulsion System in Waves for Control Purposes. *Journal of Marine Science and Engineering*, pp. 1 - 14.

[11] Murawski, L. (2004, 9). Axial vibrations of a propulsion system taking into account the couplings and the boundary. *Journal of Marine Science and Technology*, pp. 171 - 181.

[12] Pająk M., M. Ł. (2016). Rotating systems misalignment identification using fuzzy clustering method. *Vibroengineering PROCEDIA, Vol. 7,* , pp. 7- 75.

[13] Pedersen, T. F.-H. (2006). Order tracking in Vibroacoustic. *Technical Review, Nr. 1*, 15 - 28.

[14] Polanowski S., P. R. (2011, Vol. 18). ACQUISITION OF DIAGNOSTIC INFORMATION FROM THE INDICATOR DIAGRAMS OF MARINE ENGINES USING THE ELECTRONIC INDICATORS. *Journal of KONES Powertrain and Transport*, pp. 359 - 366.

[15] Rządkowski, R. (2009). *Dynamics of steam and gas turbines.* Gdańsk: IFFM Publishers.

[16] Vizentin G., V. G. (2020, 8). Marine Propulsion System Failures — A Review. *Journal of Marine Engineering* , pp. 1 - 14.

[17] Yan, H., Liu, K., Zhang, X., & Shi, J. (2016, Vol 65). Multiple Sensor Data Fusion for Degradation Modeling and Prognostics Under Multiple Operational Conditions. *IEEE Trans. Reliab*, pp. 1416–1426.

ANALYSIS OF INCIDENTS AND ACCIDENTS OF LNG AND LPG VESSELS

Maciej Gucma, Ph.D.
Maritime University of Szczecin
Waly Chrobrego 1-2 Szczecin, Poland
m.gucma@am.szczecin.pl

Jun-min Mou, Ph.D.
Wuhan University of Technology
122 Luoshi Road,Wuhan, Hubei, P.R. China
moujm@whut.edu.cn

ABSTRACT

Shipping of liquefied gases in bulks is crucial part of energy supplies for many countries. This human activity at sea is related to several risks and serious consequences. Article presents all accidents and incidents of LNG and LPG vessels from available data bases as well as comparisons between them. Since LNG and LPG ships are treated in very strict manner when it comes to operations, and accidents are not that frequent authors propose relative analyses to treat this data.

Keywords: LNG, LPG, accidents, incidents, statistics

1. INTRODUCTION

Liquefied gases are becoming extremely important part of shipping. Lot of countries, to mention South Korea, Japan or some European countries has no option to obtain subsea or ground base pipeline to get the natural gas from their neighbors. In the light of current Ukraine War (2022) and crisis that touched nearly each country in EU connected with fixed gas pipe with oppressive Russia regime, its clear that LNG shipping and is crucial here. Similar story is with the LPG demand, some industries are highly concerned over the supplies in form of seaborn transport. From the beginning of seaborne liquefied gases transport safety was prime concern. Since accidents are inevitable phenomena's counter measures are taken to lower the probability of their occurrence as well as mitigation of consequences to mention highest industry standards for risk assessment and management corelated with technical measures in line with crew training standards. Since its emphasized by IMO (Intentional Maritime Organization) in several gas code issues and several professional organizations (like SIGTTO or OCIMF) the awareness of key players is at high level. The probability of accident or incident is never zero either. Thus engineers must have in deep knowledge of previous events to properly set up countermeasures. Generic, high-level risk assessment of the global operation of ocean-going liquefied natural gas (LNG) carriers has been investigated in [1]. This analysis collects information from several sources along with published damage statistics. The United States University of Texas publish LNG Industrial Safety Accident Statistics that shows that LNG carriers kept a good safety record [2], [3]. The International Group of Liquefied Natural Gas Importers (GIIGNL) had studied the frequency of accidents and its causes [4]. Some more statistical data can be found in work [5]. This studies and relevant reports shows high sustainability and safety of LNG shipping. Our commitment to all this previous work is based on some assumptions:

1. Shipping of liquid gases can be treated basing on similarities of cargoes and containment systems as well as transfer technology,
2. LPG will have higher number of accidents/incidents since there are more LPG vessels than LNG vessels,
3. Observability of accidents and incidents will be bigger in LPG vessels since their amount is bigger,
4. There is a correlation between the number of events for both types of vessels.

2. DATABASE STRUCTURE

Currently accidents and incidents are combined in 2 mayor databases provided by DNV (Det Norske Veritas) in their Safeti software and IHS Markit database. Article is analyzing data from the later. HIS Markit is providing the data in set called Casualty & Events Data that is larger part of Maritime Portal that can be accessed in commercial manner. Our research was done by querying the data base in April 2022. Database has a frontend for customers with fields for searching the records. Our intent was to seek only for liquefied gases carriers and only fields related to this type of vessels were queried. Database main key field is ship type and here following types are available:

1. CO2 Tanker
2. Combination Gas Tanker (LNG/LPG)

3. LNG Tanker
4. LPG Tanker
5. LPG/Chemical Tanker

Event Type is next record that can be chosen and here following keys are available:

1. Crew and Passenger
2. Piracy
3. Security and Legal Dispute
4. Ship Casualties

Then there is a choice for key named significance that can have values:

1. Common
2. Non Serious
3. Notable
4. Serious
5. Significant

In general the casualty group can be as:

1. Collisions
2. Contact
3. Fire / Explosion
4. Foundered
5. Hull / Machinery Damage
6. Other
7. Stranded
8. War-loss / Hostilities

Event Sub Type is next occurrence to the field of Event Type:

1. Boarding
2. Collision
3. Contact
4. Crew Abandonment
5. Fire / Explosion
6. Foundered
7. Hull / Machinery Damage
8. Illness / Fatality / Injury
9. Kidnapping
10. Maritime Arrest
11. Overboard
12. Piracy Attack
13. Robbery
14. Stranded
15. Suspected Illegal Activity
16. Suspicious Approach
17. War-loss / Hostilities

Weather as an optional key has attributes:

1. Calm Weather/Seas
2. Fog/Mist/Poor Visibility
3. Freak Seas
4. Freezing Conditions
5. Good Vis & Good Weather
6. Good Weather
7. Heavy Swell
8. Heavy Weather etc.
9. Hurricane etc.
10. Lightning
11. Lightning & Heavy Weather etc.
12. Snow
13. Unknown/Not Reported

Cargo load status as an optional field has attributes:

1. Ballast
2. Ballasting
3. Discharging
4. Empty
5. Loaded
6. Loading
7. Not applicable
8. Part loaded
9. Tank cleaning
10. Unknown

And last there is sub field if there was pollution (yes-no attributes). The structure of data base is in principle as a layout one to many and many to many that has been presented in the diagram at figure 1.

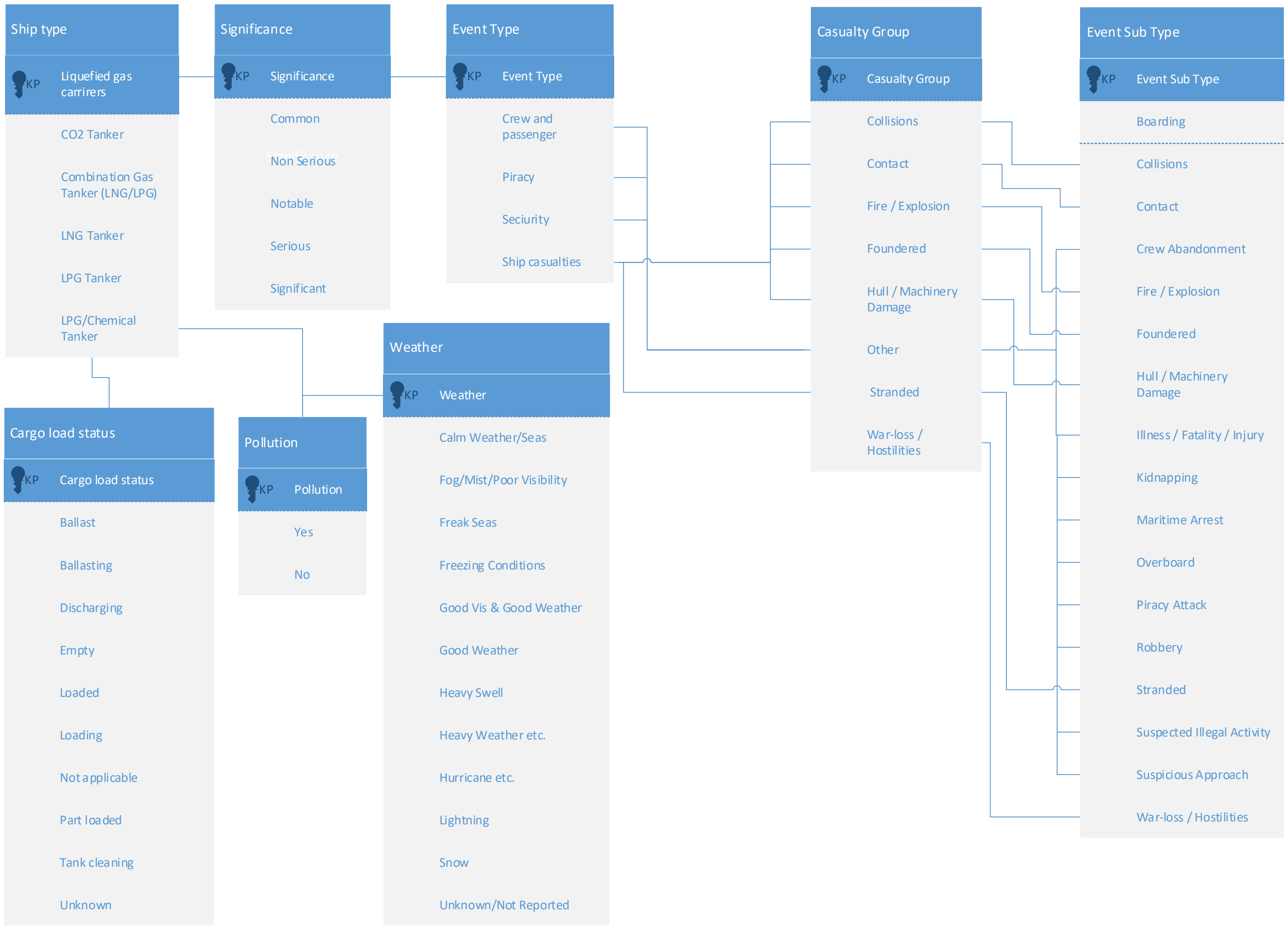


Figure 1: Diagram of dataset fields; Based on frontend structure IHS Markit database

3. DATABASE OUTPUT

General query over the general number of liquefied gas carriers that were involved in any type of event generates the following data (for April 2022):

1. CO_2 tanker 7 events,
2. Combination Gas Tanker (LNG/LPG) 2 events,
3. LPG/Chemical Tanker 56 events,
4. LNG tanker 247 events,
5. LPG tanker 1946 events.

Since other vessels are out of interest, they were joined to the main groups number 1 and 3 to LPG tankers and number 2 to LNG tanker data. Data range was not set and earliest events from database are dated back to 1963. Latest events are from 2022. Cumulative number of accidents for involved LNG and LPG vessels is presented at figure 2.

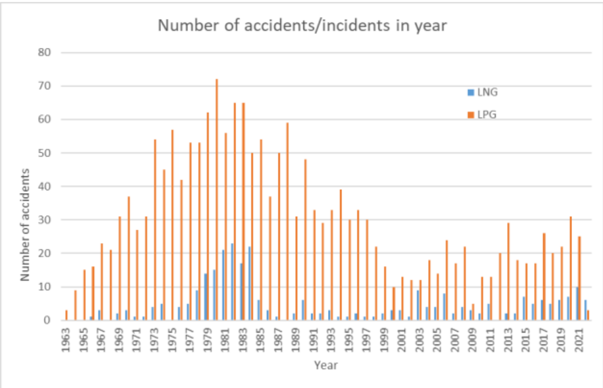


Figure 2: Number of accidents/incidents in groups of LNG and LPG vessels for analyzed time frame (1963-2022). IHS Markit database

Significance factor is not explained in the database help neither their promotional materials. Definition of incident provided in article is not in line with the SOLAS IMO and their database to mention: Maritime Casualties and Incidents database (MCI). Some other definitions found in [6] based on well-known work of Heinrich (1930) where triangle is showing observable and non-observable occurrences of unsafe acts (near mises), minor injuries, and major (fatal) injuries. Other statistics were provided for Baltic Sea Area in [7]. It's assumed that all of the data marked as: common, non-serious, notable, significant are not excluding the vessel from the trade as well as they don't generate serious losses to cargo or human life. Assuming that no injuries or death to personnel has taken place along with no serious material losses (that could exclude vessels form shipping timely or permanently) is treated as Non-Serious here. All data marked with Serious label are treated as accidents, where losses to life of crew or property took place. Results for the query is presented in table1.

Table 1: Significance factor for LPG and LNG vessels accidents/incidents. IHS Markit database

Significance	LNG	LPG
Non-Serious	199	1366
Serious	70	542

Pollution records is another type of data that seems to be key with relation one to many in database description language. In table 2 data for pollution occurrence in two vessel groups has been presented. This factor has only 2 states in IHS database.

Table 2: Pollution factor for LPG and LNG vessels accidents/incidents. IHS Markit database.

Pollution	LNG	LPG
No	264	1863
Yes	5	45

Correlation coefficient for two random variables X, Y (for LPG and LNG vessel types) is given as $\rho_{X,Y}$ with expected values of μ_X and μ_Y along with standard deviations σ_X, σ_Y, and forms as:

$$\rho_{X,Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \tag{1}$$

Where E is expected value.

Key factor to identify type of event is Casualty Group and for the selected range of results are presented in table 3.

Table 3: Casualty group factor for LPG and LNG vessels accidents/incidents. IHS Markit database

Casualty group	LNG	LPG
Collisions	39	387
Contact	11	148
Fire / Explosion	20	150
Foundered	0	19
Hull / Machinery Damage	170	867
Stranded	18	178

Correlation between data sets in Casualty group has been calculated using Eq. 1 and equals $\rho_{X,Y}$=0.978.

For the Event Type factor where non-technical failures (security breach and legal types) can be excluded for analysis data are presented in table 4

Table 4: Event Type factor for LPG and LNG vessels accidents/incidents. IHS Markit database

Event Type	LNG	LPG
Crew and Passenger	15	13
Piracy	11	52
Security and Legal Dispute	2	10
Ship Casualties	259	1757

For further analysis with use of another key in database i.e. Event Sub types related with technical means of events is presented at figure 3.

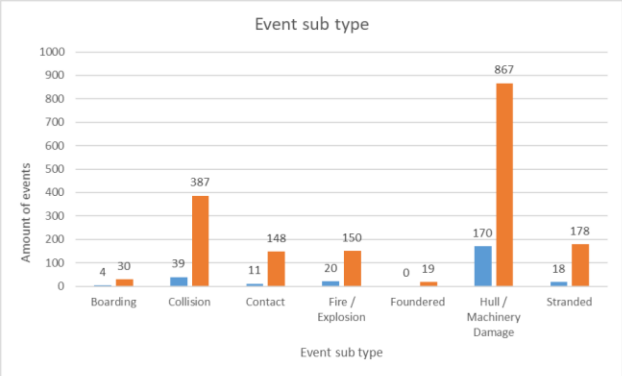


Figure 3: Number of accidents/incidents in groups of LNG and LPG vessels for analyzed time frame (1963-2022) with Event Sub Type discrimination. IHS Markit database

In analyzed Event Sub Type for LPG and LNG vessels correlation reached value $\rho_{X,Y}$=0.974.

For cargo load status Unknown status dominates, data for this database key and factor is presented in table 5.

Table 5: Cargo load status factor for LPG and LNG vessels accidents/incidents. IHS Markit database.

Cargo load status		LNG	LPG
Ballast	243	34	197
Ballasting	1	0	1
Discharging	43	11	30
Empty	30	4	25
Loaded	532	42	426
Loading	20	2	18
Part loaded	24	1	20
Tank cleaning	2	0	2
Unknown	1420	193	1111

Correlation between data sets in cargo load status has been calculated using Eq. 1 and equals $\rho_{X,Y}$=0.985.

Weather during accidents and incidents has no clear distinction in HIS Markit database. Authors decided to combine the keys in database in following manner:

1. Good Weather
2. Poor Visibility
3. Heavy Weather etc.
4. Unknown/Not Reported

Correlation between data sets in weather status has been calculated using Eq. 1 and equals $\rho_{X,Y}$=0.998. Predominant character has status unknown in both LNG and LPG sets as shown in table 6

Table 6: Weather factor for LPG and LNG vessels accidents/incidents. IHS Markit database.

Weather	LNG	LPG
Good Weather	4	30
Poor Visibility	3	40
Heavy Weather etc.	33	153
Unknown/Not Reported	247	1609

4. DISCUSSION AND RESULTS

Proposed simple statistics shows good correlation factor for LPG and LNG types of vessels although some values (like Weather type of key in database) is strongly dominated by reference to unknown. Thus largest correlation factor leads to the uncertainty. Having in mind obtaining the clearer results more data are desired and connection with other databases. Another type of data can be gathered using the Monte Carlo methods if the distributions of accidents and incident are known. For basic port design methods such simple solution can be beneficial and led to the desired results.

5. CONCLUSIONS

Using combined database for liquefied gases vessels of LNG and LPG types provides statistically interesting data especially for LNG types of vessels where accidents are rare (only 69 cases marked with Serious key in 59 years of analysis) and 207 cases of events for Non-Serious key. Correlation for the cargo load status and Event sub-type allows to treat this data as correlated and use accordingly for the harbor and ports design.

REFERENCES

[1] E. Vanem, P. Antão, I. Østvik, and F. D. C. de Comas, 'Analysing the risk of LNG carrier operations', *Reliability Engineering & System Safety*, vol. 93, no. 9, pp. 1328–1344, Sep. 2008, doi: 10.1016/j.ress.2007.07.007.

[2] M. Foss, 'LNG SAFETY AND SECURITY', Center for Energy Economics, Houston Texas, 2012. [Online]. Available: https://www.beg.utexas.edu/files/cee/legacy/LNG_Safety_and_Security_Update_2012.pdf

[3] 'Safety History of International LNG Operations', CH·IV, USA, TD-02109, Rev. 13, 2014.

[4] A. Acton, F. Katulak, J. Deveautour, K. Sakamoto, and M. Kan, 'LNG INCIDENT IDENTIFICATION—A COMPILATION AND ANALYSIS BY THE INTERNATIONAL LNG IMPORTER'S GROUP', presented at the 14th International Conference & Exhibition on Liquefied Natural Gas, Doha, 2004.

[5] L. Wang, 'STUDY ON SAFETY ESCORT OF LNG CARRIERS IN PORT WATER AREA', WORLD MARITIME UNIVERSITY, 2017.

[6] M. Anderson and M. Denkl, 'The Heinrich Accident Triangle—Too Simplistic A Model for HSE Management in the 21st Century?', in *All Days*, Rio de Janeiro, Brazil, Apr. 2010, p. SPE-126661-MS. doi: 10.2118/126661-MS.

[7] L. GUCMA and K. MARCJAN, ‘Wykorzystanie Analizy Incydentów Nawigacyjnych W Celu Oceny Bezpieczenstwa Nawigacyjnego Na Obszarach Morza Ba1tyckiego O Duzym Zageszczeniu Ruchu Statków’, *Prace Naukowe Politechniki Warszawskiej - Transport*, 2014.

ALTERNATIVE TECHNOLOGIES OF SHIPS PROPULSION

Niko Gugić, M.Eng., Ph.D. student
University of Split, Faculty of Maritime Studies
Ruđera. Boškovića 37, 21000 Split

Gojmir Radica, Ph.D.
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
Ruđera. Boškovića 32, 21000 Split
goradica@fesb.hr

Branko Lalić, Ph.D.
Nikola Račić, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera. Boškovića 37, 21000 Split

ABSTRACT

As a result of emission pollution regulation getting stricter, especially for new built ships, marine engine manufactures are being forced to develop and install new experimental technology which is in most cases ultra-low emission hybrid propulsion. Result of this type of technology being used and installed is minimized carbon dioxide (CO_2) emission, fuel consumption and transportation costs decreased, but a significant increase in building cost. This paper will cover new technologies witch still use fossil and alternative fuels, in combination with non-polluting or renewable energy drive. Considerable literature has been studied and conclusions have been drawn about the advantages and disadvantages of each technology. Guidelines for the development of maritime energy systems are provided.

Keywords: Emission regulation, Hybrid propulsion, Decarbonization, Renewable energy

1. INTRODUCTION

With the growing of global merchant fleet also comes the increase in the greenhouse gases (GHG). Primary greenhouse gases in earth's atmosphere are: water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and fluorinated gasses. Their emissions have increased from 977 million tons in 2012 to 1,076 million tons in 2018 which is a 9.6% increase in 6 years. NOx is also present in exhaust gases, but it can be reduced significantly by keeping the engine in ideal load, rpm, and sufficient air/fuel equivalence ratio [1] [2]. The International Maritime Organization (IMO) has put forward the energy efficiency design index (EEDI) to limit the greenhouse gas emission of merchant fleet and reach ambitious decarbonization scenarios with predictions that suggest the usage of carbon-neutral fuels in the late 2030s together with greenhouse gases reduction in the range anywhere between 50% and 100% by 2050. [3] [4]. This can be achieved through better Logistic and digitalization by reducing speed, achieving better vessel utilization, and finding alternative routes. Enhanced hydrodynamics gained by better hull coatings, clean bottom, air lubrification. Machinery improvements with waste-heat recovery, engine de-rating and battery hybridization. Biggest improvement can be made with the use of new fuels such as: liquified natural gas (LNG), liquified petroleum gas (LPG), biofuels, methanol, ammonia, hydrogen, and harvesting from the surroundings. After treatment measures such as carbon capture and storage can also get big improvements [5]. This paper aims to present the technologies that are at most considered and already installed on some new built ships regarding its propulsion systems. Dual fuel engines and hybrid systems.

2. ALTERNATIVE FUEL POWERED LOW SPEED ENGINES

Dual fuel engines operated by different fuels shoved a very stable engine operation on load ~75% of the rated torque and speed. This is possible with natural gas (NG) and biogas fueling without any modifications to the engine. CO_2 and NOx emissions for NG-diesel are like those for diesel in high load condition unlike biogas fueling which lowers the NOx emissions by maximum of 37%. Dual fueling also reduces Particulate matter (PM) to about 70% with similar reduction both in NG and biogas fueling. Scanning electron microscopy (SEM) analysis on collected PM indicates that dual fuel PM are smaller and rounder with a significantly higher number than diesel PM [6].

2.1. LNG

Liquid natural gas in recent years is one of the most used alternative fuels in the merchant navy fleet. These vessels transport LNG in insulated double-hulled tanks at pressures slightly above atmospheric with temperatures of around –169˚C so for propulsion it is ideal to use boil off gas and re-liquefied natural gas to burn in either gas turbines, steam boilers or dual fuel engines that as other fuel use heavy fuel oil (HFO) and marine diesel oil (MDO), when LNG is not available [7] [8]. Regarding the working principle of dual-fuel propulsion there is a low-pressure and a high-pressure plant, each with distinct working principles and characteristics.

Low pressure system.

The low-pressure technology is based on gas being injected at low pressure into the cylinder, ranging from 5 to 16 bar when the piston is in mid-stroke. This is a lean-burn Otto cycle, in which fuel and air are premixed and burned at a high air-to-fuel ratio. For ignition it uses a small amount of liquid pilot fuel, approximately 0.5% of the total injected quantity. As a result, these engines have stable combustion, low NOx emissions and high overall system efficiencies [9] [10].

High pressure system.

High pressure system operates on the diesel cycle. Gas is directly injected at high pressures of 250–300 bar into the cylinder after the diesel pilot fuel has ignited near the top dead center. Using the diesel cycle reduces the risk of knocking so the methane number is irrelevant since the fuel gas is not involved in the compression stroke. This contributes to better energy efficiency due to higher compression rates. These engines have three different modes of operation; Dual fuel mode, in which the amount of fuel gas is maximized, and the pilot fuel consumption minimized. Specified fuel gas mode, where almost any mixture of compliant fuel and gas can be specified. Compliant fuel only mode. Interchanging from one fuel mode to another is possible without any loss of efficiency and methane slip [11]. Figure 1. Shows the comparison of the low-pressure and high-pressure systems in terms of power performance, emission, and economy.

	Low pressure (WinGD X-DF)	High pressure (MAN ME-GI)
Power performance	• BMEP: 17.3 bar • Output: approx. 17% lower than the diesel engine counterpart • Dynamic response: poorer than diesel engine	• BMEP 21 bar • Output: comparable with the diesel engine counterpart • Dynamic response: comparable with diesel engine
Thermal efficiency	Approx. 47%	Approx. 50%
NOx emission	IMO Tier III	IMO Tier II
CH4 slip	3 g/kWh	0.2 g/kWh
Methane Number (MN)	MN ≥ 65 (DCC technology)	Adapt to various MN
Gas consumption	140–142 g/kWh @100%MCR	136–138 g/kWh @100%MCR
Pilot fuel consumption	• 0.8 g/kWh@100%MCR • 2.7 g/kWh@30%MCR	• 5 g/kWh@100%MCR • 12 g/kWh@30%MCR

Figure 1: Comparison of the low-pressure system and high-pressure system [10]

The overall fuel costs for operating a vessel are similar for both solutions. Using the assumed fuel prices and operating profiles low-pressure engines have better NOx emissions, gas fuel supply systems and investment costs, and high-pressure engines perform better in terms of power, thermal efficiency, gas compatibility and methane slip [12]. For liquid natural gas to be used on vessel other than LNG tankers, storage and bunkering of liquid natural gas present additional expenses together with the higher investment cost but it is still widely liked concept because ever growing availability of the LNG as a fuel, easily modified engines to dual fuel and LNG being an alternative fuel in order to comply with strict regulations, excessive costs of MDO.

2.2. LPG

Liquefied petroleum gas or LPG is a mixture of liquefied hydrocarbon gases propane (C_3H_8) and butane (C_4H_{10}). It is produced as a byproduct in numerous petroleum refining processes and its quality is relatively close to the engine fuel requirements. LPG has many different uses, including applications in industry, civil engineering, communal economy, agriculture, households, transport and like LNG growing application in maritime transport as an alternative fuel in in dual fuel engines [13]. Two-stroke dual-fuel engines operating with the diesel cycle combustion process to burn gas LPG are similar to high-pressure system used for LNG. Biggest advantage and reason for LPG to be installed onboard ships with engines running on HFO and MDO with unchanged engine efficiency, then it is possible to install approximately 20% more main engine power with an unchanged EEDI index [14].

2.3. Hydrogen

Hydrogen as an alternative fuel has been considered a promising substitute for fossil fuels used for ships propulsion. Main reason is the fact that hydrogen is a non-carbon fuel and the most abundant element in the universe [15]. Hydrogen in nature is bonded with other elements, like carbon and oxygen, it makes some of the most important compounds for the life as we know it such as water, biomass, aid for us in technical sector fossil fuels, and hydrocarbons. Therefore, several routes, consisting of thermochemical, electrochemical, photo biological, and photochemical methods, have been developed for extracting hydrogen from these compounds [16]. Up to now there is still no engine maker that produces low speed engines since hydrogen is still not widely available but as shown in Figure 2. Consumption of hydrogen will start to grow already by 2025 and continue exponentially by the year 2050, when many companies have obliged to be emission free.

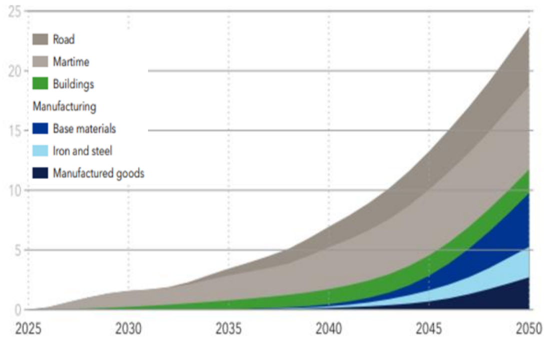


Figure 2: World hydrogen demand by sector [17]

For now, a few concepts are being developed and tested, bearing in mind that hydrogen is less knock-resistant than LNG, this is because of its low methane number, low ignition energy and high flame speed which results in high pressure increase. NO_x in exhaust gas is still present but at acceptable amounts like dual fuel engines running on LNG or LPG with possibility of further reduction using technologies already developed [18]. For now, ammonia (NH_3) is being considered as an energy source which consists of one nitrogen atom and three hydrogen atoms, therefore it is being considered as the most promising hydrogen carrier. Green ammonia is produced by extracting hydrogen from water and nitrogen from air combining them together with presence of another alternative energy source. Unfortunately, this technology is cowering only around 10% of world ammonia production with other 90% being from industrial Haber–Bosch synthesis process which is highly polluting [19] [20]. Presently around 180 M tons of ammonia are produced annually with the CO_2 emission from production plants reaching up to 1% of the total CO_2 released globally [21]. As production of ammonia starts to move in a green way so will the use of dual fuel engines that as a second fuel use green ammonia, with MAN energy solutions planning to produce first engines on ammonia by 2024. Figure 3.

Figure 3: MAN B&W dual-fuel two-stroke engine portfolio [22]

2.4. Methanol

Methanol is a sulfur free, clean-burning, simple alcohol easily produced both from fossil and green sources, with the main ones being natural gas and coal. Renewable or green methanol is produced from pulp mill, waste, and from CO_2 emissions. Methanol as alcohol is mainly produced from corn and sugar cane [23] [24]. As fuel methanol has exceptionally low sulfur content, which makes it compliable with the strictest NO_x regulation. Compared to LNG, it is in a liquid state at standard temperature and pressure which makes it much easier to handle. It has auto-ignition temperature of 464 °C which makes it much safer than diesel whose temperature is of around 240 °C. On the other hand, methanol has less energy density per unit mass and lower viscosity compered to diesel and those factors are especially important when it comes to modifying existing engines from diesel to methanol. Up to now there have been two different engine concepts for methanol. The premixed dual fuel concept and the methanol-diesel concept. Dual fuel concept for methanol is the same as the concept used for LNG, only the gas injecting nozzle is replaced with methanol injecting nozzle and a slight adjustment of air intake are necessary due to different caloric values to keep the same engine output. This output will also be limited by knocking due to octane number of methanol. The methanol-diesel concept is without premixing of methanol and air. Highly pressurized methanol is being injected into the cylinders and being injected by pilot fuel. This concept is more applicable due to having lover emissions of hydrocarbons, formaldehyde and carbon monoxide than the dual fuel concept and it is much easier and less expensive to retrofit engines to the methanol-diesel concept compared to the dual fuel concept [25] [26]. Third option is injecting a mixture of diesel and methanol since experimental results showed that the output power and torque for the methanol–diesel blend fuel are higher than for the conventional diesel fuel alone. The exhaust gas temperature and the specific break fuel consumption for the mixed methanol-diesel fuel was lower than for the pure diesel. Even the addition of 10% methanol to the diesel may have a significant impact on the engine performance and the environment [27]. Methanol's use as a clean-burning, low-carbon fuel, is growing with many engines already in use today. The biggest obstacle is complex production of green methanol, and the appealing side of methanol compared to other alternative fuels is easy handling and the possibility of storing it as a liquid at ambient temperatures and pressures as shown in Figure 4.

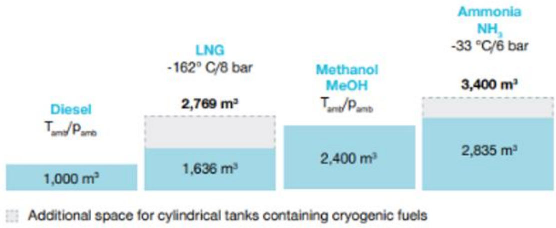


Figure 4: Comparison of storage volume for the same energy amount [28]

3. HYBRID SYSTEMS

Hybrid propulsion system is a combination of two or more power generating systems used for propulsion and other energy needed on board. There are a few combinations being considered and tested depending on the type of ship, sailing area and ratability. Currently, the diesel engine is a most reliable source of propulsion, and it is combined with batteries filled from solar energy, or a fuel cell, wind energy or shore connection [29] [30] [31] [32]. Different combinations are used to achieve different goals like shown in Figure 5. For hybrid propulsion of a cruise ship, diesel generator is combined with solar panels, and fuel cells, to achieve maximum efficiency and reduction of ships fuel consumption, pollution from exhaust gases and Increase in EEDI index. Direct current (DC) from Solar panels and fuel cell is converted to high voltage alternating current (AC) Used for main propulsion, auxiliary machinery, accommodation, and other AC consumers

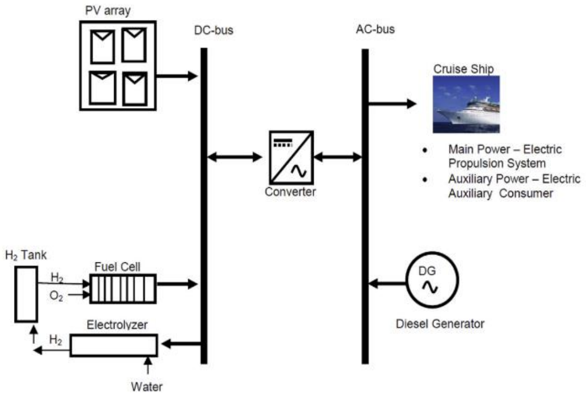


Figure 5: Renewable energy system model: solar PV/PEM fuel cell/Diesel generator [33]

This system, in area with the low solar irradiance of around 2.87 kWh/m2 /day provides all the electrical power needed for the cruise ship and offers the renewable fraction of 13.83%, with 9.44% energy being produced from solar Photovoltaic (PV) and 4.39% from the proton-exchange membrane (PEM) fuel cell. The greenhouse gas and particulate emissions reductions is 9.84% [33]. Wind assisted propulsion in combination with slow speed HFO or MDO engine is also being considered due to its enormous potential, with the wind being an abundant source of energy, and not so complicated and expensive maintenance and handling. Different sail types, arrangements, or sail control strategies can achieve great course stability under sails, better maneuvering capabilities under sails, effect of sails to damp wave motion and different consequence on added resistance in waves [34]. Biggest setback of this technology is reduced speed and being so, this technology is most applicable to bulk carriers and tankers which together represent 75% of the global ocean-going fleet, and if most of these vessels adopt wind technologies, could result in significantly reduced GHG emissions. Flettner rotors giving trust bi Magnus effect Figure 6**.** is the most popular wind technology, and for instance two Norse-power rotor sails of 30 m tall with a diameter of 5 m combined have potential to reduce average fuel consumption on a global shipping route by 7 to 10% [35].

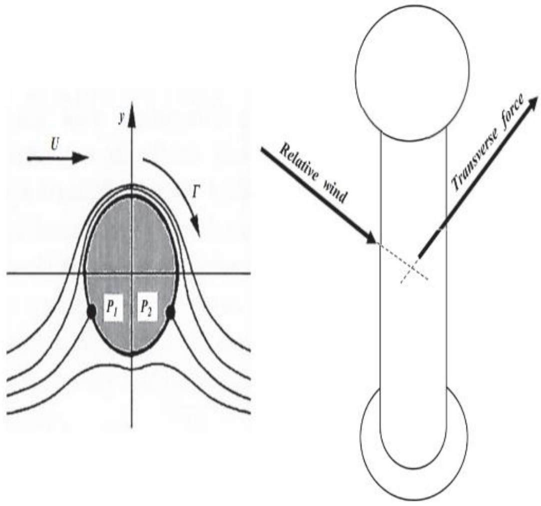


Figure 6: Magnus effect and Flettner rotors [36]

Significant fuel savings can be achieved with Flettner rotors as sails, however, with the current pricing of the sails, the selected route and fuel price, the investment costs of 6 rotors, 5 × 30 m will pay of near the end of a tanker's expected maximum target service life. Until fuel prices go up, or installation price of these sails reduces there will not be great economic benefits of rotor sails [37]. Proper marine antifouling protection can reduce energy consumption and increase operational efficiency. Several new anti-fouling paints claimed to be friendlier to the environment, have entered the market. Biocide-free paints are less environmentally damaging and do not need an approval [38]. Hybrid technologies are a promising solution for cruise ships, small boats, and ferries, because they already use medium and high-speed diesel engine in some sort of combination with electric drive, and as fuel cells, solar panels and wind turbines are getting more efficient and cheaper, fuel is getting more expensive. So, it is expected that these technologies will very soon be installed in every boat that is not equipped with low-speed diesel engine, and depending on the area of sailing it will be a diesel engine combined with both solar panels, wind turbines, and fuel cells. As for merchant navy vessels, hybrid systems are simply less economical than the low-speed dual fuel engine. For example, a medium speed diesel engine has a consumption of around 180g/kWh witch is significantly more than the low speed, dual fuel engine with consumption of 165g/kWh. Hybrid systems can provide energy for accommodation, even cargo heating which would significantly increase the EEDI index of a new built ship or EEXI index of an existing one.

4. ENERGY EFFICIENCY DESIGN INDEX (EEDI)

Energy efficiency design index (EEDI) is based on a complex formula calculating the ratio of the ship's potential CO_2 emission to its available capacity for transporting useful weight. Important indicator of the ship energy efficiency. As a result of more strict air pollution regulations, higher requirements are being set, which is the main reason for new propulsion technologies, alternative fuels, and hybrid systems [39]. As mentioned before, solar energy and solar panels are not a satisfactory solution for ships propulsion, but they can significantly contribute to the ships EEDI, used to generate electricity for ships accommodation, and based on the area of sailing, the solar irradiance, and the temperature of the solar panels [40]. For a Ro-Ro ship with a satisfactory EEDI of 30.948, adding 300 m^2 solar panels on upper decks, and with average solar irradiance of 170 W/m^2 for the Adriatic Sea generates additional 10.629 kW of electrical power. That reduces the power needed from the generator of 5.798 kW, thus improving the EEDI to 30.750 and although it does not look like much it will significantly reduce the CO_2 up to 39869.59 kg yearly [41].

5. CONCLUSIONS

Nowadays, more than ever before, ship owners and ship builders are forced to keep up with strict pollution regulations which as a result brings great developments in ship propulsion systems. Most promising solution is in alternative fuels and modern day low-speed engine makers are focused on finding and developing a fuel, easy to produce, transport, and store onboard ships, that can furthermore be used in internal combustion engines with minimum pollution. Liquid natural and petroleum gas are two solutions that are already in use but the most focus is on ammonia as a hydrogen carrier, and hydrogen itself which has to be to produce in a clean and efficient way. Other solution is green hybrid technology that combines internal combustion engine with some sort of green technology, either sails, wind turbines or solar panels. Unfortunately, current technology simply cannot satisfy the needs of large oceangoing vessels since it is still not as efficient as a low-speed internal combustion engine. For now, it is only suitable for smaller vessels, ferries and cruise ships that already use medium and high-speed engines for propulsion. What will be the next alternative propulsion system is still unknown but as the technology advances more interesting and efficient solutions are being developed.

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REFERENCES

[1] Fourth IMO GHG Study, Published by the international maritime organization 4 Albert Embankment, London SE1 7SR, www.imo.org, (2020).

[2] Jerzy K. & Wieslaw T., (2009) NOx emission from a two-stroke ship engine: Part 2 – Laboratory test. Applied Thermal Engineering 29 2160–2165

[3] Jelić M, Mrzljak V., Radica G., Račić N., (2021) An alternative and hybrid propulsion for merchant ships: current state and perspective // Energy sources part A-recovery utilization and environmental effects, 43 (2021), 1963354, 33 doi:10.1080/15567036.2021. 1963354

[4] Ding Y., Ren H. & Congbiao, S. (2019) Influence of EEDI (Energy Efficiency Design Index) on Ship–Engine–Propeller Matching. Journal of Marine Science and Technology. 7(12):425

[5]] DNV. (2021) Outlook on ship technologies and fuels. Maritime forecast to 2050. dnv.com/eto

[6] Nirendra N. & M., Robert,R. (2008) A Study of the Emissions of a Dual Fuel Engine Operating with Alternative Gaseous Fuels. SAE International in United States

[7] Liang Y., Meng Q., Yonglin J. & Il, M. (2021) Advanced design and analysis of BOG treatment process in LNG fueled ship combined with cold energy utilization from LNG gasification. International Journal of Refrigeration

[8]] Saeid M., John Y. M., Jaleel V. V. & David A. W. Elsevier. (2014) Handbook of Liquefied Natural Gas. Gulf Professional Publishing

[9] Marcel O., Ingemar N., Roland A., Takayuki H., Yoshiyuki U. & Takeshi, Y. (2016). The 2-stroke Low-Pressure Dual-Fuel Technology: From Concept to Reality. CIMAC Congress 2016, Helsinki Paper No. 233

[10] Tu H., Fan H., Lei W. & Zhou, G. (2019) Options and Evaluations on Propulsion Systems of LNG Carriers.

[11] MAN energy solutions. LNGC-optimized designs of ME-GI engines and fuel gas supply systems. Accessed 20. December 2021 from www.man-es.com

[12] Winterthur Gas & Diesel. Low and High Pressure Dual-Fuel Technology Evaluation Process. Interlaken: WinGD Low-Speed Engines Licensees Conference; 2015 Accessed 15. December From https://www.wingd.com/en/documents/general/papers/dual-fuel-technology-selection-(d-stroedecke)

[13] Maciej P., Marcin M., Ryszard P., Andrzej P., Kamil K. & Marcin, P. (2016) Liquefied Petroleum Gas (LPG) as a Fuel for Internal Combustion Engines. - Alternative Fuels, Technical and Environmental Conditions. Accessed on 16. December 2021 from https://www.intechopen.com/chapters/49697

[14] MAN energy solutions. (2018) MAN B&W ME-LGIP dual-fuel engines. Dual-fuel technology reshapes the future two-stroke engine operation. Accessed on 18. December 2021 https://www.man-es.com/docs/default-source/marine/5510-0210-00ppr-man-b-w-me-lgip-dual-fuel-engines-web.pdf?sfvrsn=eb5894b7_12

[15] Jain I. (2009) Hydrogen the fuel for 21st century. Int J Hydrogen Energy; 34:7368–78.

[16] Haryanto A., Fernando S., Murali N. & Adhikari S. (2005) Current status of hydrogen production techniques by steam reforming of ethanol: a review. Energy Fuels; 19:2098–106.

[17] DNV. Rising to the challenge of a hydrogen economy. The outlook for emerging hydrogen value chains, from production to consumption. Accessed on 19. December 2021 from https://www.dnv.com/focus-areas/hydrogen/rising-to-the-challenge-of-a-hydrogen-economy.html

[18] MAN energy solutions. Hydrogen in shipping. Accessed on 18. December 2021 from https://www.man-es.com/marine/strategic-expertise/future-fuels/hydrogen

[19] Ibrahim, D., Yusuf, B. (2018) Ammonia. Elsevier Inc.

[20] Yusuf B. & Ibrahim D. (2017) Clean fuel options with hydrogen for sea transportation: A life cycle approach. International Journal of Hydrogen Energy. Volume 43, Issue 2, 11 January 2018, Pages 1179-1193

[21] Hideaki K., Akihiro H., Kunkuma A. & Ekenechukwu, (2019) C. O. Science and technology of ammonia combustion. Proceedings of the Combustion Institute. Volume 37, Issue 1, Pages 109-133

[22] MAN energy solutions. MAN B&W two-stroke engine operating on ammonia. Accessed on 27. December 2021 https://www.man-es.com/docs/default-source/marine/tools/man-b-w-two-stroke-engine-operating-on-ammonia.pdf

[23] Alvarado M. The changing face of the global methanol industry. IHS Chem Bull 2016:10–1.

[24] Ellis J. & Tanneberger K. (2016) Study on the use of ethyl and methyl alcohol as alternative fuels in

[25] Selma B., Erik F. & Karin A. (2014) Environmental assessment of marine fuels: liquefied natural gas, liquefied biogas, methanol, and bio-methanol. Journal of Cleaner Production. Volume 74, 1 July 2014, Pages 86-95

[26] Hardikk. V., Avinash, K. A. (2019) Methanol as an Alternative Fuel for Diesel Engines. Methanol and the Alternate Fuel Economy Pages9-33

[27] Yusaf T., Hamawand I., Baker P.& Najafi G. (2013) The effect of methanol-diesel blended ration on CI engine performance. International Journal of Automotive and Mechanical Engineering (IJAME). Volume 8, pp. 1385-1395.

[28] MAN energy solutions. Methanol in shipping. Accessed on 30. December 2021 from https://www.man-es.com/marine/strategic-expertise/future-fuels/methanol

[29] Jelić M., Radica G., Račić N. and Mrzljak V., Developments in Marine Hybrid Propulsion," 2021 6th International Conference on Smart and Sustainable Technologies (SpliTech), 2021, pp. 01-06, doi: 10.23919/SpliTech52315.2021. 9566449.

[30] Geertsma R.D., Negenborn R.R., Vissert K. & Hopman J.J. Design and control of hybrid power and propulsion systems for smart ships: „A review of developments “. Applied energy, 194 (2017),30-54.

[31] Zhang C. & Jia B. (2019) The research of power allocation in diesel-electric hybrid propulsion system. Chinese Automation Congress (CAC), Hangzhou, China, IEEE Xplore, accessed 03.01.2022.

[32] Planakis N., Papalambrou G. & Kyrtatos,N. (2020) A real time power split strategy for a hybrid marine power plant using MPC. International journal of modelling, identification, and control. Vol.34, No.2, 2020.

[33] Chaouki G., Maamar B., Boris B. & Abdul, K. H. (2019) Hybrid solar PV/PEM fuel Cell/Diesel Generator power system for cruise ship: A case study in Stockholm, Sweden. Case Studies in Thermal Engineering. Volume, 100497

[34] Thomas S. & Sverre A. A. (2022) Hydrodynamic testing of wind-assisted cargo ships using a cyber–physical method. Ocean Engineering. Volume 243, 110206

[35] Mphatso N. N., Huy B. V., Alessandro S. & Aykut I. O. (2021) Wind and solar assisted ship propulsion optimization and its application to a bulk carrier. Sustainable Energy Technologies and Assessments. Volume 47, 101397

[36] Carlton J.S. Chapter 13. (2019) - Thrust Augmentation Devices. Marine Propellers and Propulsion (Fourth Edition) Pages 367-378

[37] Fabian T., Jonas W. R., Harilaos N. & Thalis Z. (2020) Reduced environmental impact of marine transport through speed reduction and wind assisted propulsion. Transportation Research Part D. Volume 83, June 2020, 102380

[38] S. Manoj, S. Mahesh, D. N. Srikanth (2018) Review of Biofouling Paints on the Marine Vessel, Engineering, Asian Conference on Energy, Power and Transportation Electrification, DOI:10.1109/ ACEPT.2018.8610796.

[39] Huilin R., Yu D. & Congbiao S. (2019) Influence of EEDI (Energy Efficiency Design Index) on Ship–Engine–Propeller Matching. Journal of Marine Science and Engineering. 7(12):425

[40] Germanischer Lloyd SE. (2013) Guidelines for Determination of the Energy Efficiency Design Index. Published by: Germanischer Lloyd SE, Hamburg

[41] Milišić D. (2021) Nove tehnologije brodskih porivnih sustava. University of Split, Faculty of maritime Studies.

EFFECTS OF THE INTRODUCTION OF FREE IJPP TICKETS IN THE REPUBLIC OF SLOVENIA; CASE STUDY OF INTRODUCING FREE TICKETS FOR THE TARGET GROUP

Danijel Hojski, B.Sc.
Imovation, d.o.o, Jarška cesta 10a, 1000 Ljubljana
info@imovation.si, danijel.hojski@student.um.si

Marjan Lep, Ph.D.
University in Maribor, FGPA (Faculty of Civil Engineering, Transportation Engineering and Architecture)
Smetanova ulica 17, 2000 Maribor, Slovenia
marjan.lep@um.si

ABSTRACT

On 1 July 2020, the product IJPP free ticket Slovenia (free ticket) for a target group of population i.e., pensioners were introduced in the system of Integrated Public Passenger Transport (IJPP). A free ticket is a single ticket that can be used in the regional bus and railway traffic throughout Slovenia for at least one year. The introduction of a free ticket aims to bring closer and encourage public passenger transport (from here on PT) by privileging vulnerable groups. In Slovenia, the introduction of free ticket represents a unique whole county-scale measure and an opportunity to determine the effects on travel demand caused by such an event.

The measured different responses and effects of introducing a free ticket are presented, such as the share of beneficiaries who accepted a new offer, frequency of use, short-term and lasting changes in the target group's travel habits, time characteristics of free ticket use, etc.

Keywords: fare-free public transport policy, public transport travel behavior, public transport demand, intelligent public transport, smart card data collection, elderly and vulnerable population

1. INTRODUCTION

On 1 July 2020, the "IJPP free regional ticket or IJPP free ticket Slovenia" (from here on free ticket) was introduced in the IJPP system. A free ticket is a unified ticket used in the regional bus and railway traffic throughout Slovenia. The introduction of the free product led to a significant instantaneous change in the IJPP system in the supply and consequently in demand for public transport, for which there is practically no preliminary information for forecasting and planning service capacities.

The purpose of the study was to monitor the effects on travel demand and travel behavior of target group passengers in regional bus and rail transport. Based on the given data and innovative approaches, a series of analyses were performed, with which we can better understand the effects of the introduction of a free product - the free ticket - for a population group. In this study, the following questions were answered by performing a series of analyses of data obtained from the back-office IJPP system:

- How many of the target population responded to the measure and obtained a ticket, how many used it, and the extent to which the product has been used?
- Are there differences in response and use between the urban and rural environment and by statistical regions of the Republic of Slovenia (from here on regions)?
- What were the day of the week and time of the day choices, and what was the trend of use during the selected period of the research?
- Are the demand patterns for free tickets different from the demand of other users, and what are the differences, if any?

2. METHODOLOGY

2.1. Field of research

The IJPP system uses technology that guarantees users simple, easily understand-able, and quick usage. A contactless check-in ticket validation system has been set up to achieve the user-friendly principle. There is a single tariff for the IJPP system, based on which users can use the links to which they are entitled under the same financial conditions as the products on the single IJPP card. Due to the implementation of smart card technology, every transaction within the IJPP system is recorded in real-time in the back-office system. As the card is placed on the terminal, a communication is carried out, where every operation i.e., transaction, is recorded and stored in the back-office.

The IJPP system covers all regular regional bus and railway traffic lines throughout Slovenia. With the measure, the population group of pensioners (from here on beneficiaries) are entitled to the product of a free ticket. Pensioners are persons who receive an old-age, disability, or survivor's pension under the regulations of the Republic of Slovenia or from a foreign pension insurance institution and are not classified as employed, unemployed, or students according to their activity status [2]. According to the data for the third quarter of 2020, Slovenia had a population of 2,100,126 at the time of the introduction of the measure and the conduct of the survey. 532,169 persons were entitled to a pension, which was 25.3% of the total population [5]. Demographical and spatial characteristics of Slovenia for year 2020 are shown in Table 1.

Table 1: Demographical and spatial characteristics of Slovenia.

	Surface [Km^2]	Population	Number of beneficiaries
Slovenia	20,272	2,100,126	532,169
City municipalities	1,883	755,651	187,466
Ljubljana	275	295,504	67,946

The research was spatially limited to the area of operation of regional bus and railway PT in the entire territory of the Republic of Slovenia. Furthermore, the parameter of " statistical region " was added based on the statistical data of the Statistical Office of the Republic of Slovenia (SURS). Regions of the Republic of Slovenia are shown in Figure 1. Data for regions for year 2020, relevant for research, is shown in Table 2 and Figure 2 [4,5].

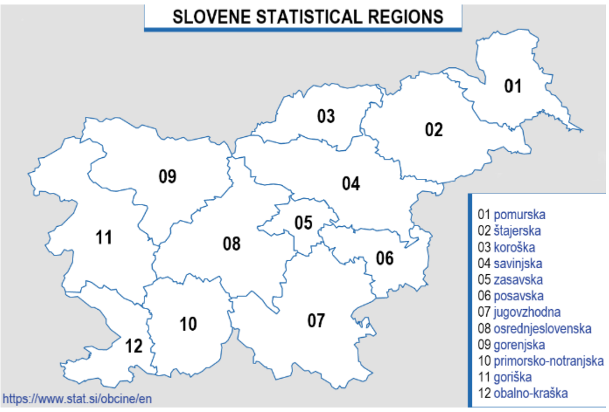


Figure 1: Statistical regions of the Republic of Slovenia

The research was limited in time to the validity period of introducing a free ticket for the following four months: July, August, September, and October 2020. In mid-November, public transport in Slovenia was stopped due to the declaration of a COVID-19 epidemic, and research was not possible. The suspension of public transport followed several previous restrictive measures due to the deteriorating epidemiological situation in October, which clearly shows a decline in traffic compared to the same period in 2019. In July and August, classes and lectures in educational institutions were generally not held due to the summer vacation. The use of IJPP was thus significantly lower during this period. The data used for more detailed analyses of the application of the IJPP were thus covered for the first two weeks of September 2020. Travel demand was also affected by the weather conditions, which were very favorable for this part of the year, with temperatures up to 33°C, average wind speed below 1m/s and precipitation around 0mm/m^2 [1].

Table 2: Characteristics of statistical regions of Slovenia

Statistical region	Surface [km^2]	Population	Share of beneficiaries	Average gross pension [Eur]	GDP by region per person [Eur]
Pomurska	1,336	114,238	26.4%	582,89	14,937
Podravska	2,17	325,994	28.6%	654,3	17,838
Koroška	1,041	70,755	25.3%	672,84	17,885
Savinjska	2,301	257,847	27.2%	687,81	19,987
Zasavska	485	57,156	26.3%	711,98	11,574
Posavska	968	75,824	24.3%	649,5	18,314
Jugovzhodna	2,675	145,357	25.7%	659,82	21,63
Osrednjeslovenska	2,334	555,274	27.0%	803,05	31,169
Gorenjska	2,137	206,621	26.8%	707,74	19,833
Primorsko-notranjska	1,456	52,841	27.4%	666,58	15,837
Goriška	2,326	118,041	26.0%	699,37	19,93
Obalno-kraška	1,043	115,913	28.3%	732,83	22,627
SLOVENIA	20,272	2,100,126	25.3%	709,50	22,083

2.2. Data collection

The IJPP operates at 5,417 bus and railway stops and 2883 lines running in the system. In 2020 there were approximately 500,000 registered users, which provided some 12,000,000 validations. Every bus and train under IJPP is equipped with a terminal that contains a reader with an integrated GPS unit. Consequently, the data set used in this study came from the SCAFC and AVL systems of the IJPP. All validations contain the information about the transaction location (bus/train stop ID) and time (time and date).

As the free ticket measure was introduced, a new user status was granted to beneficiaries for classification. A special card was presented for the free ticket product, which each beneficiary received who applied for a free ticket.

The administrative cost of making and initializing the name card was 3 EUR and represented the only cost for the unlimited use of the IJPP system. Each user of the IJPP system is assigned user status and each product a product status.

The research included data on types of purchase transactions, activation, and validation of tickets. Every ticket issue transaction is recorded as a purchase. The first use of the product is recorded in the IJPP system as product activation, while each subsequent use of the product is recorded as product validation. Activation thus rep-resents the first validation of the product.

The transactions scheme of the IJPP system is shown in the Figure 2.

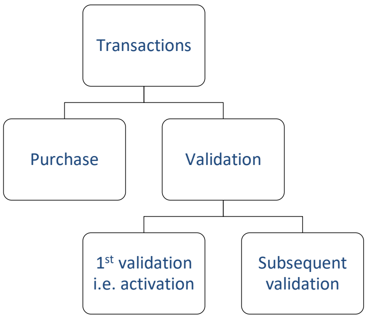


Figure 2: Transaction scheme of the system IJPP

To conduct the analysis, the authors used the following data for ticket purchases: unique identification number, card status, product status, date and time of the trans-action, and the municipality where the card was issued. Subsequently, the authors used the following data for activations and validations of tickets: unique identification number, card status, product status, date and time of the transaction, and the municipality where the transaction was recorded. Based on further data processing, the authors included data on the Republic of Slovenia's post office and statistical region for each transaction, where the product was issued or validated.

The IJPP data set, which had been recorded at the time of transactions, enabled detailed analyses of beneficiaries' quantitative, periodic, and spatial response and use of a free ticket, based on innovative approaches to data collection and processing. Aggregate data were used for the research, where a card identification number was used to separate the products. Each card is assigned a unique identification number in the IJPP system. For the analyses, the following data were included for each transaction:

- unique card identifier,
- type of transaction,
- information on user status and product type,
- time and date,
- unique identifiers for the terminal,
- unique identifier for stop, timetable, and ride, and
- municipality and settlement.

3. RESULTS

3.1. Response to the free ticket introduction

In the period of four months after introducing the free ticket, 148,766 beneficiaries obtained the card and the product, representing 28% of the total population eligible for the free ticket. The share of holders among beneficiaries varied considerably from region to region, ranging from 14% to 40%. The shares of free ticket holders in comparison with beneficiaries by region are shown in Figure 3.

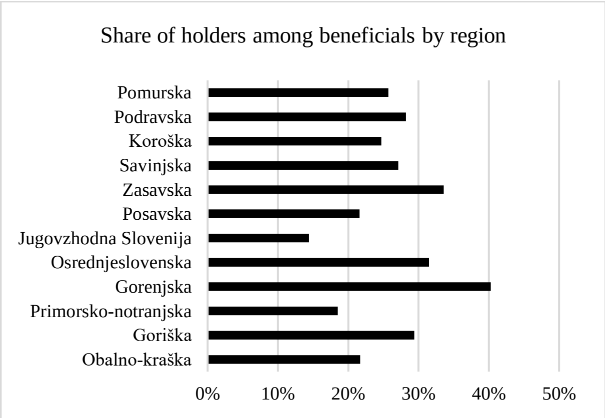


Figure 3: Share of issued free tickets in comparison with beneficiaries by region

The authors determined how the issuance of free tickets took place for the re-search period by weeks. The response of beneficiaries was the highest in July and amounted to as much as 62.5% of all purchases in the research period. The issuance of a free ticket has not yet meant the actual use of the IJPP system. The activation data determined the share of free tickets used. During the study period, 66,669 were activated, which means that only 45% of all issued tickets were used. The main features of the response to the introduction of a free ticket are shown in Table 3.

Table 3: Main characteristic of response upon free ticket introduction

Main characteristic of response upon free ticket introduction	
Number of issued tickets	148,766
Response among beneficials	28%
Share of activated tickets	45%
Average usage of a single ticket	11-times

3.2. Use of free ticket

The responsiveness of the obtained free ticket activation is recorded as the reaction time between the types of purchase and activation transactions. The average reaction time was 22,75 days. In just over four weeks after the purchase, just under 70% of all activated tickets were activated. The authors analyzed the frequency of use to understand the use of the free ticket product. Further, they determined the frequency of use by comparing all activations and validations for all activated products. The average frequency of use for the study period was 11 validations. Frequency of free ticket validations is Figure 4.

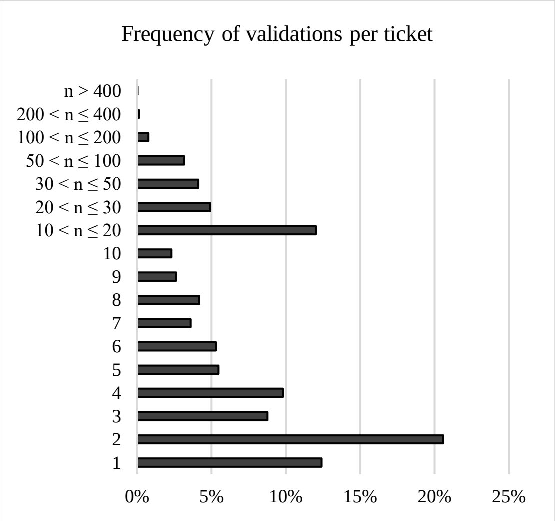


Figure 4: Frequency of free ticket validations

The results show that the free ticket was primarily not used regularly or daily. The authors found that as many as 33% of all tickets were used once or twice. Ten or fewer validations were thus recorded for 75% of all tickets, and 20 or less of validations by as much as 86%.

The trend of validations differs from the trend of ticket purchases. Just over 28% of all validations were recorded in the first two months. The curve then increased over the weeks, peaking in the September, when 35.5% of all validations over the research period were recorded. The measure of introducing a free ticket at the end of the four months research period has seen a sharp decline in beneficiaries' response, which is evident from purchases. The trend of use of the acquired tickets, which is evident from validations, also indicates a decrease. Trend of use of the acquired tickets, which is evident from validations, indicates a declination in the use as well. The reasons for the recorded negative trend in demand for free of charge could not be determined from the surveyed data. The trend of purchases, activations, and validations of free tickets is shown in Figure 5.

The spatial distribution of validations was performed at the level of statistical regions of the Republic of Slovenia. The authors found the validations not to be evenly distributed among the regions. To obtain representative usage data, validations with free tickets were compared with the share of beneficiaries who obtained a free ticket. The number of issued free tickets, shares of free ticket holders' and shares of validations of the free tickets by region 'are shown in Table 4.

The most validations were recorded in the Osrednjeslovenska region (175,936), followed by the Gorenjska region (124,989). Other regions had a significantly lower number of validations, under 100,000. To obtain representative data, the number of validations was compared with the number of issued free tickets. The number of vali-dations per issued ticket was obtained from the comparison. The free ticket was most used in the Obalno-kraška 10.3) and Zasavska regions (10.0). A higher share of use was also recorded in the Gorenjska region. Higher shares of validations, except for the Zasavje region, were again recorded in more developed regions, especially those with tourism. In the Zasavje region, the share may be high due to less developed road con-nections, especially with the Osrednjeslovenska region, where the capital city Ljubljana is located.

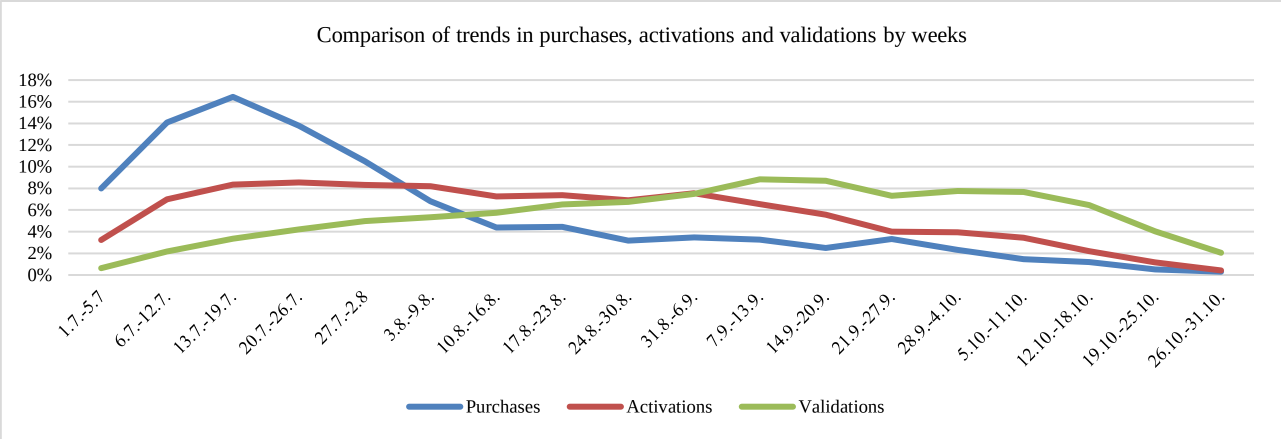


Figure 5: Comparison of trends in purchases, activations and validations by weeks.

Table 4: Validations of free tickets by region depending on the holders' shares among the beneficiaries

Statistical region	Issued free tickets	Holders among beneficiaries	Validations	Validations per issued ticket
Pomurska	8,185	25,70%	31,023	3.8
Podravska	23,526	28,20%	89,132	3.8
Koroška	4,826	24,70%	20,633	4.3
Savinjska	18,042	27,10%	84,666	4.7
Zasavska	5,536	33,60%	55,562	10.0
Posavska	4,366	21,60%	18,454	4.2
Jugovzhodna Slovenija	5,216	14,40%	25,502	4.9
Osrednjeslovenska	39,816	31,50%	175,936	4.4
Gorenjska	21,45	40,30%	124,989	5.8
Primorsko-notranjska	2,609	18,50%	10,07	3.9
Goriška	9,94	29,40%	28,537	2.9
Obalno-kraška	6,523	21,70%	67,393	10.3

3.3. Travel behavior of free ticket users

The study analysed data for the time of the day choice and the time of the week choice. During the research period, most free ticket validations were performed on weekdays (88%). Travel demand of free ticket holders by day of the week is shown in Figure 6.

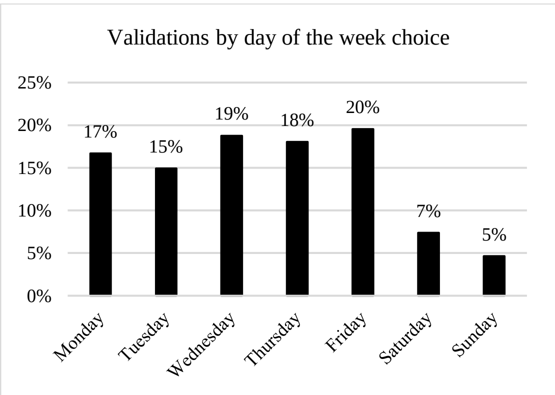


Figure 6: Validation by free tickets by day of the week choice

The authors identified the time of the day choice distribution on validations based on the analysed validations of free tickets by hours. In the analysis, the morning and early afternoon hours (9-15) stand out when 75% of all validations with free ticket were performed. The distribution by part of the day differs for weekdays and weekends. On weekends, especially on Sundays, an increase was observed during the afternoon and evening hours (15-20); it amounted to 50% of all daily validations. A smaller number of validations were recorded for noon hours (11-14). The trend of validations for weekdays, Saturdays, and Sundays by part/time of the day is shown in Figure 7.

The time of the day distribution of validations by region is not evenly distributed. The spatial distribution of validations by the time of the day choice is shown for the most attractive tourist regions (Gorenjska, Obalno-kraška, and Osrednjeslovenska). These regions accounted for 62% of all tourist visits in Slovenia in 2019 [3]. During the weekend, an increase in the number of validations in was observed in both peak periods. During the afternoon peak period, the shares of validations in these regions are significantly higher. The Gorenjska and Obalno-kraška regions thus account for 45% of all validations in the afternoon peak period.

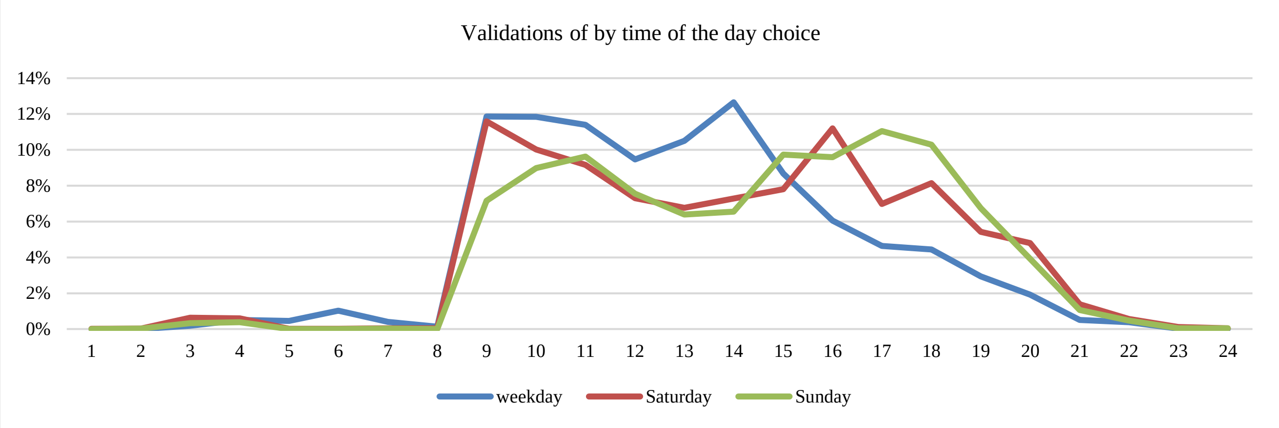


Figure 7: Time of the day choice for weekdays, Saturdays, and Sundays

3.4. Effects of introduction of free tickets on the IJPP system

The number of pensioners who used the IJPP system before the introduction of the free ticket (i.e. between 2016 and June 2020) could not be determined, because there was no product status "pensioner" in the IJPP ticketing system. Consequently, prior data on their use could not have been obtained exactly. Prior to the introduction of the free ticket, there were two product statuses in the IJPP system, i.e., regular ticket and subsidized ticket for the population included in the education programs. Validations with the subsidized ticket accounted for the vast majority of all validations, namely 96%. Pensioners who had previously used the IJPP system must use regular ticket. By comparing the shares of purchases of IJPP tickets for the investigated period of 4 months (1.9.-1.11.) for 2019 and 2020, the share of sales of regular tickets in 2020 did not decrease. It can be assumed that the percentage of pensioners who previously used the IJPP system was significantly less than 4%.

The authors compared the findings on the travel patterns of free ticket users with the characteristics of the remaining traffic in the IJPP system (from here on non-free tickets validations) to evaluate the effects of added travel demand from the use of free tickets. The authors included data for the first two weeks of September 2020 for comparative analysis. 1,008,584 validations were performed in the IJPP system during the study period, of which 90,928 were free tickets, which represented 9.0% of all validations.

Free ticket validations were compared using non-free tickets validations to identify differences in traffic flow distribution characteristics. By day of the week choice 97% of validations were carried out on non-free tickets on weekdays, while the share of free tickets was lower (88%). On this basis, the contribution from free tickets to the full use of the IJPP system during the weekend was 28,8%.

The next indicator of characteristics is the use distribution by the time of the day choice. For non-free ticket validations, particularly during the workdays, there were significant peak periods, i.e., morning (6-8) and afternoon (13-16) peaks, where a total of just under 70% of all validations were recorded. As shown before, the distribution of validations for free tickets differs significantly from non-free tickets validations.

The most pronounced deviation is in the first part of the day (6-13). In the morning rush hour (6-9) the share with a free ticket is negligible. The distribution is quite different in the morning (9-13) when free ticket validations generally account for just under a third of all IJPP system. A comparison of the daily flow of free ticket validations and non-free tickets validations in the IJPP system is shown in Figure 8.

Due to the small number of non-free ticket validations during the weekend, the contribution of validations with a free ticket was more significant than on weekdays. In the peak period, i.e., in the for-non (9-12) and the first part of the afternoon (12-15), validations with a free ticket accounted for half of all IJPP validations, whereas in the second part of the afternoon (15-18), they accounted for a third of all IJPP validations in the measured period.

A comparison of the distribution of validations by part of the day shows that the time of the day choice of free ticket users differs significantly from other IJPP users' traffic flows. Differences in the time of the day choice were determined based on a comparison of validations by region. Significant discrepancies were found in the distribution of validations of free and non-free tickets by region.

Both, on weekday and especially on the weekends, significant deviations in the share of validations were found in the Gorenjska (up to 3,6 times higher), Obalno-kraška (up to 5,5 times higher), and Osrednjeslovenska region (up to 2.7 times lower). Deviations in the distribution of validations were recorded in other regions as well, but they were not as pronounced. The compared data shows differences in the distribution of validations by region and between validations in urban and rural areas. Data on urban areas were obtained based on a settlement where validation was carried out. These settlements with the same name as municipalities with the status of urban municipalities were considered urban areas (source: www.gov.si).

Among the validations of free tickets, the share of validations with a free ticket in a rural area was 58%, which indicates a significantly higher share of validations from rural areas. For non-free tickets validations, 62% of validations were performed in the urban area. Non-free tickets validations are also characterized by a very pronounced centralization of validations in the capital city of Ljubljana. 43.3% of non-free ticket validations were performed in the urban area of Ljubljana. For comparison, only 17.4% of free ticket validations in urban area of Ljubljana were recorded

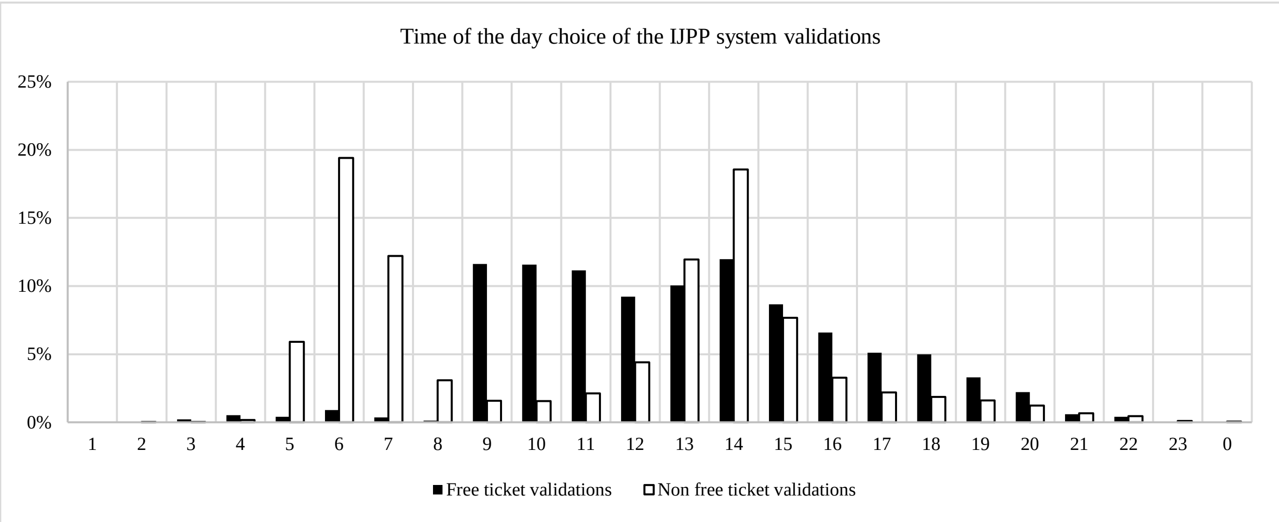


Figure 8: Time of the day choice comparison of free ticket validations and non-free tickets validations in the IJPP

A comparison of spatial distribution between free ticket and non-free ticket validations is shown in Table 5. Shares of free ticket validations in terms of rural and urban areas are shown in Figure 9.

Table 5: Main characteristic of response upon free ticket introduction

	Shares of validations [%]	
	Free ticket	Non-free ticket
Rural area	62	42
Urban area	38	58
Urban area of Ljubljana	14.4	43.3

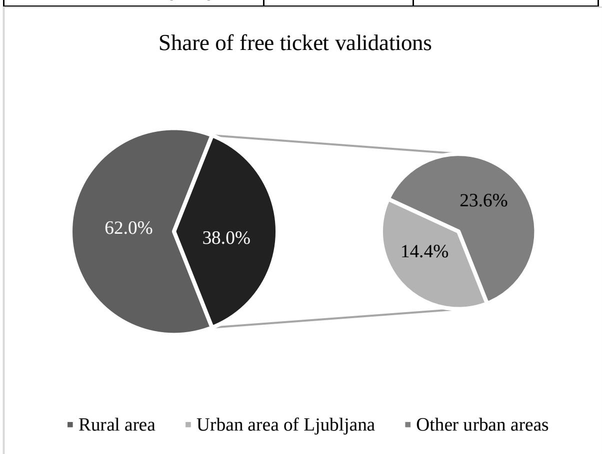


Figure 9: Spatial shares of free-ticket validations

4. CONCLUSION AND DISCUSSION

With the introduction of a free ticket in the IJPP system, there was a significant change in the supply and consequently in the travel demand for public transport for the target group of beneficiaries, representing 25.3% of the 2,100,126 total population in the Republic of Slovenia. The analysis showed that the IJPP system used a minimal number of beneficiaries before introducing the free ticket, as 96% of all validations came from subsidized tickets for the population in educational processes. During the research period, i.e., four months after introducing the free ticket, 150,139 free tickets were issued, representing 28.0% of all eligible persons for the free product. The trend of issuing tickets was the highest in the first month after the introduction, when it presented 62.5% of all tickets from the research period were issued. According to the number of beneficiaries, the distribution of purchases by statistical regions was not uniform. The shares between the regions varied from 14.2-40.0%. The analysis of the actual use of tickets revealed that only 45% of all issued tickets were activated, which shows the psychological moment, where a large part of the population exercises the right to a bonus that they do not intend to use. Most activated tickets were not used daily, as in the four-month research period, the single activated ticket recorded only 11 validations on average.

The most representative two-week research period was chosen to analyse the free ticket use, i.e., the first two weeks of September. Other study periods were significantly affected by summer holidays, restrictive measures, and other influences related to COVID-19 coronavirus disease. A total of 90,928 free ticket validations were recorded during the study period, representing 9,0% of the total use of the IJPP system. Based on a comparison of the number of validations by region, considering the shares of beneficiaries by region that received a free ticket, it was found that the use of free tickets by region was markedly uneven, with usage rates differing by more than ten times. An analysis of validations by day of the week, time of the day, and by regions in the Re-public of Slovenia was performed to understand travel demand characteristics. Based on a comparison with the travel demand of other users of the IJPP system, the authors found that the travel demand characteristics of free ticket holders differ significantly. Differences were found at all levels of analysis. On a weekly basis, free tickets had a higher share of weekend use (12%) than other IJPP tickets (3%). Discrepancies for the time of the day validation flow and spatial distribution were found for users of the free ticket compared to other users of the IJPP system. For non-free ticket users, it was characterized by a curve of two distinct peak periods, where 70% of all free ticket validations were performed. In the distribution of free ticket use, it was found that the daily distribution of validations with free tickets did not record significant hourly peak periods. About 75% of all daily validations with a free ticket were performed in the for-noon and afternoon.

Also identified in spatial terms were differences in travel demand. Differences were found at the regional level and at the urban and rural levels. The use of a free ticket is less centralized. 17.4% of validations were performed with a free ticket in the urban area of the capital of Slovenia, Ljubljana. Significantly more non-free tickets were made, namely 43.3%. The compared tickets' validation ratios between urban and rural areas are almost reversed. 42% of validations were performed with a free ticket in urban areas.

From the spatial point of view, differences were found at the levels of regions and the urban and rural environment. The use of a free ticket is less centralized. 17.4% of validations were performed with a free ticket in the urban area of the capital of Slovenia, Ljubljana. Significantly more non-free tickets were made, namely 43.3%. The compared tickets' validation ratios between urban and rural areas are almost reversed. 42% of validations were performed with a free ticket in urban areas.

The study representatively demonstrated a difference in the characteristics of the travel demand of free ticket users. For travel planning, this means a change in travel demand in a very brief time. The use of modern approaches to ITS technology enables immediate and detailed insight into the data that were processed and analysed with innovative approaches. The characteristics identified with the introduction of the free ticket may in the future be the starting point for automated detection of sudden deviations in travel demand of morning and forenoon validations, which would, based on known correlations be-tween traffic flows in the system, result in immediate proposals for afternoon and evening traffic flows. Such an algorithm of automatic demand detection would enable operators to use capacities more efficiently – to reduce delivered overcapacities and to avoid overcrowded busses or not served costumers due to lack of available seats, as a main performance indicator.

REFERENCES

[1] Ageny of Republic of Slovenia. Available online: https://www.arso.gov.si/ (accessed on January 29, 2022).

[2] Razpotnik B., Methodological note: Socio-economic characteristics of the population and migrants, December 2021, published by the Statistical Office of the Republic of Slovenia, p. 6. https://www.stat.si/StatWeb/File/DocSysFile/8351 (accessed on January 30, 2022).

[3] Statistical bureau of Republic of Slovenia, arrivals and overnight stays of domestic and foreign tourists, municipalities, Slovenia, annually. Available online: https://pxweb.stat.si/SiStatData/pxweb/sl/Data/-/2164525S.px (accessed on March 15, 2021).

[4] Statistical bureau of Republic of Slovenia, number of pensioners. Available online: https://pxweb.stat.si/SiStatData/pxweb/en/Data/-/05G3007S.px/ (accessed on December 17, 2021).

[5] Statistical bureau of Republic of Slovenia, number of residents. Available online: https://pxweb.stat.si/SiStatData/pxweb/sl/Data/-/05A1002S.px (accessed on December 17, 2021).

[6] Statistical bureau of Republic of Slovenia. Available online: https://www.stat.si/statweb (accessed on December 17, 2021).

THE ANALYSIS OF THE CORROSION PROCESS OF A CU-AL-NI SHAPE MEMORY ALLOY IN MARINE IMMERSION AND COSTAL ENVIRONMENT

Špiro Ivošević, Ph.D.
University of Montenegro, Faculty of Maritime Studies Kotor
Put I Bokeljske brigade, Kotor, Montenegro
spiroi@ucg.ac.me

Nataša Kovač, Ph.D.
University of Donja Gorica, Faculty of Applied Sciences
Oktoih 1, Donja Gorica, Podgorica, Montenegro
natasa.kovac@udg.edu.me;

Gyöngyi Vastag, Ph.D.
University Novi Sad, Faculty of Sciences
Trg Dositeja Obradovića 3, 21 000 Novi Sad, Serbia
djendji.vastag@dh.uns.ac.rs

ABSTRACT

The application of shape memory materials in the marine environment requires laboratory or real-world research that should determine the depth and rate of corrosion and analyze the changes in the chemical composition of the alloys. For the purposes of this study, a real-world experiment was conducted during 12 months with a Cu-Al-Ni alloy that was produced by new continuous casting methods. Six alloy samples were placed in three different types of the environment for 6 and 12 months. Focus Ion Beam (FIB) and semi-quantitative energy dispersive X-ray (EDX) analysis determined the corrosion depth and chemical composition of the alloy. The values for each type of the environment were obtained by the measuring of corrosion depth with FIB and by the application of a linear model to the values of corrosion rate. The rate and depth of corrosion of the alloy increased over time, resulting in the formation of a corrosive layer on the alloy surface. Depending on the environment in which the alloy was located, the corrosive layer increased over time thus preventing further diffusion of corrosive agents (mostly oxygen) over the surface of the alloy. In this paper, the EDX method was used to analyze the percentage of oxygen in the corrosive rust layer that appeared on the alloy in all environmental conditions after 6 and 12 months of exposure. The comparison of the results of the corrosion rate and depth on the alloy surface with the rate of the increase in oxygen percentage in the rust indicated the dependence of the corrosion rate of the Cu-Al-Ni alloy on the rate of oxygen increase. The data show that the formation of the corrosive layer in the sea has a dominant effect on the deceleration of the corrosion of the alloy that is exposed to the marine environment.

Keywords: marine environment, Cu-Al-Ni alloy, corrosion, linear regression

1. INTRODUCTION

Corrosion is one of the most dominant causes of material degradation that affects a partial or complete destruction of materials. More precisely, corrosion is a chemical or electrochemical process of the destruction of metals, which is manifested through rusting, discoloration and tarnishing [1]. Corrosion represents a dominant degrading factor in various industries and occurs in all types of the environment such as atmosphere, sea, land and sludge, etc. The losses caused by corrosion in aircraft, automotive, marine, and other industries occur in many countries. The latest estimates indicate that the damage caused by corrosion of materials (predominantly metals) comprises about 3-4% of the Gross National Income of developed countries [2].

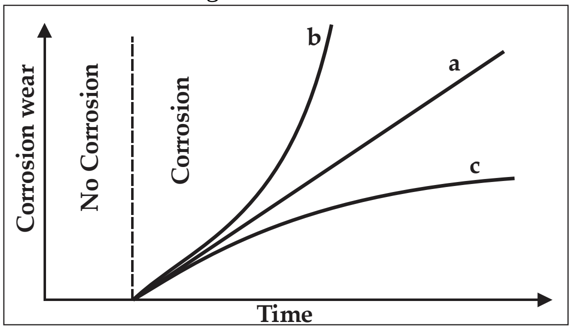
Corrosion is especially notable in the marine environment on the metals that are submerged in the sea, splashed or located in tidal and costal environment. All types of vessels and marine installations are typically made of different metal materials which are, due to the complex environmental conditions, subjected to monotonous degrading processes. Depending on the environmental conditions in which metals are located and, on the chemical, mechanical and physical characteristics of metals, there are different types of corrosion e.g. general corrosion, pitting, erosion, cavitation, stress, etc. The degrading processes can be described through the depth of corrosion (mainly expressed in nm or mm of wear) or the weight loss of materials (expressed in grams, kilograms or tons) over time (expressed in days, months, years).

Electrochemical corrosion occurs as a process of interaction between metals and the corrosive environment. Corrosivity is more notable on metal materials that are placed in the seawater that contains certain amount of salt because salt increases the electrical conductivity of the media around the metal. The process is additionally intensified by the presence of microorganisms. Due to the environmental influences, inhomogeneities emerge on meatal surfaces and increase the susceptibility to corrosion that further leads to the creation of the cathode or anode components in the metal structure [3].

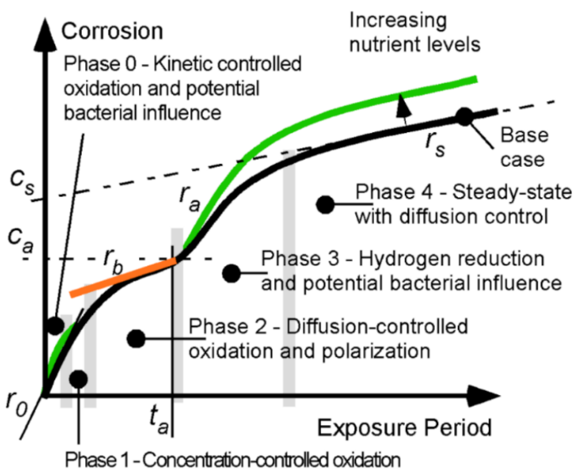
Atmospheric corrosion can take different forms and can be classified as high, damp or wet. However, in the marine environment, the focus is on the wet film which is related to sea spray, rainwater, dew, and other forms of the contact with seawater particles. In coastal areas, where the land and sea are in immediate contact, the marine atmosphere and environment depend on the topography of coast, waves at the surfline, dominant winds and relative humidity. Salt dissolution on metal surfaces and humidity above 55% are dominant factors that cause severe corrosive damage to many structural materials. Chloride ions in the marine atmosphere are considered derivatives of sodium chloride [4].

Numerous biological, chemical and physical factors of seawater accelerate corrosion [5]. Furthermore, seawater contains a considerable number of animals and plants that can also influence corrosion process. The observation indicated that a micro alga communities emerge on metal surfaces immediately upon the immersion of a metal into seawater [6].

The atmosphere, tidal zone and immersion have different effects on the corrosive processes of metal structures. Regarding the corrosion of metal materials, it should be noted that there is a phase without corrosion when the surface protection is still efficient. Corrosion process starts after the cracking of the coating and the contact of a metal with the external environment. The development of corrosion depends on the environment and can be accelerated or decelerated over time, as shown in Figure 1.a. Linear (Figure 1.a - curve a) and nonlinear corrosion models were developed based on previous research and the analysis of corrosion processes, which can be presented by different curves (b and c) in Figure 1.a. Corrosion process which increases and accelerates over time corresponds to the conditions of immersion into the sea (b curve in Figure 1.a). On the other hand, the corrosion process which is initially accelerated and subsequently decelerated is more typical for the structures which are not submerged into the sea and whose corrosive layer prevents further exposure of the metal to the corrosive environment (curve c in Figure 1) [7].



a) A simple linear model [7]



b) Melchers' four-phase model [9]

Figure 1: The overview of different corrosion models

Based on the existing studies, corrosion process can be explained in detail through several phases. Four-phase corrosion model suggested by Melchers is presented in Figure 1.b. The first and the second phase can be described as aerobic whereby corrosion process is controlled by the rate of oxygen formation on a corroded surface. Corrosion over time continues to produce rust (corrosion product) and the rate of oxygen diffusion trough rust becomes rate-controlled. This process is usually described as nonlinear process under aerobic conditions. The third and fourth phases are considered anaerobic as they start when rust layer increases to the extent of preventing the entrance of oxygen from the environment into a corroded surface [8, 9].

Although corrosion process was described in numerous studies, the recent applications of new materials for different maritime purposes requires testing in laboratory and real-world conditions with the aim of determining the mechanical, physical and chemical characteristics of the new materials. Furthermore, corrosion resistance is particularly important for the use of metals and alloys such as shape memory alloys.

Among various shape memory alloys, the alloys based on Cu, Al and Ni are the most widely distributed in the combinations of binary, trinary and quaternary systems. The mechanical and chemical characteristics, biocompatibility and corrosion resistance are the main reasons for the application of shape memory alloys in medicine, aviation, automotive, maritime, robotic and other industries.

The Cu-Al-Ni alloys are characterized by lower production costs, an easy control of alloy composition, higher modulus of elasticity, better work-cost ratio and machinability. The corresponding transformation temperature ranges between -200 °C to 200 °C depending on the content of Al and Ni [10]. The greatest disadvantage of the Cu-Al-Ni alloys is a low reversible deformation (one-way memory effect is up to 4%, while two-way memory effect is only about 1.5%) [11].

The application of copper-based alloys has recently attracted a lot of attention in various branches. The application of new alloys in maritime industry is particularly challenging and requires laboratory and real-world experimental research. This paper investigates the possibility for the use of the Cu-Al-Ni alloys with a memory shape in the marine environment. The marine environment implies a constant exposure to the marine atmosphere and the immersion into seawater. In addition to these two static conditions, the dynamic influences of ebb and flood currents in tidal and splashing zones should also be taken in consideration.

The same authors previously analyzed the depth and rate of corrosion depending on the length of exposure and oxygen percentage in the alloy [12, 13, 14, 15]. This research, however, compares the depth and rate of corrosion of the Cu-Al-Ni alloy samples depending on the oxygen content in the corrosion product that emerged on each sample of the examined alloy after 6 and 12 months of exposure. The research should facilitate the analysis of corrosion processes and products on the surfaces of alloys depending on the length of exposure and environmental conditions.

2. METHODOLOGY AND MATERIALS

2.1. Methodology

The research is based on the analysis of the varied influences of the marine atmosphere and immersion into seawater as well as the changeable influences of the sea and atmosphere in tidal zone over 6 and 12 months.

The experiment with the Cu-Al-Ni alloy rod samples was conducted at three different marine locations between August, 2018 and December, 2019. The samples in seawater were exposed to the marine environment between August 2018 and August 2019, while samples in atmosphere and tidal zone were exposed between December 2018 and December 2019. During the experiment, the average temperature was 17,05 ^{0}C in shallow seawater and 17,55 ^{0}C on the surface. The salinity was 36,54 ‰ in shallow water and 29.93 ‰ on the surface. More details about the atmosphere and seawater parameters can be found in a previously published article [12].

The alloy samples and the corrosion products formed on each sample were analyzed after the period of exposure. In that sense, the samples were examined by means of energy dispersive X-Ray spectroscopy (the EDX analyses) and Focus Ion Beam (FIB) methods that provided measuring data that is necessary for the future analysis.

The FIB method was used for the calculation of corrosion depth (in nm) on the surface of alloy samples. The number of corrosion depth measurements was a part of the empirical database which was used for the development of a linear corrosion model.

The EDX analysis indicated the distribution of the chemical compositions of the metals which were taken from the corrosive residues of the corrosion product on alloy surface. The chemical composition of the Cu-Al-Ni alloy was determined by means of an electron microscope and semi-quantitative analysis. The microscope contained an Energy Dispersive Spectrometer (EDS) - Oxford INCA 350 - for microchemical analysis. Since corrosion process occurs mostly due to the increase in oxygen content, the EDX analysis indicated the number of measured data on oxygen content in corrosion product after exposure and such data were used as an empirical database for future analyses.

In previous studies, the change in the increase in corrosion depth and oxygen content in the examined alloy were described by corresponding linear models. This paper examines the increase in the corrosion rate of the examined alloy and oxygen content in corrosion product (rust) for the three types of the environment after 6 and 12 months of exposure. In that sense, the conducted statistical analysis aims to compare the linear dependence between corrosion depth and rate on the percentage of oxygen in all of the analyzed samples.

2.2. Materials

The research focused on a Cu-Al-Ni alloy that was produced by a standard casting process in the shape of a rod and with the length of 50 mm and diameter of 7 mm. The production of the Cu-Al-Ni SMA bars was based on pure metals delivered by Zlatarna Celje d.o.o. Slovenia: Cu (99.99 wt.%), Al (99.99 wt.%) and Ni (99.99 wt.%).

The samples were adequately cut, processed and prepared for testing [16]. Furthermore, Inductively Coupled Plasma (ICP) analysis and X-Ray Fluorescence (XRF) analysis were performed to identify the ratio of chemical elements of the initial composition of the Cu-Al-Ni alloy. Copper (Cu) was the basis, the percentage of aluminum (Al) was between 9.4 - 9.6% (XRF) and 12% (ICP) while the percentage of nickel (Ni) was between 3.9% (ICP) and 4.4% (XRF) [16].

Six samples, without previously applied protective coating were located in three separate zones. Three samples were analyzed after 6 months and three samples after 12 months of exposure.

Figure 2 shows the samples exposed to three different environmental conditions after 6 and 12 months of exposure. The least changed was the sample exposed to the air, while the most affected was the sample that was placed in the sea. Only the lower part of the sample that was in the sea for 6 months notably corroded due to the exposure to accumulated sand and salt, while the surface of the sample that was in the sea for 12 months was almost entirely corroded.

The samples from Figure 2 were subjected to the FIB analysis with the aim of determining the depth of corrosion. The corrosion depth that was calculated and expressed in nanometers facilitated the calculation of corresponding corrosion rate by means of the existing, well-known, linear models [15].

In this article, based on the rust formed on the alloy surface, the EDX analysis determined the chemical composition of the corrosion product of the Cu-Al-Ni samples. Figures 3.a and 3.b show the tested samples of the corrosion product on the Cu-Al-Ni sample that was in the sea for 6 and 12 months. Figure 3.c shows the corrosion product that was formed in the sea during 12 months and subsequently subjected to the EDX analysis.

a) Six-month exposure to the atmosphere

b) Six-month exposure to tides

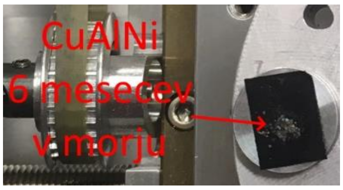
c) Six-month exposure to the sea

d) twelve-month exposure to the atmosphere

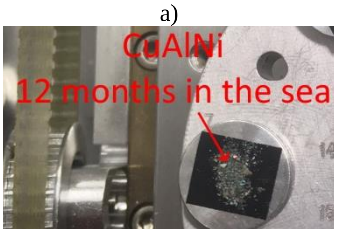
e) Twelve-month exposure to tides

f) Twelve-month exposure to the sea

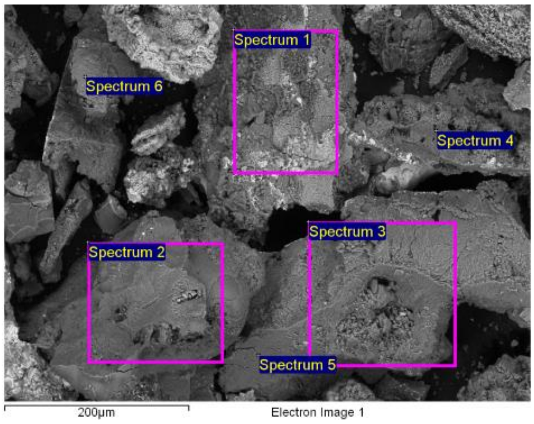
Figure 2: The sample rods of the Cu-Al-Ni shape memory alloy after 6 and 12 months of exposure to three types of the environment



a)



b)



c)

Figure 3: The samples of the corrosion product that was formed in the sea after 6 months of exposure (a) and 12 months of exposure (b), the EDX view of the sample after 12 months of exposure (c)

The analysis included 6 samples of the Cu-Al-Ni alloy - 3 samples were examined after six months and 3 samples after 12 months of exposure. Similarly, 6 samples of rust were also taken into consideration - 3 samples were analyzed after 6 months of exposure and 3 samples after 12 months of exposure. According to the performed measurements and the application of the methods described, the data on the depth of corrosion in nm are presented in Table 1 while corresponding empirical data and the percentage of oxygen are presented in Table 2 for the three types of the environment examined.

Table 1: The corresponding number of empirical data and the average depth of corrosion for the three types of the environment after 6 and 12 months

AIR	6	12	TIDE	6	12	SEA	6	12
No. of points	20	27	No. of points	20	21	No. of points	20	20
Avg. corrosion depth in nm	220.3	975	Avg. corrosion depth in nm	775.00	3330	Avg. corrosion depth in nm	787.50	2110.00

:

Table 2: The corresponding number of empirical data and the average values of oxygen content in corrosion products in three types of the environment and exposure periods

AIR	6	12	TIDE	6	12	SEA	6	12
No. of points	12	12	No. of points	12	12	No. of points	18	12
Avg. in % O_2 in corrosion product	13.8	37.3	Avg. in % O_2 in corrosion product	18.49	49.6	Avg. in % O_2 in corrosion product	30.3	50.31

Considering the data from Table 1 and Table 2, it can be concluded that the lowest values correspond to the influences of the atmosphere, while the highest values correspond to the influences of the sea. On the basis of a linear model of corrosion development, the following chapter will consider the increase in the corrosion rate of the examined alloy and the percentage increase in oxygen in corrosion product.

3. RESULTS

3.1. The Analysis of Corrosion Rate and Depth in Relation to Oxygen Content in Corrosion Product

The diagrams in Figures 4 and 5 were created by the application of a linear corrosion model and the analyses of corrosion rate of the alloy and oxidation of corrosion product after exposure. The diagrams show the dependence of corrosion rate expressed in nm/months on the percentage of oxygen content in the three types of the environment examined. Furthermore, Figure 4 shows the dependence of corrosion depth on oxygen content in corrosive product in %(w/w). In both cases, the values of corrosion rate and oxygen content are the lowest in the air. In the legends used in Figure 4 and Figure 5, the label index indicates the marine environment in which the experiment was performed (a, t, and s were used as labels for air, tide, and sea, respectively). Additionally, the types of the marine environment are highlighted with corresponding colors – the air with blue, tide with red, and sea with green color.

Corrosion rate and depth of the examined alloy as well as percentage increase in oxygen in corrosion product are the lowest in the air and the highest in the sea. The rate of change in oxygen in corrosion product is higher than the rate of other changes in the alloy. The most notable changes in comparison with the depth and rate of corrosion were observed in the tidal zone that is characterized by the dynamic processes of alternation of wet and dry cycles. It should be noted that the rate of percentage growth of oxygen in corrosion product is higher in comparison with the examined changes in the alloy in the three types of the environment.

3.2. The Analysis of Oxygen Content in Corrosion Product

Figure 6 shows the amount of oxygen detected by the EDX analysis in corrosion product on the surface of the alloy samples that were exposed to different types of the coastal environment for 6 and 12 months, respectively.

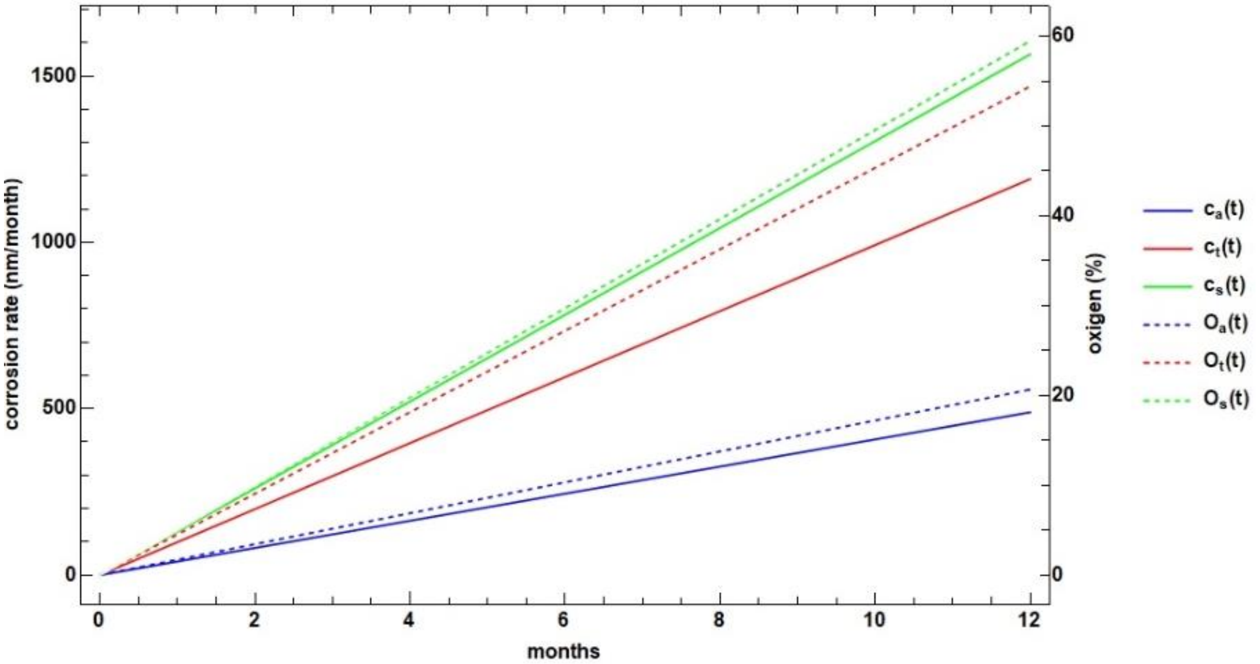


Figure 4: The corrosion rate of the alloy and oxygen rate in corrosion product in three types of the environment

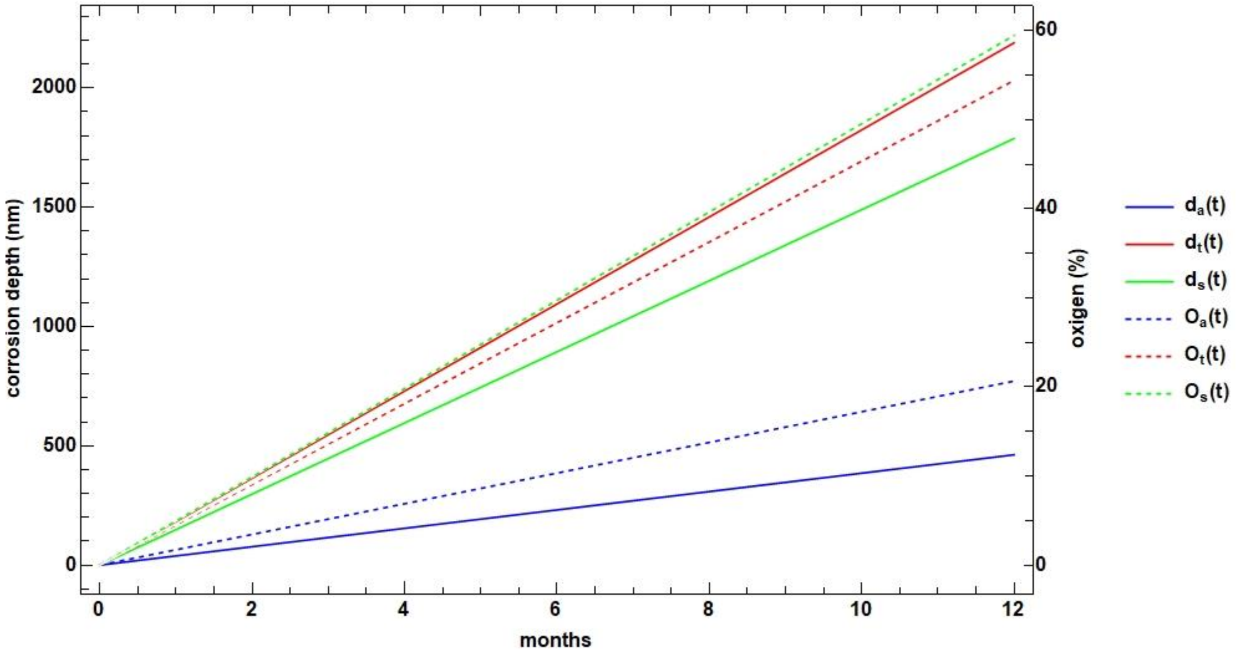


Figure 5: The corrosion depth of the alloy and oxygen rate in corrosion product in three types of the environment

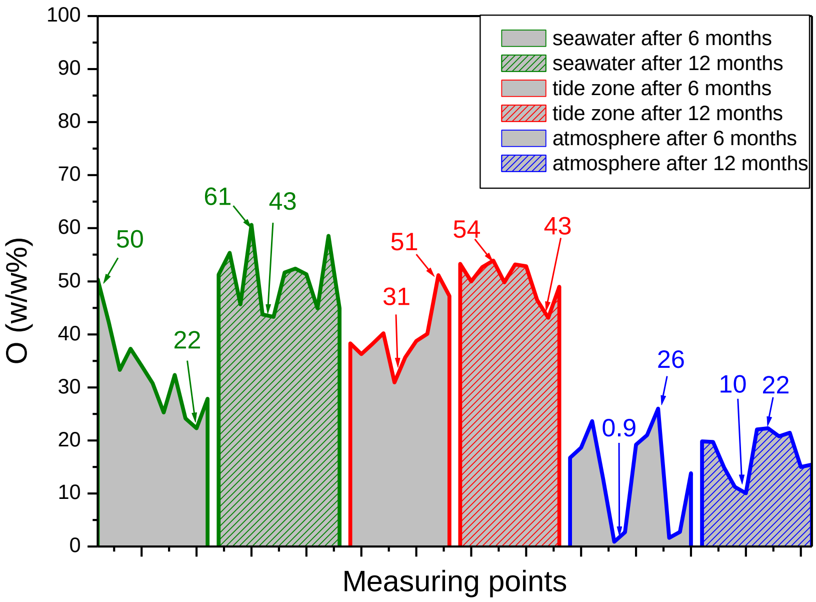


Figure 6: The content of oxygen in corrosion product at the tested locations after 6 and 12 months

Figure 6 clearly shows that the oxygen content detected by the EDX analysis in the corrosion product formed on the Cu-Al-Ni alloy surface varies both, as a function of the type of corrosive environment, and as a function of the length of exposure.

Considering the types of the corrosive environment, Figure 6 shows that in the first 6 months, as expected, the lowest percentage of oxygen was detected in the corrosion product that was formed under the influence of the air. The number of oxides in the corrosion product formed under the influence of seawater and tides has approximately the same order of magnitude – it is, on average, slightly higher under the influence of tides. On the other hand, the values relevant for the sea influences are significantly higher in comparison with the number of oxides formed under the influence of the air (25-50%). Based on the considerations above and on the assumption that the corrosion of alloy elements occurs through the formation of oxides [17], it can be concluded that the degradation of the Cu-Al-Ni alloy is significantly slower under the influence of the air, and has approximately the same rate under the influence of the other two marine locations.

Several effects were noticed after the analysis of the influence of the length of exposure to different types of the corrosive environment on the amount of the oxygen detected in corrosion product. The amount of oxygen slightly increases (~ 4%) after additional six-month exposure to the influences of the marine atmosphere. There was a more notable reduction in scattering between measured points, which indicates that the surface deposits become more homogeneous over time. Similarly, under the influence of tidal zone, there is, on average, a slight increase in the amount of oxygen in the analyzed sample (~ 10%) during the prolonged exposure. With the increase in the length of exposure, seawater leads to the most significant increase in the amount of oxides in corrosion product (on average ~ 17%). Therefore, the formation of corrosive products during prolonged exposure of a Cu-Al-Ni alloy to the corrosive environment undergoes the greatest changes under the influence of seawater.

4. CONCLUSION

This paper analyzed the changes in a Cu-Al-Ni alloy and the corrosion product of the alloy after 6 months and 12 months of exposure. Corrosion depth and rate of the examined alloy as well as the percentage of oxygen in corrosion product in three different types of coastal environment (the sea, air and ebb and flood tides) were analyzed by means of a linear model of corrosion development. The obtained results confirmed the assumptions for all types of the environment:

- The increase in the rate and depth of corrosion of the examined alloy is the least notable in the atmosphere compared to other two types of the marine environment examined.
- The increase in oxygen in corrosion product is higher than the corrosion rate of the examined Cu-Al-Ni alloy samples in all types of the environment, whereby the highest increase was observed in tidal zone, which could be attributed to the dynamic processes of the alternation of wet and dry cycles.
- The results of the EDX analysis indicated that the oxygen content in the corrosion product that was formed on the surface of the Cu-Al-Ni alloy depends on both, the corrosive environment and the length of exposure of the alloy to such environment.
- The lowest number of oxides was registered in the corrosion product formed under the influence of the air and such oxide content was the least changed over time.
- The greatest changes in oxygen content as a function of time were detected in the corrosion

product formed under the influence of seawater.

The future research should investigate the impact of changes on other chemical elements such as chlorides, carbon, etc. over the extended period of time. Other shape memory materials should also be included in examination.

REFERENCES

[1] Speller F.N., 1951. Corrosion (Causes and Prevention) McGraw-Hill Book Company Inc., New York.

[2] G. Koch, Trends in Oil and Gas Corrosion Research and Technologies: Production and Transmission Woodhead Publishing, (2017), Cambridge, England.

[3] Evans U.R and Hoar T.P, 1932. Proc. Roy. Soc. (A), 137-343.

[4] S. Syed, Atmospheric Corrosion of Materials, Emirates Journal for Engineering Research, 11 (19, 1-24 (2006)

[5] Schumacher, M.: Seawater corrosion handbook, NJ: Noyes Data Corporation, 1979

[6] Southwell C R, Bultman J D, Hummer C W Jr 81979), Etimating service life of steel in seawater, In. Schumacher M (ed) Seawater Corrosion Handbook. Noyes Data Corporation, New Jersy, pp 374-387.

[7] Wang, T.; Spencer, G.; Elsayed, J. Estimation of corrosion rates of oil tankers. In Proceedings of the 22nd International Conference on Offshore Mechanics and Arctic Engineering, Cancun, Mexico, 8–13 June 2003; pp. 253–258

[8] Melchers, Robert, E.: "Advances in Mathematical-Probabilistic Modelling of the Atmospheric Corrosion of Structural Steels in Ocean Environments", 3rd International ASRA Net Colloquium, Glasgow, UK, 10–12th July 2006.

[9] Robert E. Melchers, Modeling and Prediction of Long-Term Corrosion of Steel in Marine Environments, International Journal of Offshore and Polar Engineering, Vol. 22, No. 4, December 2012, pp. 257–263

[10] M. Mišović, B. Radulović / B. Perović, Metal Materials II, Podgorica: Univerzitet Crne Gore, 2001.

[11] D. Ćubela, „SHAPE MEMORY ALLOYS," u Mašinstvo, 2002.

[12] Špiro Ivošević, Nataša Kovač, Gyöngyi Vastag, The determination of corrosion rate through oxygen content in a cu-al-ni alloy under the influence of seawater, 2nd International Conference of Maritime Science & Technology NAŠE MORE 2021, Dubrovnik, Croatia, 17 – 18 September 2021.

[13] Kovač, N.; Ivošević, Š.; Gagić, R.; "Estimation of the NiTi alloy corrosion rate dependence on the percentage of oxygen in three different seawater environments", International Conferences on Science and Technology, ICONST EST 2021, Budva 8-10.09.2021.

[14] Ivošević, Š., Kovač, N., Vastag, G., Majerič, P., Rudolf, R.: A Probabilistic Method for Estimating the Influence of Corrosion on the CuAlNi Shape Memory Alloy in Different Marine Environments, Crystals 2021, 11, 274. https://doi.org/10.3390/cryst11030274

[15] Kovač, N.; Ivošević, Š.; Vastag, G.; Vukelić, G.; Rudolf, R.; Statistical Approach to the Analysis of the Corrosive Behaviour of NiTi Alloys under the Influence of Different Seawater Environments. Appl. Sci. 2021, 11, 8825. https://doi.org/10.3390/app11198825

[16] Ivošević, Š., Majerić, P., Vukićević, M., Rudolf, R., "A Study of the Possible Use of Materials With Shape Memory Effect in Shipbuilding", Journal of Maritime & Transportation Sciences, Vol. Special edition No. 3, 2020, pp. 265-278.

[17] Vastag Gyongyi, Ivosevic Spiro, Nikolic Danilo, Vukelic Goran, Rudolf Rebeka : Corrosion Behaviour of CuAlNi SMA in different Coastal Environments, Int. J. Electroch. Sci., (2021), vol. 16 br. 11, Article ID: 21121

IMPORTANT NOTE

This paper is a result of the research on different influences of the sea and atmosphere to the production and application of smart materials of shape memory alloys in maritime industry. The PROCHA-SMA project is a part of the EUREKA Project,which is realized jointly by the Faculty of Stomatology in Belgrade, Zlatarna Celje d.o.o. in Belgrade, Serbia, and the Faculty of Maritime Studies Kotor, the University of Montenegro.

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AN OVERVIEW OF RISK ASSESSMENT METHODS FOR MARINE POWER SYSTEMS

Ivana Jovanović, M.Eng.
Nikola Vladimir, Ph.D.
Maja Perčić, M.Eng.
Marija Koričan, M.Eng.
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10002 Zagreb, Croatia
ivana.jovanovic@fsb.hr

ABSTRACT

The maritime sector is exploring the applicability of alternative powering options and ways to implement new technologies to increase safety, efficiency, and autonomy of ship power systems. The technological development of power systems, their complexity, and high costs of their malfunction or downtime have led to employment of different approaches in safety engineering. In order to reduce hazards and failures in ship operation, shipbuilders use several methods during design phase to identify, investigate and manage all safety concerns. For this purpose, there is range of methods, as for instance Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Mode Effects Analysis (FMEA), and Failure Mode, Effects and Criticality Analysis (FMECA), which can be used separately or combined. This paper reviews these methods with their advantages and limitations in their application to risk assessment of ship power systems.

Keywords: Ship power system, Risk assessment, FTA, ETA, FMEA, FMECA

1. INTRODUCTION

Our lives are connected through a web of different systems, each having a different design and set of components. Additionally, each of these systems might include hazards that present risks to humans and environment. Due to stricter requirements to increase ship energy efficiency and their environmental performance [1], [2], [3], as well as to increase level of its autonomy, [4], the ship power systems become rather complex, with unknown safety level. The aim of system safety, as a sub-discipline of engineering, is to implement scientific, engineering and management knowledge to provide identification, evaluation, prevention and control of identified hazards throughout the life cycle and within the defined boundaries of operational effectiveness, time, and cost [5]. Accident or mishap is defined as an unplanned event/s resulting in death or injury of person damage or loss of equipment/ property, or damage to the environment [6], [7]. The process of system safety aims to ensure that tasks are done in the safest possible way, free from unacceptable risk [7]. System safety process incorporates the concept of people, procedures, facility, and/or equipment that must operate within a specific work environment to accomplish a task or set of tasks. The function of system safety is to pursue an evaluation to the greatest extent possible, with respect to the complexity of the task, system, operation, or procedure [7].

The aim of this paper is to review of most often used safety assessment methods in order to select appropriate method for risk assessment of marine power system. The remainder of this paper is structured as follows. To gain understanding of the subject of investigation, Section 2 outlines system safety concepts. The methods and techniques are explained in Section 3, and Section 4. draws the conclusions.

2. SYSTEM SAFETY CONCEPTS

The hazard analysis process is a systematic, comprehensive method to identify, evaluate, and control hazards in a system [8]. Figure shows how to apply hazard analysis.

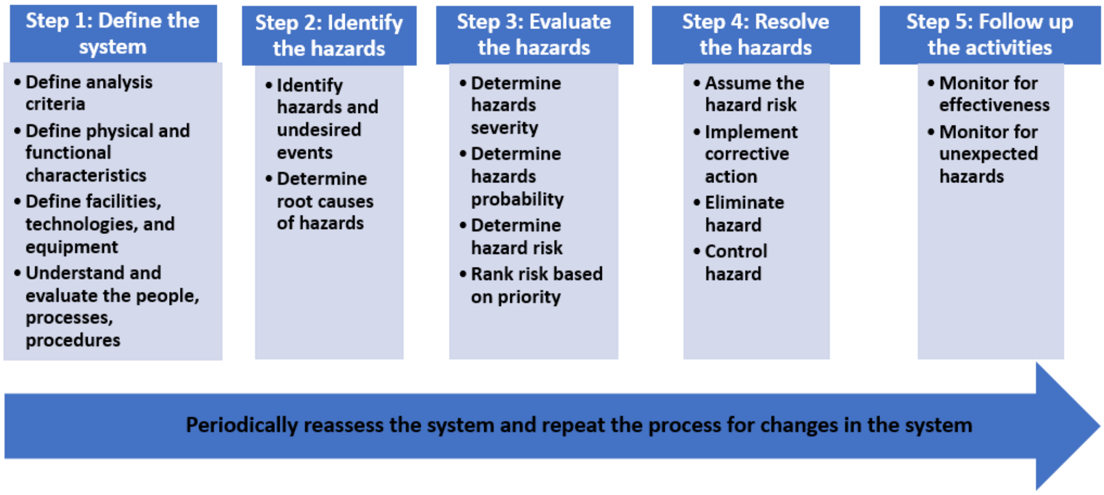

Figure 1: Hazard Analysis Process

In order to conduct as much as accurate risk assessment, it is necessary to identify all possible hazards, then categorize the hazards in terms of severity of consequences and evaluate the probability of the hazard occurring. The hazard severity categories provide a qualitative indication of the relative severity of the possible consequences of the hazardous condition(s). This categorisation system can be applied to a variety of industries and is extremely useful in attempting to qualify the relative importance of system safety engineering. The hazard probability levels represent a qualitative estimation on the relative likelihood of occurrence of a hazard.

When using the severity and probability techniques simultaneously, hazards can be examined, qualified, addressed, and resolved based upon the hazardous severity of a potential outcome and the likelihood that such an outcome will occur [7].

Figure shows the Hazard Risk Matrix which incorporates the elements of the Hazard Severity table and the Hazard Probability table to provide an effective tool for approximating acceptable (green area) and unacceptable (red area) levels or degrees of risk. Orange area is classified as undesirable but can be managed with appropriate changes, while yellow area is acceptable with management review. By establishing an alphanumeric weighting system for risk occurrence in each severity category and level of probability, we can further classify and assess risk by degree of acceptance [7]. The purpose of the matrix is to help prioritize hazards for corrective action. The categorization of hazards is based on severity and likelihood. Some hazards may be very likely to occur but of very minor consequences.

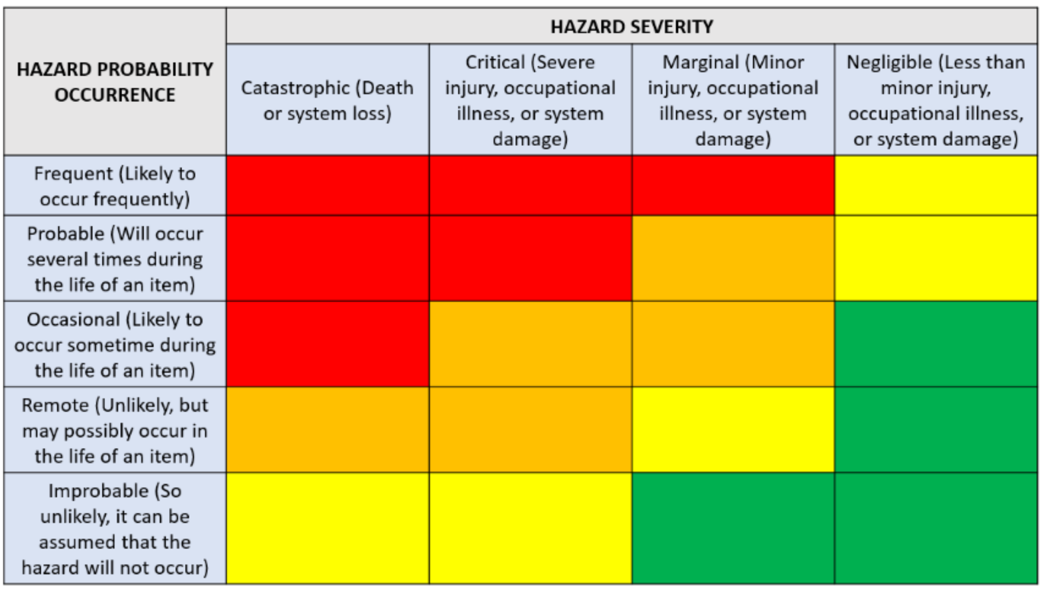

Figure 2: Hazard Risk Assessment Matrix

3. METHODS AND TECHNIQUES

There are two categories of hazard analyses: types and techniques. The type establishes analysis timing, depth of detail, and system coverage. The technique refers to a specific and unique analysis methodology that provides specific results. System safety is built upon seven basic types, while there are over 100 different techniques available [6]. Seven analysis types in safety engineering are [6]:

1. Conceptual design hazard analysis type (CD-HAT)
2. Preliminary design hazard analysis type (PD-HAT)
3. Detailed design hazard analysis type (DD-HAT)
4. System design hazard analysis type (SD-HAT)
5. Operations design hazard analysis type (OD-HAT)
6. Health design hazard analysis type (HD-HAT)
7. Requirements design hazard analysis type (RD-HAT)

There are many different analysis techniques to select from when performing the analysis types, and there are many different factors that must go into the hazard analysis, such as the system life-cycle stages of concept, design, test, manufacture, operation, and disposal [6].

System safety hazard analysis techniques are quite often classified as being either an inductive or deductive methodology. For example, a failure mode and effects analysis (FMEA) is usually referred to as an inductive approach, while an FTA is referred to as a deductive approach. In system safety, inductive analysis tends to be for hazard identification (when the specific root causes are not known or proven), and deductive analysis for root cause identification (when the hazard is known). A deductive analysis is a top-down access while an inductive analysis is a bottom-up access [6].

In further subsections, four hazard techniques are described in more detail.

3.1. Fault Tree Analysis (FTA)

Fault tree analysis (FTA) is a deductive method, based on top-down approach, which aims to determine the root causes and probability of occurrence of a specified undesired event. FTA is applied to evaluate large complex dynamic systems in order to understand and prevent potential problems. A fault tree (FT) is a model that logically and graphically represents the various combinations of possible events occurring in a system that resulted in an undesired event or state. Fault trees are graphical models using logic gates and fault events to model the cause –effect relationships involved in causing the undesired event. The graphical model can be translated into a mathematical model to compute failure probabilities and system importance measures [7].

The FTA technique can be used to model an entire system, with analysis coverage given to subsystems, assemblies, components, software, procedures, environment, and human error. FTA can be conducted at different levels, such as conceptual design, top-level design, and detailed component design. FTA has been successfully applied to various industries, such as aviation, maritime, transportation, nuclear, medical, and chemical industry. The technique can be applied to a system very early in design development and thereby identify safety issues early in the design process [6].

The theory behind FTA is to start with a top undesired event (UE) (e.g., hazard) and model the system faults that can contribute to this top event [6].

Main advantages of FTA are [6], [7]: Ability to model complex system relationship in an understandable manner, and it can be effectively performed on varying levels.

Main disadvantages of FTA are [6], [7]: It is time consuming, and modeling sequential timing and repair is difficult.

Baig et al [9] conducted a review on recent modifications of FTA method and concluded that unavailability of reliability data is major problem, and it can be solved by developing correlations between reliability and different parameters. Comparison of conventional and fuzzy FTA is provided by Mahmood et al. [10]. Many advantages of fuzzy FTA are outlined, particularly in cases where there is inadequate amount of accurate reliability information.

3.2. Event Tree Analysis (ETA)

Event tree analysis (ETA) is an indicative analysis technique which identifies, evaluates and reveals all possible outcomes following the occurrence of an initiating event (IE). Event tree (ET) is visual display of accident scenarios following initiating event. The objective of ETA is to determine whether the initiating event will develop into a hazard or if the event is sufficiently controlled by the safety systems and procedures implemented in the system design. Various different outcomes can occur as a result of single initiating event, and ETA provides capability to acquire probability for each outcome [6],[7].

Main advantages of ETA are [6], [7]: Visual model displays cause/effect relationships, and combines hardware, software, environment, and human interaction.

Main disadvantages of ETA are [6], [7]: An ETA can only have one initiating event, therefore multiple ETAs will be required to evaluate the consequence of multiple initiating events, and can overlook subtle system dependencies when modeling the events.

Ronza et al. [11] collected data for 828 accidents in port areas and used that data to determine probabilities of various accidents scenarios which enabled event tree assessment. The reliability of ETA is justified by a wide range of historically documented accidents. Marine accidents in Bangladesh, being one of the highest frequencies in world, were driving force to determine sequence events leading to accident in order to prevent the occurrence of them. Raiyan et al. [12] utilized ETA combined with quantitative study to successfully identify factors that are most likely to lead to accident. The event trees can help future researchers and designers to eliminate these factors.

3.3. Failure Mode and Effects Analysis (FMEA)

Failure mode and effects analysis (FMEA) is indicative method for the assessment of the effects of potential failure modes of subsystems, assemblies, components, or functions. It is primarily a reliability tool to identify failure modes that would affect overall system reliability. FMEA has the capability to include failure rates for each failure mode in order to achieve a quantitative probabilistic analysis. Additionally, the FMEA can be extended to evaluate failure modes that may result in an undesired system state, such as a system hazard, and thereby also be used for hazard analysis [6].

There are three approaches to performing an FMEA [6]:

1. **Functional Approach:** The functional FMEA focuses on functions that need to be performed (any functional level for the analysis: system, subsystem, unit, or assembly). This approach focuses on ways in which functional purposes of a system fail. The functional approach is more of a system-level analysis.
2. **Structural Approach:** The structural FMEA is performed on hardware and is fixated on potential hardware failure modes. The structural approach is a detailed analysis at the component level and focuses on how it is done.
3. **Hybrid Approach:** The hybrid FMEA is a combination of the structural and the functional approaches. The hybrid approach begins with the functional analysis of the system and then focuses on hardware that directly affects functional failures identified as safety critical.

Main advantages of FMEA are [2], [3]: It provides a reliability prediction of the item being analyzed, and it is relatively inexpensive to perform, yet provides meaningful results.

Main disadvantages of FMEA are [2], [3]: It focuses on single failure modes rather than failure mode combinations, and it is not designed to identify hazards unrelated to failure modes.

Cicek et al. [13] employed FMEA for fuel oil system risk assessment pointing out that FMEA enables successful evaluation of failures that are important in real sense and is appropriate and beneficial for establishing preventive maintenance plan for marine systems. Comparative analysis of turbocharger system in diesel engine is provided by Xu et al. [14]. Compared to conventional FMEA, fuzzy-logic-based FMEA technique provides a few advantages. Helvacioglu and Ozen [15] applied FMEA in reliability analysis for yacht system design concluding that it is powerful technique to overcome problems. In addition to traditional RPN, Ling et al. [16] introduced a new index called prevention into traditional RPN, which can be used to examine validity of design changes. Lazakis et al. [16] identified critical main engine systems/components and their relevant parameters to be monitored by combination of FTA and FMEA and outlined that their combination provides beneficial insight for identifying critical systems. In order to improve conventional FMEA, Dinmohammadi and Shafiee [18] developed fuzzy FMEA for offshore wind turbine systems, demonstrating that latter approach is more practical and flexible. Both fuzzy and grey theory are used in combination with FMEA to investigate tanker equipment failure prediction [19].

3.4. Failure Mode, Effects and Criticality Analysis (FMECA)

FMECA is virtually the same as FMEA except that it also identifies the criticality of the component under study. The engineer emphasizes the probability of failure much more than in FMEA. The criticality is divided into its constituent parts [8]:

- Failure effect probability (β): The β values are the conditional probabilities that the failure effect will result in the identified criticality classification, given that the failure mode occurs.
- Failure mode ratio (α): The failure mode ratio is the probability expressed as a decimal fraction that the part or item would fail in the identified mode.
- Part failure rate (λp): The part failure rate is the failure rate of individual piece, part, or component.
- Operating time (t): Operating time is the amount of time in hours or the number of operating cycles of the item per mission.

All of these are combined to give the failure mode criticality number (C_m) [8]:

$$C_m = \beta \cdot \alpha \cdot \lambda_p \cdot t. \tag{1}$$

This information is then compiled in a criticality matrix, and the analysis can rank the items based on which is the most critical failure to the system.

Many industries require FMECA to be integrated in the design process of technical. This is, for example a common practice for military industry, the aerospace, and the automobile industry. The same requirements are becoming more and more usual within the offshore oil and gas industry [6]. FMECA gives the highest value when carried out during the design phase of a system. The main objective of the analysis is to reveal weaknesses and potential failures at an early stage, to enable the designer to incorporate corrections and barriers in the design. The results from FMECA may also be useful during modifications of the system and for maintenance planning. A limitation of FMECA is further the inadequate attention generally given to human errors. This is mainly due to the concentration on hardware failures [8].

Combination of FMECA and FTA is used for novel predictive maintenance strategy proposed by Lazakis et al. [20]. Combination of this techniques provided upgrade of existing ship maintenance regime. Tryviza et al. [21] performed FTA and FMECA analysis to assess reliability and safety of an ammonia-powered fuel-cell system. Milioulis et al. [22] proposed novel based methodology to analyze safety of LNG fuel feeding system. This methodology includes FTA and FMECA assessments. The FMECA led to the identification of failure modes and the RPN calculation, while FTA allowed for the quantitative evaluation of the identified top events and the comparative assessment of the alternative system configurations.

Figure shows a logical relationship with ETA and FTA incorporated into FMEA for use in validity assessment of safety codes and standards [23].

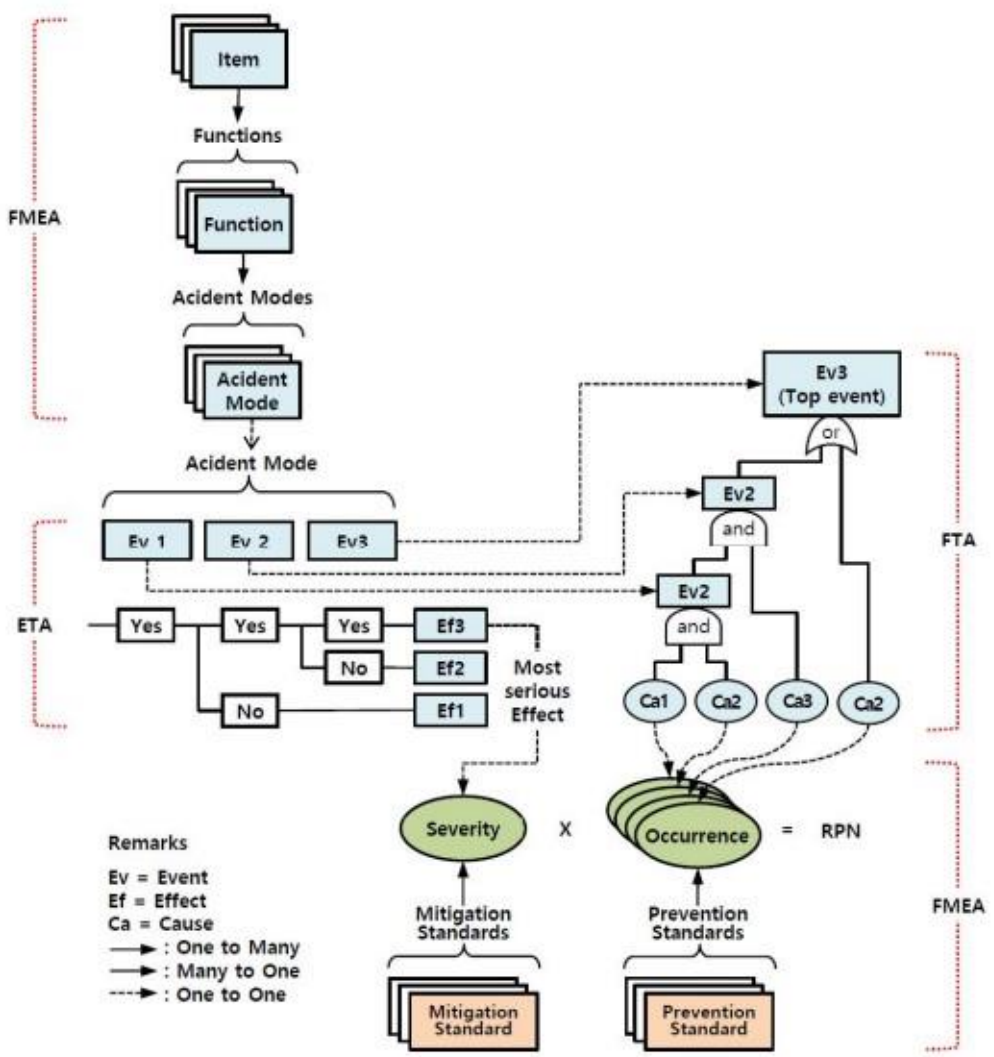

Figure 3: Relationship between FMEA, FTA, and ETA [23]

4. CONCLUDING REMARKS

Reliability and safety analysis is of crucial importance in maritime transportation given that maritime accidents often led to human loss, environmental disaster, and severe ship/equipment damages. The IMO (International Maritime Organization) adopted FSA (Formal Safety Assessment) to address risk analysis on-board ship, whereas DNV (Det Norske Veritas) proposed Technology Qualification (TQ) process for case-specific analysis. However, various tools and techniques, separately and combined, are used during design and operation phase.

Table provides comparison of analyzed techniques by means of important characteristics, to assist when

choosing an appropriate technique for specific problem. In

Table, + indicates strength, - weakness, and +/- moderate effect of method on stated characteristic. While FTA/ETA can be performed in any life-cycle phase after requirements are defined, FMEA/FMECA can only be performed after design is finalized. Time required to perform FMEA/FMECA analysis of complex systems is twice as short as for FTA/ETA analysis.

The main findings of this paper are summarized as follows:

- Systematic safety assessment is necessary for design of all ship systems,
- Detailed safety assessment of complex ship systems requires combination of different methods,
- Literature review indicate that combination of FTA and FMECA is successful tool for the identification of potential hazards and failure modes of systems for system design that employs novel technologies.

Table 1: Comparison of hazard analysis techniques

Characteristics	FTA	ETA	FMEA	FMECA
Structured, rigorous, and methodical approach.	+	+	+/-	+/-
Relatively easy to learn, do, and follow.	+	+	+	+
Minor training needed.	+	+	-	-
Time to perform.	-	-	+	+
Combines hardware, software, environment, and human interaction.	+	+	-	-
Commercial software is available.	+	+	+	+
Permits probability assessment.	+	+	+	+
Follows fault paths across system boundaries.	+	+	+/-	+/-
Is relatively inexpensive to perform.	+/-	+/-	+	+
Modeling multiple phases.	-	-	+	+

ACKNOWLEDGEMENT

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REFERENCES

[1] Perčić, M., Ančić, I., & Vladimir, N. (2020). Life-cycle cost assessments of different power system configurations to reduce the carbon footprint in the Croatian short-sea shipping sector, Renewable & sustainable energy reviews, 131, Paper No. 110028, 12 p.

[2] Ančić, I., Perčić, M., & Vladimir, N. (2020). Alternative power options to reduce carbon footprint of ro-ro passenger fleet: A case study of Croatia, Journal of Cleaner Production, 271, Paper No. 122638, 15 p.

[3] Perčić, M., Vladimir, N., & Fan, A. (2020). Life-cycle cost assessment of alternative marine fuels to reduce the carbon footprint in short-sea shipping: A case study of Croatia, Applied Energy, 279, Paper No. 115848, 18 p.

[4] Jovanović, I., Vladimir, N., Perčić, M., & Koričan, M. (2022). The feasibility of autonomous low-emission ro-ro passenger shipping in the Adriatic Sea, Ocean Engineering, 247, 2022., Paper No. 110712, 12 p.

[5] Stephenson, J. (1991). System safety 2000: A practical guide for planning, managing, and conducting system safety programs. New York: Van Nostrand Reinhold.

[6] Clifton, A., & Ericson, I. I. (2005). Hazard analysis techniques for system safety. J. Wiley.

[7] Vincoli, J. W. (2006). Basic guide to system safety. John Wiley & Sons.

[8] Bahr, N. J. (2014). System safety engineering and risk assessment: a practical approach. CRC press.

[9] Baig, A. A., Ruzli, R., & Buang, A. B. (2013). Reliability analysis using fault tree analysis: a review. International Journal of Chemical Engineering and Applications, 4(3), 169.

[10] Mahmood, Y. A., Ahmadi, A., Verma, A. K., Srividya, A., & Kumar, U. (2013). Fuzzy fault tree analysis: a review of concept and application. International Journal of System Assurance Engineering and Management, 4(1), 19-32.

[11] Ronza, A., Félez, S., Darbra, R. M., Carol, S., Vílchez, J. A., & Casal, J. (2003). Predicting the frequency of accidents in port areas by developing event trees from historical analysis. Journal of loss prevention in the process industries, 16(6), 551-560.

[12] Raiyan, A., Das, S., & Islam, M. R. (2017). Event tree analysis of marine accidents in Bangladesh. Procedia engineering, 194, 276-283.

[13] Cicek, K., Turan, H. H., Topcu, Y. I., & Searslan, M. N. (2010, March). Risk-based preventive maintenance planning using Failure Mode and Effect Analysis (FMEA) for marine engine systems. In 2010 Second International Conference on Engineering System Management and Applications (pp. 1-6). IEEE.

[14] Xu, K., Tang, L. C., Xie, M., Ho, S. L., & Zhu, M. L. (2002). Fuzzy assessment of FMEA for engine systems. Reliability Engineering & System Safety, 75(1), 17-29.

[15] Helvacioglu, S., & Ozen, E. (2014). Fuzzy based failure modes and effect analysis for yacht system design. Ocean Engineering, 79, 131-141.

[16] Ling, D., Huang, H. Z., Song, W., Liu, Y., & Zuo, M. J. (2012, January). Design FMEA for a diesel engine using two risk priority numbers. In 2012 Proceedings Annual Reliability and Maintainability Symposium (pp. 1-5). Ieee.

[17] Lazakis, I., Raptodimos, Y., & Varelas, T. (2018). Predicting ship machinery system condition through analytical reliability tools and artificial neural networks. Ocean Engineering, 152, 404-415.

[18] Dinmohammadi, F., & Shafiee, M. (2013). A fuzzy-FMEA risk assessment approach for offshore wind turbines. International Journal of Prognostics and Health Management, 4(13), 59-68.

[19] Zhou, Q., & Thai, V. V. (2016). Fuzzy and grey theories in failure mode and effect analysis for tanker equipment failure prediction. Safety science, 83, 74-79.

[20] Lazakis, I., Turan, O., & Aksu, S. (2010). Increasing ship operational reliability through the implementation of a holistic maintenance management strategy. Ships and Offshore Structures, 5(4), 337-357.

[21] Trivyza, N. L., Cheliotis, M., Boulougouris, E., & Theotokatos, G. (2021). Safety and reliability analysis of an ammonia-powered fuel-cell system. Safety, 7(4), 80.

[22] Milioulis, K., Bolbot, V., & Theotokatos, G. (2021). Model-based safety analysis and design enhancement of a marine LNG fuel feeding system. Journal of Marine Science and Engineering, 9(1), 69.

[23] Chae, C. (2017). Validity Verification Technique Based on FMEA-FTA/ETA for Safety Codes and Standards.

MARITIME SERVICES IN ADRIATIC SEA AND WORLDWIDE STRATEGIES OF CONTAINER SHIPS OPERATORS

Ronan Kerbiriou
Olivier Joly
Université Le Havre Normandie
25 rue Philippe Lebon, Le Havre, France
ronan.kerbiriou@univ-lehavre.fr, olivier.joly@univ-lehavre.fr

ABSTRACT

The AIS is a tracking system used on ships to provide information on surrounding traffic situation and supplements marine radar as a collision avoidance device. The data acquired from AIS systems also constitute a new means of information for the maritime community, or the wider public. This part of the analysis is based on a database constructed using the IHS maritime database (https://maritime.ihs.com/) and with collected data from AIS Hub, a data sharing service which provides access to real time ship positions for vessel tracking systems. This paper proposes an analysis based on AIS signals (2016, 2018 &2020 periods) to study the strategy of Shipping Container Companies. This communication proposes a starting point for the analysis of the interconnection between the global trades maritime services (deep-sea containers shipping lines) and feeder and Short Sea Shipping services in the Adriatic Sea. This work jointly implements Data Mining (Principal Components Analysis), Mapping and some Graph Theory tools (entire graph structure) applied both to maritime global and local networks and to the strategies of Container Carriers and their linked local partners.

Keywords: AIS, Container shipping, Adritic Sea

1. INTRODUCTION

The AIS is a tracking system used on ships to provide information on surrounding traffic situation and supplements marine radar as a collision avoidance device. AIS devices are mandatory on all large vessels according to the IMO SOLAS Convention (SOLAS Convention, 2004). The data acquired from AIS systems also constitute a new means of information for the maritime community, or the wider public. This part of the analysis is based on a database constructed using the IHS maritime database (https://maritime.ihs.com/) and with collected data from AISHub, a data sharing service which provides access to real time ship positions for vessel tracking systems. Above all, broadcasting AIS data in real-time makes a tangible contribution to the scientific community. The automatic character of transmitting vessel positioning signals and its generalization provide an opportunity to track and analyze the vessels' itineraries. Once this source of information has been properly checked through matching it with external data with regard to vessels and ports, it opens the way to reasoning on a global scale as well as on the scale of port approaches, in real-time as well as long term. The method, founded on a spatial analysis within a geographical information system (GIS) combined with a database server, makes it possible to reconstruct each vessel's trajectory in such a way as to identify the navigation lanes then to match the daily traffic in its temporal and quantitative dimensions. It is then relevant to analyze the maritime networks. As AIS data is "Big Data", it requires specific techniques for data handling and processing which has limited its use. We create a platform to develop capacity and methods for better use of this massive source of maritime data. It has to receive, decode, clean, store and analyze AIS messages.

This paper proposes an analysis based on AIS signals (2016, 2018 & 2020 period) to study the maritime service of the port of the Adriatic Sea and the strategy of Global Carriers Shipping Companies.

This study is a continuation of previous work that we have already presented in international conferences. In a first presentation, we studied the strategy of Global Carriers Shipping Companies of new generation container large Post Panamax, New Post Panamax and triple E ocean going vessels. These large container ships, giants of the seas, structure the world maritime traffic and more particularly the Europe-Asia trade. During a second conference, we studied the maritime service calling at Baltic Sea ports. During our presentation, we will use analytics from these two early communications.

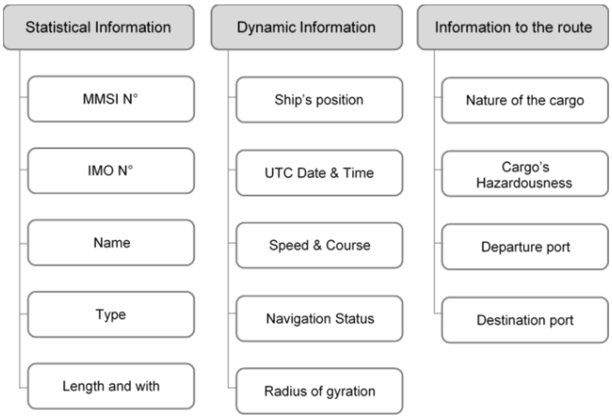
2. MODEL AND DATA

2.1. A work based on AIS data

This work is based on a database constructed using the IHS maritime database (https://maritime.ihs.com/).

AIS data is accessible through several ways such as collaborative websites, own receivers or subscription to commercial data suppliers, providing sometimes free-of-charge access to vessel identification and positioning in real-time the world over. It contains a lot of significant information, which is a precious resource for research. AIS data analysis provides insight in ship traffic and forms the basis of the network analysis. So, it can produce improved and optimized maritime traffic information like density maps, maritime routes (lanes), a network of maritime routes: nodes, hierarchy... Speaking about our study, AIS data appear as a source of information about strategies of containerships operators.

The AIS is a tracking system used on ships to provide information on surrounding traffic situation and supplements marine radar as a collision avoidance device. AIS devices are obligatory on all large vessels according to the IMO SOLAS Convention (SOLAS Convention, 2004). AIS presents advantages for maritime transportation actors: improvements in safety, progresses in fleet management and navigation. The data acquired from AIS systems also constitute a new means of information for the maritime community, or the wider public (See Fig 1).



Source: Adapted from Le Guyader, Brosset, Gourmelon, 2011.

Figure 1: Nature of AIS data

2.2. Study framework

For this paper and within the framework of this international conference, we will study the maritime service of the Adriatic space. We have thus selected all the ports of the Adriatic Sea carrying out containerized traffic. At first, we will present the containerized service of the ports of the Adriatic then we will study their interconnections between them and with the other ports in particular of the Mediterranean Sea. For this we will use tools from graph analysis and statistical studies that we will combine. To have an evolutionary study, we have chosen three reference years for analysis: 2016, 2018 and 2020. These years are studied because they mark stages in the evolution of the strategies of world maritime operators. To cope with this new environment, shipping companies have joined forces in alliances since 2015 with the aim of exchanging space on board. But many shipping companies have not been able to resist this combination of low freight rates and transport overcapacity. From December 2015 with the acquisition of the company NOL by CMA CGM, we have therefore witnessed the acquisition or merger between operators. The latest is the acquisition of NILE DUTCH by HAPAG LLOYD in March 2021. Between 2015 and 2020, we went from 16 operators organized in 4 alliances to 9 operators in 3 alliances. With the tightening of shipping companies, the three new alliances are: 2M, Ocean Alliance and The Alliance. Three alliances, bringing together 9 maritime operators, representing more than 20 million TEUs of transport capacity or 80% of the total capacity of the global maritime fleet of container ships. And more particularly, they account for 95% of maritime transport capacity on East-West trades. Today, the world's main ports are highly dependent on the service offers of these operators and in particular on the major global trades linking East Asia, Europe and North America.

In the meantime, it can also be noted that the container ship fleets have experienced exponential growth in their transport capacities. Since the 2000s, the size of container ships has evolved exponentially. This has increased from a maximum transport capacity of 8000 TEUs in 2000 for vessels measuring 300 metres in length to transport capacities of up to 24000 TEUs. Transport capacity has increased 3-fold in the space of 20 years. These developments in the strategic organization of shipping companies that operate on the main world trades have an impact on the maritime service of secondary areas including the ports of the Adriatic Sea.

2.3. Combined methodology

This paper jointly implements Data Mining (Principal Components Analysis), Mapping and some Graph Theory tools applied both to maritime global networks and to the strategies of Global Carriers (operators) in the Adriatic Sea port and their connection with the others ports.

We use Principal Components Analysis (PCA) to discover hidden structures, and reach an objectivity which is difficult to attain with classical techniques. In our case, the graph theory is used to allow the study of the maritime networks of the operators of large container ships and thus to highlight their structures. Several methods exist to simplify a graph whose objective is to remove certain vertices or links. We have retained the method of dominant flows. This method has the advantages of being easy to use, easily understandable by an uninformed reader and makes it possible to highlight the deep structure of the maritime network studied. The principle of this method is to define a threshold and to keep all the superior relations. The threshold of 50 connections was retained for our network analysis, which corresponds to at least one weekly connection

3. RESULTS

To cope with this new environment, shipping companies have joined forces in alliances since 2015 with the aim of exchanging space on board. With the tightening of shipping companies, the three new alliances are: 2M, Ocean Alliance and The Alliance. In the Adriatic Space, there are also 31 independent containership operators.

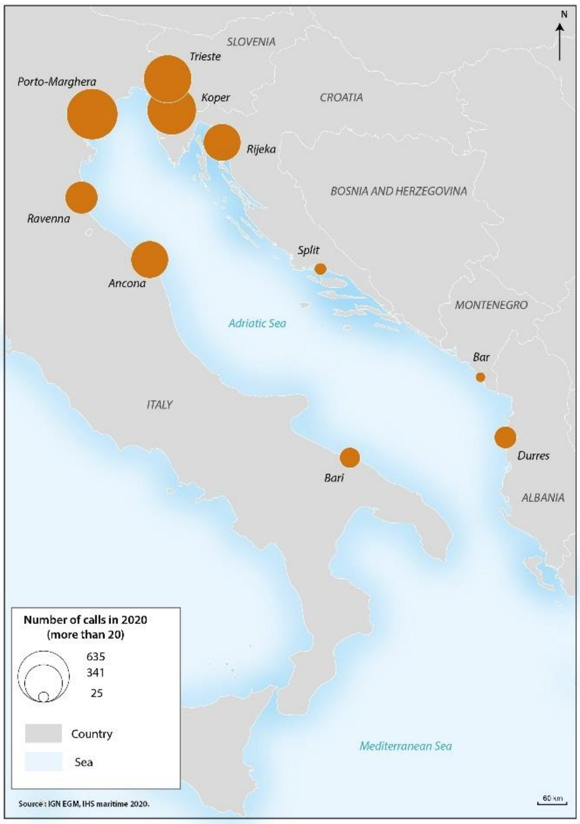
Figure 2: Maritime alliances and independent operators in the Adriatic Sea in 2020

The place of containerized traffic in the Adriatic Sea is relatively modest. In 2020, container traffic was 3.2 million TEU, the equivalent of Haropa Port. This traffic is mainly concentrated in 4 ports which are located in the North of the Adriatic Sea: Koper (945,000 TEU), Trieste (776,000 TEU), Porto Marghera (529,000 TEU) and Rijeka (344,000 TEU). Container traffic in the southern Adriatic Sea is almost nil. The Adriatic Sea, being a dead end sea, is on the fringes of the main international maritime trades. This maritime space is mainly served by transhipment in a hub port. The port statistics approach is classic in transport geography in order to compare port areas with each other. The purpose of this paper is not to compare ports with each other but to position them more broadly in the regional and global maritime network by studying their interconnections between them and with other ports. This analysis of maritime connections will make it possible to highlight the main existing maritime relations between the Adriatic ports and also to study the crossing points of container ships and therefore of goods before serving the Adriatic Sea. What are the port hubs that serve the Adriatic ports?

In the presentation of our results, we will first analyze the stopovers. Then, via a graph analysis, we will study the intra and extra Adriatic connections. Finally, via a statistical analysis using principal component analysis tools, we will carry out an approach by maritime operators to study their strategies.

Table 1: Number of calls by ports in 2016, 2018 and 2020

Port	Number of calls 2020	Number of calls 2018	Number of calls 2016
Ancona	341	428	447
Bakar	1		
Bar	25	14	34
Bari	104	102	142
Brindisi	2		28
Chioggia	1	7	4
Durres	122	127	133
Koper	585	671	675
Monfalcone	5	2	8
Monopoli	1		
Ortona	5	3	
Ploce	7	1	
Porto Marghera	635	760	664
Porto Nogaro	3	4	11
Pula		2	2
Ravenna	409	539	533
Rijeka	328	287	344
Sibenik	1	1	1
Split	37	49	46
Trieste	557	581	575
TOTAL	3169	3578	3647



Source: IHS maritime

Figure 3: Calls of containerships in the ports of Adriatic Sea in 2020

Table 2: Capacity of TEU by ports in 2016, 2018 and 2020

Port	Capacity TEU 2020	Capacity TEU 2018	Capacity TEU 2016
Ancona	546 624	603 209	612 044
Bakar	523		
Bar	29 917	14 965	36 540
Bari	100 501	91 174	150 355
Brindisi	1 046		31 522
Chioggia	372	2 970	1 562
Durres	131 741	137 720	152 879
Koper	1 979 116	2 130 894	2 022 681
Monfalcone	2 361	880	3 217
Monopoli	411		
Ortona	2 093	1 065	
Ploce	6 916	925	
Porto Marghera	1 024 063	1 274 642	1 049 725
Porto Nogaro	1 085	1 897	5 064
Pula		1 031	744
Ravenna	615 476	686 038	722 261
Rijeka	1 292 078	1 203 537	1 183 654
Sibenik	190	1 033	465
Split	27 000	44 195	44 663
Trieste	2 200 311	1 931 887	1 564 486
TOTAL	**7 961 824**	**8 128 062**	**7 581 862**

We propose a typology of container terminal ports in the Adriatic based on the choices made by alliances and independent operators. Three configurations are observed. 9 out of 19 ports, which are small or medium-sized ports, are served almost exclusively by small independents. 7 other larger ports are served mainly by the 2M alliance. 3 ports have a shared service offer.

Table 3: Typology of Adriatic ports per operator's categories based on TEU's capacities in 2020

Typology	Adriatic Ports
Independant Operators	Bakar
	Brindisi
	Chioggia
	Monfalcone
	Monopoli
	Ortona
	Porto Nogaro
	Sibenik
	Split
2M Alliance	Bari
	Durres
	Koper
	Ploce
	Ravenna
	Rijeka
	Trieste
Shared by all Operators	Ancona
	Bar
	Porto Marghera

In this study, we have chosen to express the Adriatic seaports in the space of container ship operators. This allowed us to characterize the ports of call according to the strategies implemented by these same operators. Over the three-year period studied, it appears that the geographical positioning of the 2M alliance operators is different from that of the other two alliances (Ocean Alliance and The Alliance) and the other independent operators. We observe that in 2020 some ports are placed by the 2M alliance on an equal footing in terms of calls: Bar, Bari, Durres, Ploce, Porto-Marghera, Ravenna. The PCA 2020, carried out using port capacities, also highlights a completely different configuration of port calls, this time involving two small independent operators: Lyndon Marine Ltd and Mednav Chart SAL, which distribute their calls evenly over three secondary ports (Bakar, Brindisi and Porto-Nogaro). This shows a great heterogeneity in the organization of port calls of container ships in the Adriatic area in 2020 (continuation of the trend observed since 2016).

From 2016 to 2020, the number of stopovers seems to stabilize. On the other hand, the transport capacity offered in stopovers in its ports has increased from 7.58 million TEUs in 2016 to nearly 8 million TEUs in 2020, i.e. a 5% increase in the capacity offered. This means that the average size of container ships calling has increased significantly following the global trend. The average size of container ships calling was 1300 TEU in 2016 and in 2020, 2500 TEU. The average size of container ships has almost doubled in just 4 years. The ports of the Adriatic Sea are benefiting from the effect of cascading and the tightening of supply around a few global operators.

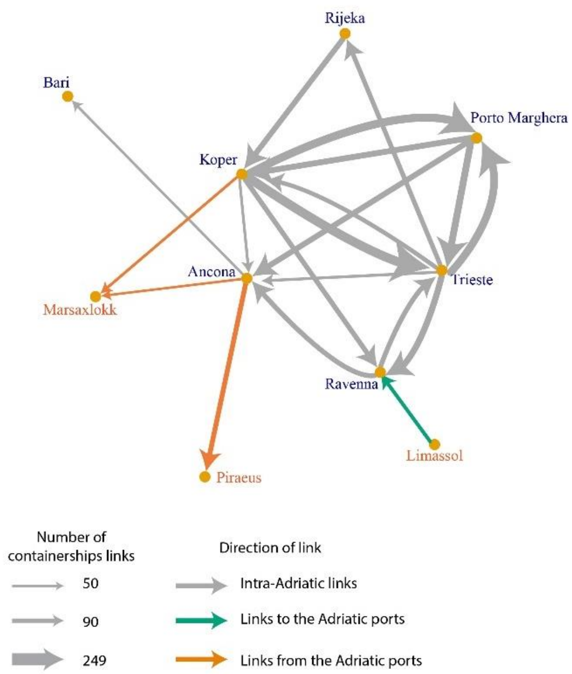


Figure 3: Links-graph of maritime connection of ports of Adriatic Sea in 2016 (over of 49 connections)

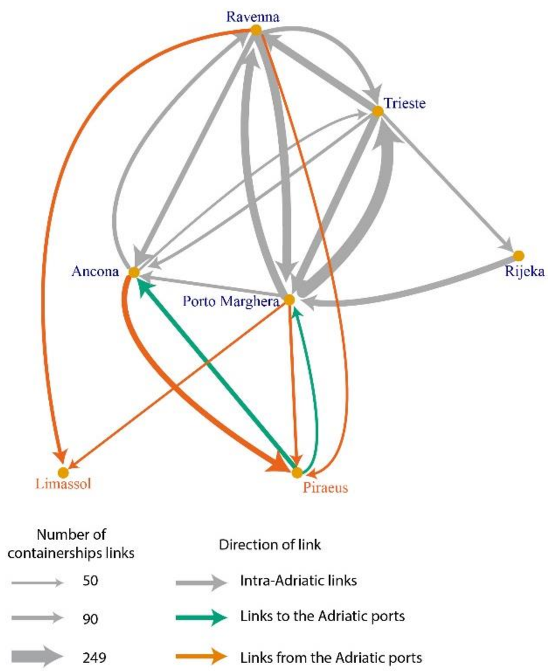


Figure 4: Links-graph of maritime connection of ports of Adriatic Sea in 2018 (over of 49 connections)

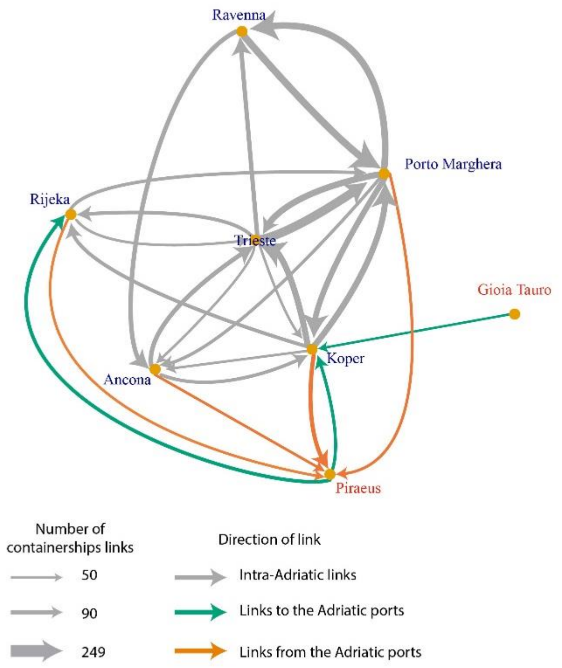


Figure 5: Links-graph of maritime connection of ports of Adriatic Sea in 2020 (over of 49 connection)

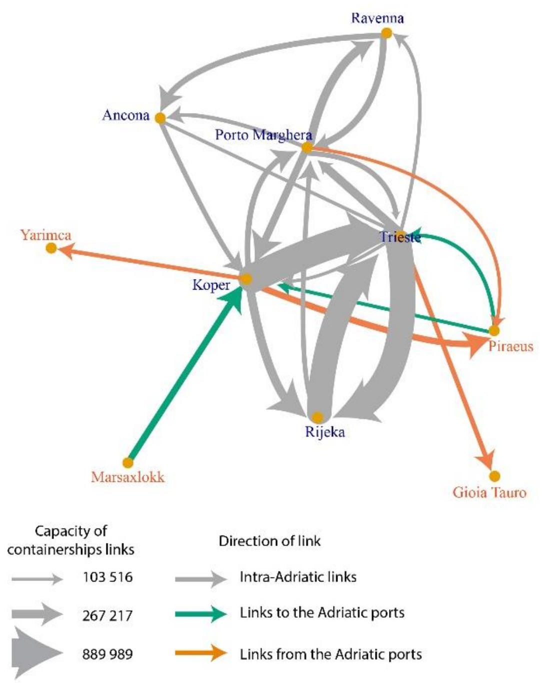


Figure 6: Capacity-graph of maritime connection of ports of Adriatic Sea in 2020 (over of 100 000 TEU)

Table 3: Number of calls and maritime connection of Adriatic Sea Ports in 2016, 2018 and 2020

	2016	2018	2020
Number of calls	2770	2750	2970
Number of maritime connection	3581	3531	3766
Share of intra-Adriatic	45%	46%	40%
Share of extra-Adriatic	55%	54%	60%

Table 4: Mains ports of maritime connection of Adriatic Sea Ports in 2016, 2018 and 2020

	2016	2018	2020
Piraeus	331	520	632
Gioia Tauro	291	243	340
Limassol	89	161	109
Marsaxlokk	280	59	106
Yarimca	5	2	14
Augusta	12	322	5

The graphs produced illustrate the dominant flows highlighting the general structure of the maritime network between the ports of the Adriatic Sea and the connection with the other ports. Between 2016 and 2020, there is a significant change in the structure of the network. In 2016, in number of routes, the network focused on routes connecting ports internally in the Adriatic Sea. Connections with other Mediterranean ports were relatively weak. The number of connections between the ports of Koper, Porto-Marghera, Trieste … were about 200 per year, which represents one ship every two days. On the contrary, the connections with the other ports were about a single weekly connection. In 2018 and 2020, the graph shows a significant increase in connections with other ports. In 2016, the connections between the Adriatic ports were rather balanced. In 2020, the port of Trieste seems to be establishing itself as the hub port of the region, in particular with the development of links with the port of Piraeus. This is even more striking when analyzing transport capacities between ports. The transport capacity between Trieste and Rijeka is very high (around 900,000 TEUs of transport capacity between its two ports). Ships have a very high transport capacity between these two ports.

4. CONCLUDING REMARKS

This preliminary work presented in the framework of this ICTS 2022 conference, on the spatialized strategies of container ship operators present in the Adriatic space, will be put in perspective with identical work on two other cul-de-sac seas: the Baltic Sea and the Black Sea. The aim is to link the strategies of the large container ship operators structuring the major globalized maritime trade routes with the practices of local and/or independent operators or subsidiaries specialized in feedering and short sea shipping. At the international level, the fluctuating strategies of global carriers sometimes appear to be a-spatialized (with no real link to the local service of the markets). Pure competition seems to be taking place between the global carriers, linked to an oligopolistic situation that is in the process of stabilizing. The analyses show a real similarity in the strategies observed in the Baltic and

Adriatic areas in the evolution of regional maritime networks and the strategies of maritime operators. In the Adriatic, as specified, the port of Trieste seems to be establishing itself as a regional hub in connection with the port of Piraeus (Greece), as does the port of Gdansk (Poland) in direct connection with the port of Bremerhaven (Germany). These two links are operated mainly by an international operator (MSC for the Adriatic and Maersk for the Baltic) and offer significant transport capacity (large container ships).

REFERENCES

[1] Ducruet C. (2011), Simplification et partitionnement d'un graphe. halshs-00579065

[2] L'Hostis, A., (2007). Graph theory and representation of distances : chronomaps, and other representations. Mathis Ph. Graphs and networks, multilevel modelling,, Lavoisier, pp.177-191. hal-00278991

[3] Togzon. J. L. (1995) Systematizing international benchmarking for ports. Maritime Policy & Management. Vol.22. n°2. pp. 171-177)

[4] Garrison W. L. (1990) Networks: Reminiscence and lessons. *Flux* n°1, 1990. pp. 5-12

[5] Halim R. A., Tavasszy L. A., Kwakkel J. H. (2016) The impact of the emergence of direct shipping lines on port flows. In *Maritime Networks Spatial structures at time dynamics*. Edited by César Ducruet. Routledge, New-York., Chapter 15, pp265-284

[6] Guinand F, Pigné Y. (2016) Time considerations for the study of complex maritime networks. In *Maritime Networks Spatial structures ad time dynamics*. Edited by César Ducruet. Routledge, New-York., Chapter 10, pp 163-189

[7] Joly O., Martell. H. (2003) Infrastructure Benchmarks for European Container ports. The 4th Inha–Le Havre International Conference: Regional Cooperation & Economic Integration – European & East Asian Experiences. Incheon 8-9th of October 2003, Section IV. Logistics and Port Economics, pp. 147-154

[8] Jung P. H., Thill J.-P. (2022) Sea-land interdependence and delimitation of port hinterland-foreland structures in the international transportation system. Journal of Transport Geography 99 (2022), Elsevier, 12 p.

[9] Rabino G. A., Occelli S. (1997) Understanding spatial structure from network data: theoretical considerations and applications. Cybergeo: European Journal of Geography, *Systèmes, Modélisation, Géostatistiques*, 29. URL : http://journals.openedition.org/cybergeo/2199 ; DOI : https://doi.org/10.4000/cybergeo.2199

[10] UNCTAD (2021) *Review of Maritime Transport 2019*. United Nations, Geneva, 2019, 147p.

[11] UNCTAD (2020) *Review of Maritime Transport 2019*. United Nations, Geneva, 2019, 146p.

[12] UNCTAD (2019) *Review of Maritime Transport 2019*. United Nations, New-york and Geneva, 2019, 109p.

[13] UNCTAD (2018) *Review of Maritime Transport 2019*. United Nations, New-york and Geneva, 2019, 102p.

[14] Faury O., Alix Y., Serry A., Kerbiriou R., Pelletier J.-F., (2020). Analysis of the Russian Artic port system using AIS data. In *Artic Shipping Climate change, commercial traffic and port development*. Edited by Lasserre F., Faury O., Routledge, New-York, Chapter 10, pp 174- 194

BLADE DEFORMATION OF A PRESSURE-LOADED POLYAMIDE MARINE PROPELLER

Radosław Kiciński, Ph.D.
Andrzej Grządziela, Ph.D.
Bogdan Szturomski, Ph.D.
Polish Naval Academy, Faculty of Mechanical & Electrical Engineering
Śmidowicza 69 str., 81-103 Gdynia
r.kicinski@amw.gdynia.pl

ABSTRACT

In the world trends, the interest in plastics in various industrial sectors is more noticeable. The use of plastics allows for reducing the use of strategic materials at the expense of ecology. There are ideas of using ship propellers made of polymers to propel ships. This approach reduces generated noise and the mass of the rotating parts, reducing fuel consumption and increasing the propeller's efficiency due to flow optimization. The paper presents a single propeller blade's stress distribution and deformation loaded with a non-uniform pressure field. The results are summarized in drawings and diagrams showing the deformation of the propeller at the same pressure but with different Young's modulus (different materials).

Keywords: Marine propeller, finite element method, polymers

1. INTRODUCTION

The use of screw propellers is dominant in maritime and navy shipbuilding. The design of the propeller as a device that converts mechanical energy into hydrodynamic energy has a specific efficiency. It depends on many design factors such as the number of blades, the dimensionless geometric coefficient of the propeller (H / D), etc. The trends in the world production of propellers are focused mainly on materials with high stiffness (high Young's modulus) such as bronze, steel and aluminium. Also, the characteristics available in the literature refer primarily to the mentioned materials.

In nature, however, it isn't easy to find solutions that have been adopted by humanity to propel ships. Observing the animals living under the surface of the oceans, we notice that depending on the speed of swimming, fish and marine mammals have flexible fins. Literature studies indicate that due to the different Froud and Strouhal numbers, both fish and mammals evolve towards achieving the maximum efficiency of the thruster, the fin [6].

Humanity has repeatedly modelled itself on nature, so it seems to be a good direction of research in this case. This article decided to present the foil deformation with different material stiffness. The deformation and stress state are shown for a set flow velocity and angle of attack. Numerical simulations were carried out for metallic and polymer materials showing the deformability of the foil under the influence of water pressure.

The presented research results can be used to analyze hydraulicity interactions in the propeller or ship's rudder design. Another area of research is the influence of deflection on increasing the area of maximum efficiency values.

The structures of two media, i.e. water and propeller material, adapt to the shape and interactions called hydroelastic adaptation. This issue is often used in the design of flexible ship propellers [4,8,9,12]. Work on hydroelasticity is a hot topic today and many researchers are considering various aspects of it. A very broad description, taking into account the mass of accompanying water and additional damping effects, can be found in [11].

The hydroelastic effect of the propeller blade is aimed at the adaptive blades along with the variable load. The paper presents a comparison of metallic materials and isotropic polymers to obtain the required pitch changes. It is assumed that the resulting flexible propeller will have the same geometry and performance as a rigid propeller. However, it should be noted that the pitch decreases as the load increases. Furthermore, it assumes that the flexible propeller adapts to the variable trace flow, possibly improving propeller efficiency beyond design conditions.

It was assumed in the considerations that the propeller acts downstream of the ship, where the flow velocities in the stream cross-section are spatially variable. The propeller, as a device, operates at a design advance factor based on the average rate of the incoming flow. It is different for a single blade as the speed changes many times during each revolution. It is due to passage through a spatially varying velocity field which causes by the contact with the propeller shaft, proximity to the fuselage and variable fluid flow channel, and interaction with the rudder. The research assumes that the goal is to produce an elastic propeller blade that will adapt to changes in flow conditions concerning the design state by analyzing the material's physical properties and the shape of the propeller without load. The tests would enable the design of a flexible propeller. A unique feature of this propeller will be the efficiency curve corresponding to some extent to the envelope of the propeller series with increasing pitch.

2. MATERIAL AND METHODS

The primary work purpose is to check how the foil will deform depending on the material from which it was made. NACA profiles are aeroplane wing shapes developed by the National Advisory Committee for Aeronautics (NACA). The profiles are standardized, and their shape is described by equations and is generally available. The examined profile belongs to a four-digit series, in which the first digit represents the bend as a percentage of the chord. The second digit describes the distance of the maximum inclination from the leading edge of the foil in tenths of the chord. The last two digits represent the profile's maximum thickness as a percentage of the chord [6]. The equation for a symmetric profile is as follows [3]:

$$y_t = 5t\begin{pmatrix} 0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + \\ + 0.2843x^3 - 0.1015x^4 \end{pmatrix} \qquad (1)$$

where:

- x – is the profile length expressed as a percentage,
- y_t – is half the profile thickness for a given distance,
- t – is the maximum thickness of the profile as a fraction of the chord.

Parameters in a numeric code can be entered into equations to generate a profile cross-section precisely and calculate its properties. For example, the NACA profile 0012 is symmetrical, 00 indicates no camber 12 indicates the profile has a 12% thickness to chord length ratio.

Based on the data in [7], foil shape was reflected using CAD (computer-aided design) programs. The values shown in the equation are considered dimensionless. Therefore, a reference should be made to physical values to calculate a specific load. A profile with a chord length of 0.2 m and a width of 0.4 m was adopted for further consideration. Then, a mesh of eight-node hexagonal linear elements with a mesh density of 0.002 m was generated on the model. The whole task consisted of 120,800 finite elements (Figure).

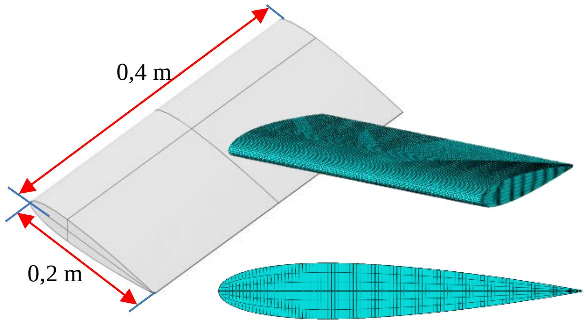


Figure 1: The foil geometry and the mesh view

3. BOUNDARY CONDITIONS AND LOAD

Having a specific foil model, its shape, and dimensions, the load should be determined. The foil theory shows that the foil is acted on by normal forces described as pressure and tangential forces described as drag. In the case of laminar flows and small angles of attack, the tangential forces are much lower than the normal forces and can be neglected for determining the lift of the profile. Determining the lift force of a profile is very complex and requires advanced experiments using comparative methods or approximate solutions. One analytical method for determining the lift force is the panel method. It is a relatively simple computational tool for engineers and students to determine ideal flows with negligible compressibility and viscosity. This method is widely described in the literature [7,10] and omitted here. However, it is so popular that there are procedures for MATLAB, Phyton, and Fortran to be used in practice. One of the available tools is [2], which allows, among other things, to determine the pressure coefficients acting on a given NACA profile. A pressure coefficient is a dimensionless number that describes the relative pressures in the flow field in fluid dynamics. The pressure ratio is used in aerodynamics and hydrodynamics. Each point in the fluid flow field has its unique pressure ratio. In many situations, the pressure coefficient is independent of the body size [1]. This coefficient results from the Bernoulli equation and is defined as:

$$c_p = \frac{\Delta p}{\frac{1}{2}\rho V_\infty{}^2} \qquad (2)$$

where:

- Δp – pressure increase at a given point;
- ρ – free stream fluid density;
- V_∞ – the free flow speed or the speed of the body through the fluid.

For the determination of pressure deformation of the foil, the pressure coefficient is insufficient. Therefore, it is necessary to define the boundary conditions and parameters of the fluid flow. Moreover, there is no pressure coefficient in the physical interpretation. Thus, the pressure load is used in the FEM analysis. For this purpose, the formula (2) should be transformed to determine the pressure acting at a given point in the profile. After transformation, we get:

$$\Delta p = c_p \left(\frac{1}{2}\rho V_\infty{}^2\right) \tag{3}$$

Flow conditions can be assumed for any velocity and depth of flow. The only unknown in the equation is the pressure coefficient. This value was determined by the panel method using the MATLAB code [2]. The program defines the shape of the profile and its attack angle, which allows the pressure coefficient to be determined. In the case under consideration, the angle of attack was set at 8° because, according to the available data [14], it is the maximum angle for which the flow does not detach from the foil. After entering the data into the program, the pressure coefficient for the NACA0012 profile was obtained (Figure).

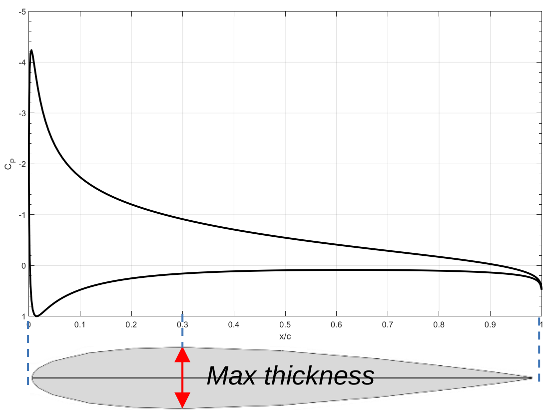


Figure 2: The values of the pressure coefficient for the NACA 0012 profile determined by the panel method, angle of attack 8°

Substituting the values obtained from the panel method into the formula (3), the values of the pressure increase acting on the wing were obtained. Pressure is a force that is normal to the surface, so its distribution is visualized differently from the pressure coefficient distribution. When analyzing the formula (3) it can be noticed that it depends on the fluid density and the flow velocity of the liquid. In the case under consideration, it was assumed that the foil moves at a speed of $V_\infty = 1$ m / s at a depth of $H = 1$ m, in water with a temperature of $T = 10$ °C and dynamic viscosity of $1.31 \cdot 10^{-3}$ Pa · s. Such a flow is characterized by the Reynolds number at the $Re = 1.53 \cdot 10^5$, which makes it possible to assume that it is a laminar flow and ignore the phenomena of turbulence and cavitation. The pressure distribution on the NACA0012 profile at an 8° angle is shown in Figure.

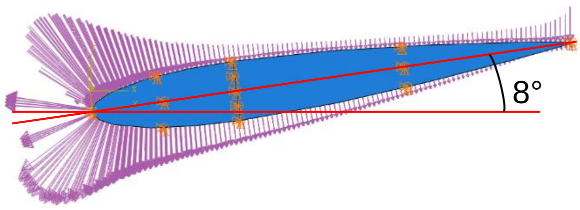


Figure 3: Pressure distribution on the NACA0012 profile

Substituting the determined flow values into formula (3), the formula for determining the pressure value on the finite element of the model is obtained. The final profile load is:

$$\Delta p(x) = 548{,}16 \cdot c_p \tag{4}$$

The calculated load was then applied to a foil model having a different Young's modulus. Marine propellers are made of corrosion-resistant materials as they operate directly in seawater, which is a corrosion accelerator. The materials used to produce thrusters are usually aluminum and stainless steel alloys. Other popular materials are nickel, aluminum and bronze alloys, which are 10 ~ 15% lighter than other materials and have higher strength. In addition to metallic materials, composites are used for ship propellers due to their better strength and stiffness-to-weight ratio. Their disadvantage is that they cannot be repaired after damage, while their advantage is complete corrosion resistance [5,12]. The materials selected for the analysis and their properties are presented in Table.

Table 1: Mechanical properties of materials selected for analysis

Material type	Ref.	Young modulus	Yield strength	Density	Foil mass
		MPa	MPa	kg/m3	kg
AISI 304	[15]	193 000	210	7900	101,9
Naval Brass 464	[13]	100 000	172	8410	108,5
Aluminum	[16]	69 000	95	2700	34,8
PA6	[17]	2 400	37	1150	14,8

4. SIMULATION RESULTS

Several simulations have been carried out using Abaqus CAE FEM solver. The load was kept constant during the simulation, and only material parameters were changed. The simulations were carried out to test the displacement of the foil ends, loaded only with the dynamic pressure. Due to the low flow velocity, the deformation of the foil is slight but noticeable. The results of the simulation of deformation of a PA6 polyamide foil at a 10-fold magnification are presented in Figure. For the remaining cases, displacements in the node are presented, where they are the largest and are shown for comparison in Table .

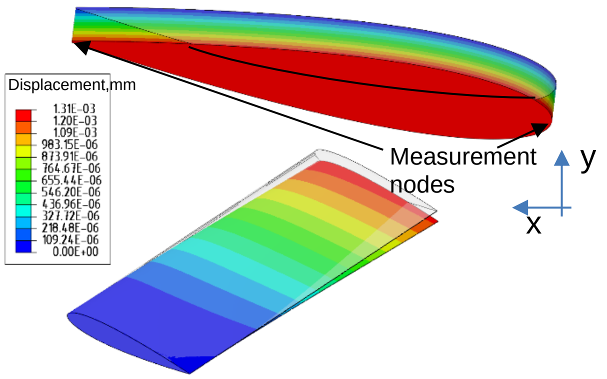


Figure 4: Results of deformation of a PA6 foil at ten times magnification

Based on the simulations, it was noticed that the displacements for typical materials used in shipbuilding are almost negligible and do not change the geometry of the foil. For a foil made of PA6 polyamide, a deflection of 1.3 mm may change the flow around the foil. A difference was also noticed between the deformation of the leading edge and the trailing edge, which slightly affects the foil rake angle.

Table 2: Maximum displacement on the leading edge and trailing edge

Material type	Leading-edge		Trailing edge		Leading and trailing edge difference	
	Displacement (x)	Displacement (y)	Displacement (x)	Displacement (y)	dx	dy
	mm	mm	mm	mm	mm	mm
AISI 304	0.0022	-0.0162	0.0021	-0.0152	0.000137	-0.00097
Naval Brass 464	0.0043	-0.0308	0.0040	-0.0289	0.000271	-0.00193
Aluminum	0.0062	-0.0452	0.0059	-0.0424	0.000382	-0.00272
PA6	0.1794	-1.2985	0.1684	-1.2202	0.010983	-0.07833

5. CONCLUSIONS

High stiffness is required from the materials used for ship propellers. Materials such as steel, aluminum or bronze retain high stiffness but significant weight. In the case under consideration, the mass of the foil may differ even seven times, which is essential in the case of rotating machines, which is undoubtedly the ship's propeller. Furthermore, using isotropic polymers in the construction of marine propellers may reduce the required power from marine engines, translating into lower fuel consumption.

Despite significant differences in the values of Young's modulus, deformations of the foil are not substantial. Therefore, the analysis will continue for higher flow rates and other angles of attack. In the presented methodology, the panel method is limited, which does not consider cavitation, turbulence, and other complexities of fluid mechanics.

Studies in the field of flows most often ignore profile deformations. In the case of low flow velocities and high material stiffnesses, these deformations are negligible. However, when polyamides are used, they should be considered in calculations related to the design of marine propellers. Another innovation in the approach to this issue is the description of the foil pressure load using the panel method combined with FEM, which is a simplification for the commonly used FSI (fluid-structure integration) ways.

The presented solution refers only to the dynamic pressure generated by the profile lift force. It does not consider the deformations originating from hydrostatic forces acting on the profile. This approach makes it possible to show the deformations that arise, regardless of the depth of a foil operation.

REFERENCES

[1] Ira H. Abbott and Albert E. VonDoenhoff. 2010. *Theory of wing sections: including a summery of airfoil data* (Unabr. and corr. republ., [Nachdr.] ed.). Dover Publ, New York, NY.

[2] Alexander Giles. 2022. *Panel method for NACA XXXX aerofoils*. MATLAB Central File Exchange. Retrieved January 13, 2022 from https://www.mathworks.com/matlabcentral/fileexchange/52771-panel-method-for-naca-xxxx-aerofoils

[3] Eastman N. Jacobs, Kenneth E. Ward, and Robert M. Pinkerton. 1933. *The characteristics of 78 related airfoil sections from tests in the variable-density wind tunnel*. Retrieved January 13, 2022 from https://ntrs.nasa.gov/citations/19930091108

[4] Karolina Jurczyk, Pawe\l Piskur, and Piotr Szymak. 2020. Parameters identification of the flexible fin kinematics model using vision and genetic algorithms. *Polish Maritime Research* (2020).

[5] Aleksander Kowarsch and Zbigniew Zaczek. 1989. *Miedź i jej stopy w budownictwie okrętowym* (Wyd. 1 ed.). Wydawn. Morskie, Gdańsk.

[6] George Lauder, Peter Madden, Ian Hunter, James Tangorra, Naomi Davidson, Laura Proctor, Rajat Mittal, Haibo Dong, and Meliha Bozkurttas. 2005. Design and performance of a fish fin-like propulsor for AUVs. (January 2005).

[7] James Liburdy. 2021. VI. The Panel Method: An Introduction. (September 2021). Retrieved January 13, 2022 from https://open.oregonstate.education/intermediate-fluid-mechanics/chapter/the-panel-method-an-introduction/

[8] Ching-Chieh Lin, Ya-Jung Lee, and Chu-Sung Hung. 2009. Optimization and experiment of composite marine propellers. *Composite Structures* 89, 2 (June 2009), 206–215. DOI:https://doi.org/10.1016/j.compstruct.2008.07.020

[9] H. J. Lin, W. M. Lai, and Y. M. Kuo. 2010. Effects of Stacking Sequence on Nonlinear Hydroelastic Behavior of Composite Propeller Blade. *Journal of Mechanics* 26, 3 (September 2010), 293–298. DOI:https://doi.org/10.1017/S1727719100003841

[10] Han Liu. 2018. Linear Strength Vortex Panel Method for NACA 4412 Airfoil. *IOP Conf. Ser.: Mater. Sci. Eng.* 326, (March 2018), 012016. DOI:https://doi.org/10.1088/1757-899X/326/1/012016

[11] Pieter Maljaars, Mirek Kaminski, and Henk Den Besten. 2018. Boundary Element Modelling Aspects for the Hydro-Elastic Analysis of Flexible Marine Propellers. *Journal of Marine Science and Engineering* 6, 2 (June 2018), 67. DOI:https://doi.org/10.3390/jmse6020067

[12] Y. L. Young. 2008. Fluid–structure interaction analysis of flexible composite marine propellers. *Journal of Fluids and Structures* 24, 6 (August 2008), 799–818. DOI:https://doi.org/10.1016/j.jfluidstructs.2007.12.010

[13] 2014. Naval Brass 464 - Elgin Fasteners. Retrieved January 19, 2022 from https://www.elginfasteners.com/resources/materials/material-specifications/naval-brass-464/

[14] NACA 0012 AIRFOILS (n0012-il). Retrieved January 13, 2022 from http://airfoiltools.com/airfoil/details?airfoil=n0012-il

[15] Stal nierdzewna AISI 304 / 1.4301 - przydatne informacje - Informacje. Retrieved January 19, 2022 from https://siatkitkane.com.pl/blog/13_stal-nierdzewna-aisi-304-14301-przydatne-informacje.html

[16] Young's Modulus, Tensile Strength and Yield Strength Values for some Materials. Retrieved January 19, 2022 from https://www.engineeringtoolbox.com/young-modulus-d_417.html

[17] Polyamide 6 | Designerdata. Retrieved January 19, 2022 from https://designerdata.nl/materials/plastics/thermo-plastics/polyamide-6

DECARBONIZATION OF FISHING OPERATIONS IN PURSE SEINE FISHERIES

Marija Koričan, M.Eng.
Nikola Vladimir, Ph.D.
Maja Perčić, M.Eng.
Ivana Jovanović, M.Eng.
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10002 Zagreb, Croatia
marija.korican@fsb.hr

ABSTRACT

Reduction of ship emissions is nowadays one of the most important research topics in maritime sciences. This is particularly true for decarbonization, where different technical and operational measures, as well as various business strategies, are being investigated to reduce carbon dioxide (CO_2) emissions. Fishing vessels generally do not belong to these categories, but their effect on humans and environment is very important since fishing operations are mainly performed in coastal waters. On the other hand, fishing vessels are mainly equipped with an outdated low-efficient diesel engines resulting in relatively high emissions. In Croatia, fishing has a long tradition and the indented coast of the Adriatic, as well as the rich sea, have enabled the coastal population to engage in fishing for generations. The Croatian fishing fleet includes 5% purse seiners, which make the largest amount of catches. This paper investigates the possibilities of implementing alternative fuels in power systems of purse seiners and their effect on the reduction of CO_2 emissions. 5-year data on fuel consumption and catch of purse seiners with different technical characteristics from the Croatian fishing fleet are used to calculate the level of emission release of possible solutions. Life-Cycle Assessment (LCA), which includes the ship operation and the process of fuel supply, is used to compare a diesel-powered configuration with alternative ones. In conclusion, a complete assessment of the efficiency of alternative fuels is given and guidelines for further research are proposed.

Keywords: Fishing vessels; Alternative fuels; Adriatic Sea; Carbon Footprint; LCA

1. INTRODUCTION

Fisheries and aquaculture present an important source of nutrition for more than 500 million people. The fishing sector is a valuable source of protein and essential minerals (FAO, 2012a). Fishing is one of the oldest sectors developed in communities with access to sea or freshwater. In the beginning, energy demands were covered by human labour (e.g. rowing, catching, transport) and solar energy (e.g. fish processing – drying, smoking). Today, energy demands are mainly covered by using fossil fuels (FAO, 2012a).

Fishing vessels, next to airborne transportation, consume the largest portion of energy and emit high values of harmful gases in the seafood product value chain (Jafarzadeh et al., 2017). As stated in Vladimir et al. (2021), marine vessels consume 330 Mt of marine fuel per year and 77% of it is Heavy Fuel Oil (HFO). The high percentage of fossil fuels in the marine sector causes emissions of harmful gases, such as CO_2, NO_X, SO_X and PM. Kim et al. (2021) stated that Greenhouse Gas (GHG) emissions of global fisheries increased by 28% from 1990 to 2011. Currently, the level of CO_2 emissions is about 2-6% of global CO_2 and a high rise is expected by 2050 (Vladimir et al., 2021). Global warming is a concern in different transport branches, not only marine, due to which agreements and strategies have been signed up worldwide with the goal to reduce emissions. The most mentioned agreement in recent years is the Paris Agreement, aiming at keeping the global temperature rise below 2 °C above the pre-industrial level and limiting the temperature increase to 1.5 ◦C (Koričan et al., 2022).

Another problem, regularly pointed out by environmental organizations, is overfishing. Both overfishing and harmful emissions are a counter product of the underdevelopment of the fishing sector (FAO, 2021a). Outdated equipment, small investments and poor management all have an important role in fisheries. With a better understanding of this field of agriculture and the development of more advanced methods in fisheries, there could be a significant improvement in the mitigation of GHGs and protection of the marine environment in general. Therefore, strategies are being formed with an emphasis on global waters and marine resources, and the socio-economic importance of their preservation (FAO, 2021b). One of the actions taken is the implementation of Emission Control Areas (ECA), i.e. locations with controlled content of sulphur oxides and nitrogen oxides. Expansion of such areas could have a significant impact on environmental protection and a direct effect on the type of fuel used in marine vessels (Prussi et al., 2021). Another options for emission reduction are market-based measures like taxation, as described by Isaksen et al. (2015). In Norway, general

CO_2 tax rates are showing a stable growth through the years. However, due to the underdevelopment of the sector, distant fishing is fully exempted from the tax and coastal fishing pays a reduced rate. In the next few years, these exemptions are likely to be lifted.

2. PURSE SEINE FISHING

Purse seining has a long tradition, and it is one of the most technologically developed fisheries in the world, especially tropical tuna purse seine fishery targeting skipjack, yellowfin and bigeye tuna (Basurko et al., 2022). Over the years the basic structure of a purse seiner has adopted different technologies to increase holding capacities, freezing technology, improvements in locating devices, such as sonars, GPS, drones etc., lighting systems (Figure 1), catching gear and others. These types of improvements directly affected the fuel consumption of the vessels and indirectly the environment by increasing GHGs emissions. A good example is given by Nhat et al. (2022). In their paper, the traditional lighting system was compared with Light-Emitting Diode (LED) technology. The results showed that purse seine vessels using LED lamps had advantages such as radiation spectrum, and correlated colour temperature, but also decreased the fuel consumption. These results are also indicated by Ricci et al. (2022), who showed that low-energy LED lamps have potential benefits at the economic level for the fishermen and a possibility of reducing GHGs emissions.

Figure 1: Lighting system on the purse seiner

Purse seiner is characterized by several fishing actions, very different compared to trawlers (Figure 2). Basurko et al. (2016) state that tuna purse seiner dedicates 56% of total fuel consumption to cruising and trawlers consume approx. 68% of fuel during fishing activities. The authors also state that fuel cost for trawlers represents 40%-50% of the total annual costs, while for tuna purse seiners the value goes to 70%. Fishing vessels with purse seines have a lower average fuel usage than trawlers, but the values significantly depend on the target species and ocean basin where they are caught. Parker et al. (2015) compared the fuel usage of tuna purse seiners depending on species and location. Their result showed a difference from 364 l/t for skipjack tuna and 395 l/t for yellowfish tuna. When the location is in focus, for the example of skipjack tuna, the seiners used 349 l/t in the Pacific, 445 l/t in the Atlantic and 459 l/t in the Indian Ocean. The paper also investigated emissions caused by the tuna purse seiners and calculated an average value of 1,140 kg CO_2-e per tonne of tuna landed (varies by ocean and species). However, fishing vessels with purse seines are mainly used for small pelagic species, caught for aquaculture feed production, rather than for direct human consumption.

The focus of this paper is a purse seining vessel operating in the Adriatic Sea, Croatia. The aim is to present the environmental issues of fishing vessels operating in the Mediterranean and several possibilities for mitigating the effect of the use of fossil fuels in their daily operations.

3. METHODOLOGY

3.1. Analysis of a purse seiner operating in the Adriatic Sea, Croatia

The Adriatic Sea is considered as a clean and well-preserved sea, rich both with flora and fauna. The relatively high water temperature and warm sea currents as well as moderate changes in tide made the Adriatic an ideal location for developing the tourism and fishing industry. According to the Croatian Bureau of Statistics (2022), purse seiners make up about 5% of the entire fishing fleet and land majority of catches, almost 89%. In this paper, a purse seiner operating in the central Adriatic (Croatia) is analyzed. The main particulars of the considered ship are given in Table 1. Since the operating time of fishing vessels depends on weather conditions and is rarely recurring, it is assumed that the average operating time of a purse seiner is 12 hours at sea.

Table 1: Main particulars of purse seiner

PURSE SEINER				
Length overall (LOA), m	27.74			
Breadth, m	6.28			
Draught, m	2.54			
Gross Tonnage (GT)	96			
Engine power, kW	526			
Speed – average, kn	6.9			
Speed – maximum, kn	11.5			
Fuel consumption FC, kg per year				
2015	2016	2017	2018	2019
57,351.0	57,423.7	47,315.8	69,638.9	56,119.8
Landed fish, kg per year				
2015	2016	2017	2018	2019
601,828	502,544	469,221	543,702	400,861

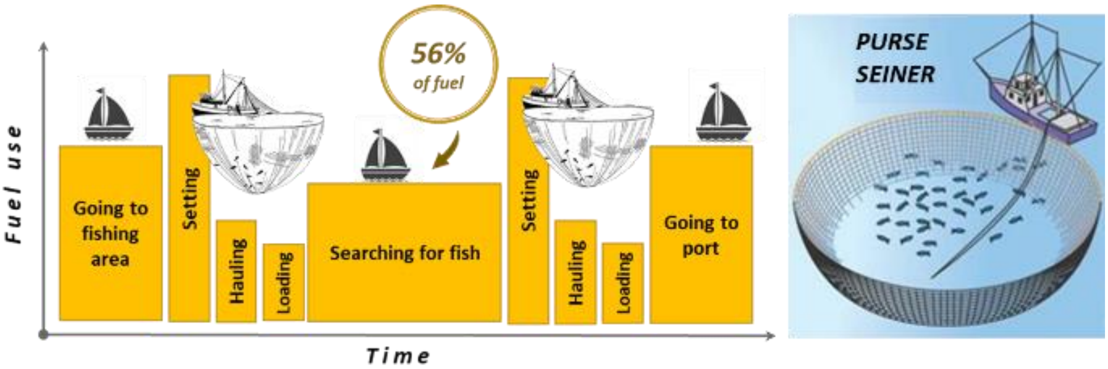


Figure 2: Fishing actions of purse seiners

3.2. Life-Cycle Analysis (LCA)

LCA is a method that is often used to analyse the environmental impact of a product. In this paper, LCA is performed to highlight the most environmentally friendly alternative power system, taking into account the emissions released through its life-cycle. (Perčić et al., 2021).

These emissions can be arranged into three categories. The first one refer to the Well-to-Pump (WTP) phase, which includes the fuel cycle from the extraction of raw material to the production of fuel and its transport to the refuelling station. The second category is Pump-to-Wake (PTW) and it refer to the fuel usage, i.e. the emissions released during the operating activities of the ship. These emissions are commonly named Tailpipe Emissions (TE) and are calculated using the following equation:

$$TE = FC \cdot EF, \quad (1)$$

where *FC* presents fuel consumption and *EF* presents the emission factor. The annual energy consumption is calculated by the following equation:

$$EC_A = \frac{FC}{SFC}, \quad (2)$$

where the *SFC* presents the specific fuel consumption (Perčić et al., 2021).

To gather complete information about the emissions during purse seining, the third category of emissions represents the manufacturing (M) phase which takes into account emissions released during the manufacturing process of the main elements in the analyzed power system.

By performing an LCA by means of GREET 2021 software (GREET, 2021).

3.3. LCA of different power configurations

The diesel-powered system presents a common energy system worldwide, used as a starting point for comparing different alternative fuels and their characteristics. LCA of diesel-powered systems includes the manufacturing process of a diesel engine, crude oil recovery and its transportation to the refinery, production of diesel and its distribution to the refuelling station. Within the PTW phase and the diesel combustion in the engine is considered (Figure 3).

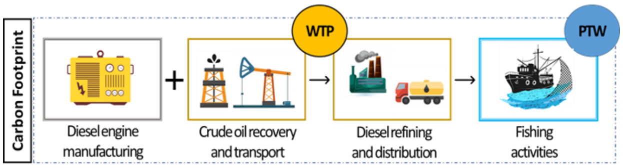


Figure 3: LCA analysis of a diesel-powered vessel

The WTP phase (the production and distribution of fuel) is described using parameters for diesel. Since the analyzed purse seiner is operating in the Adriatic Sea, the characteristics of "Eurodiesel Blue", diesel fuel with up to 0.5% sulphur, are used in calculations. Crude oil is considered to be the raw material for diesel production in Croatia, mainly transported from the Middle East and transported by tank trucks from the exploitation site to the port (500 km), further loaded onto a tanker and shipped to Omišalj, Croatia (4,000 km). From Omišalj, the oil is transported to the refinery in Rijeka, Croatia, 7 km (Perčić et al., 2021). The emissions released during fishing are calculated using equation (1), with the emissions factors presented in Table 2.

Table 2: Emissions factor (*EF*, g emission/kg fuel)

	Diesel	LNG
CO_2	3206	2750
CH_4	0.06	51.2
N_2O	0.15	0.11
NO_X	61.21	7.83
SO_X	2.64	0.02
PM	1.02	0.18

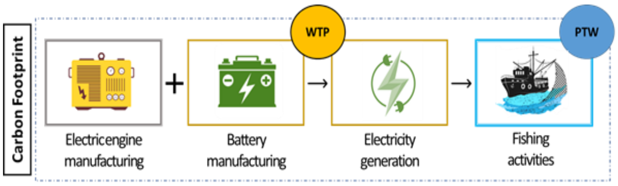
Electrification is one of the most mentioned alternative power configurations in recent years, due to a staggeringly high level of emissions reduction. The battery-powered system consists of a Lithium-ion (Li-ion) battery, which has a high energy density compared to other types of batteries, approximately 0.15-0.22 kWh/kg (Perčić et al., 2021). The battery capacity *BC* (kWh), depending on the required daily energy needs, is calculated as follows:

$$BC = P_{eng} \cdot t_{day}, \tag{3}$$

where P_{eng} stands for engine power (kW) and t_{day} (h) stands for daily operating time. The LCA analysis of a battery-powered configuration (Figure 4) consists of the manufacturing process of the electric engine and battery, and the process of electricity generation (WTP phase). Since the vessel does not release exhaust gases, the PTW emissions are equal to zero (Perčić et al., 2021). For calculating the environmental impact of the manufacturing phase, the battery weight (*BW*) is calculated (Koričan et al., 2021):

$$BW = \frac{BC}{BSE}, \tag{4}$$

where *BSE* presents the battery's specific energy equaling 0.22 kWh/kg. When performing the LCA analysis, it is assumed that the battery will need replacement once in the lifetime of the fishing vessel.



3.4. Figure 4: LCA analysis of a battery-powered vessel

LNG (Liquified Natural Gas) has been proven as an acceptable marine fuel, especially considering the reduction in GHGs that can be achieved. When it comes to CO_2, the emissions are approx. reduced by 20-25%, while NO_X can be reduced by 85-90% compared to heavy fuel oil. When considering SO_X, emissions can be eliminated (Leira, 2018). LNG is natural gas, consisting of mainly methane and a lower concentration of CO_2, nitrogen, hydrogen sulphide or helium. The natural gas is liquified (i.e. cooled and condensed), therefore simplifying transportation of gas when pipeline investments are not cost-effective (Leira, 2018).

There are several ways to exploit LNG as fuel. In this paper, natural gas is assumed to be used in a dual-fuel diesel engine. This type of engine provides higher efficiency than a mono-fuel engine, and enables a smooth switch, without power and/or speed lost, from diesel to natural gas (Perčić et al. 2021). Diesel is considered a pilot fuel in the amount of 1% (x_P), while the rest is natural gas (x_{LNG}). To calculate the fuel consumption of LNG (FC_{LNG}) and pilot fuel (FC_P), the specific consumption needs to be determined. For a load of 75%, the specific consumption of LNG (SFC_{LNG}) is 0.1544 kg/kWh, while the specific consumption of pilot fuel (SFC_P) is 0.0018 kg/kWh (Perčić et al., 2021). The fuel consumption is calculated by the following equations (Perčić et al., 2021):

$$FC_{LNG} = x_{LNG} \cdot SFC_{LNG} \cdot EC, \tag{5}$$

$$FC_P = x_P \cdot SFC_P \cdot EC. \tag{6}$$

The LCA of an LNG-powered vessel is presented in Figure 5. As shown, the LCA includes the manufacturing of a dual-fuel engine, the processes of pilot-fuel production and LNG production, and the emissions released during fishing activities.

The PTW emissions, released during LNG and diesel combustion, are calculated using equation (1). The *EFs* for LNG are listed in Table 2. The WTP phase consists of two parts, one concerning the LNG and the other concerning the pilot fuel. Diesel is chosen as pilot fuel and its WTP phase is described in the begging of the subchapter 2.3. The WTP phase of LNG includes the processes of natural gas recovery, its liquefaction and transportation. As presented in Perčić et al. (2021), LNG is transported from Qatar via LNG carriers, around 7000 km to Croatia, and further transportation corresponds to the transportation of diesel.

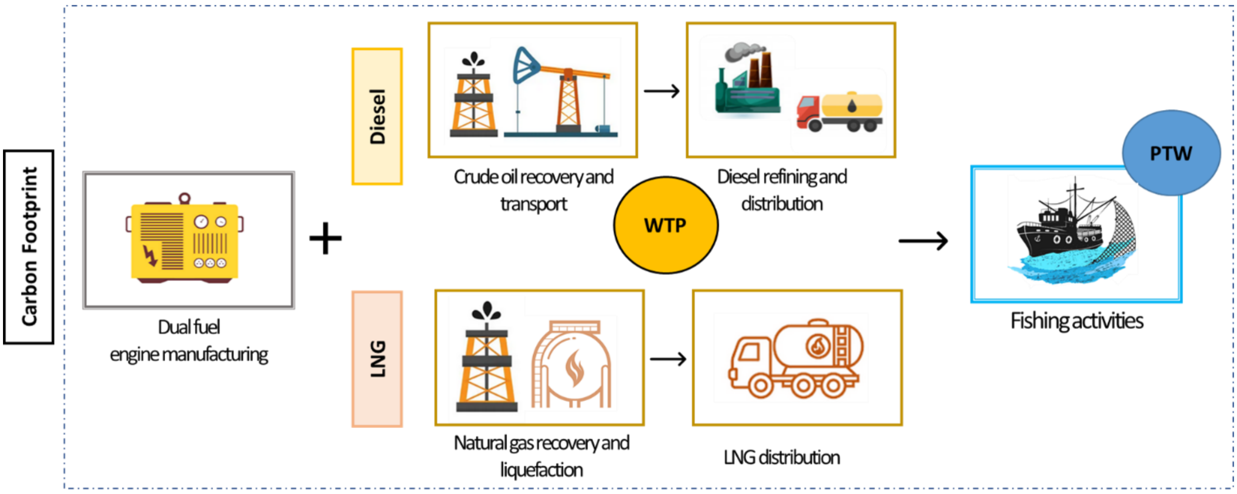


Figure 5: LCA analysis of an LNG-powered vessel

4. RESULTS & DISCUSSION

After conducting an LCA of the described power configurations, the results are presented in Figure 6. The results are separated by phases, showing the concentration of $CO_{2\text{-eq}}$, NO_X, SO_X and PM. The LCA analysis was conducted for a lifetime of 20 years (assumed lifetime of a fishing vessel).

When analyzing the M phase , it is visible that the battery-powered configuration emits the highest concentrations of harmful gases. The emissions of manufacturing a diesel engine are relatively low, only 0.103% of total emissions, regardless of whether the diesel-powered system was observed or the LNG-powered. Compared with them, the battery-powered system showed 136 times higher values in the manufacturing phase.

The WTP phases of diesel-powered and LNG-powered systems show similar values. Around 99% of emissions consist of $CO_{2\text{-eq}}$ and the rest contains NO_X, SO_X and PM. When comparing diesel-powered and LNG-powered systems, the proportion of NO_X, SO_X and PM are slightly higher, by approximately 0.1%.

The WTP phase of the battery-powered system showed higher values than the previously mentioned. The emissions in the WTP phase make 80.19% of overall emissions, about six times higher in value than the ones in diesel-powered and LNG- powered systems. However, the concentration of NO_X, SO_X and PM in all three power systems show low values, from 0.02% to 0.28%.

The PTW emissions are the focus of this research since they depend on fuel type and its consumption. The emissions from the WTP phase cannot be easily manipulated since they depend on fuel production from raw materials, transportation, distribution, and similar activities. Therefore, PTW phase offers the ability to mitigate harmful emissions by changing the vessels' energy system, reducing fuel consumption, and adapting fishing activities. The diesel-powered system showed a significantly high level of PTW emissions, consisting of 98.04% of $CO_{2\text{-eq}}$, 1.84% NO_X and the rest of SO_X and PM. The LNG-powered system also showed a high level of PTW emissions with 99.81% of $CO_{2\text{-eq}}$. However, the level of NO_X has lower values, about 0.18%. The most environmentally friendly option, considering the PTW emissions, is the battery-powered configuration. Since there are no released emissions during fishing activities, the PTW phase of a battery-powered configuration equals zero.

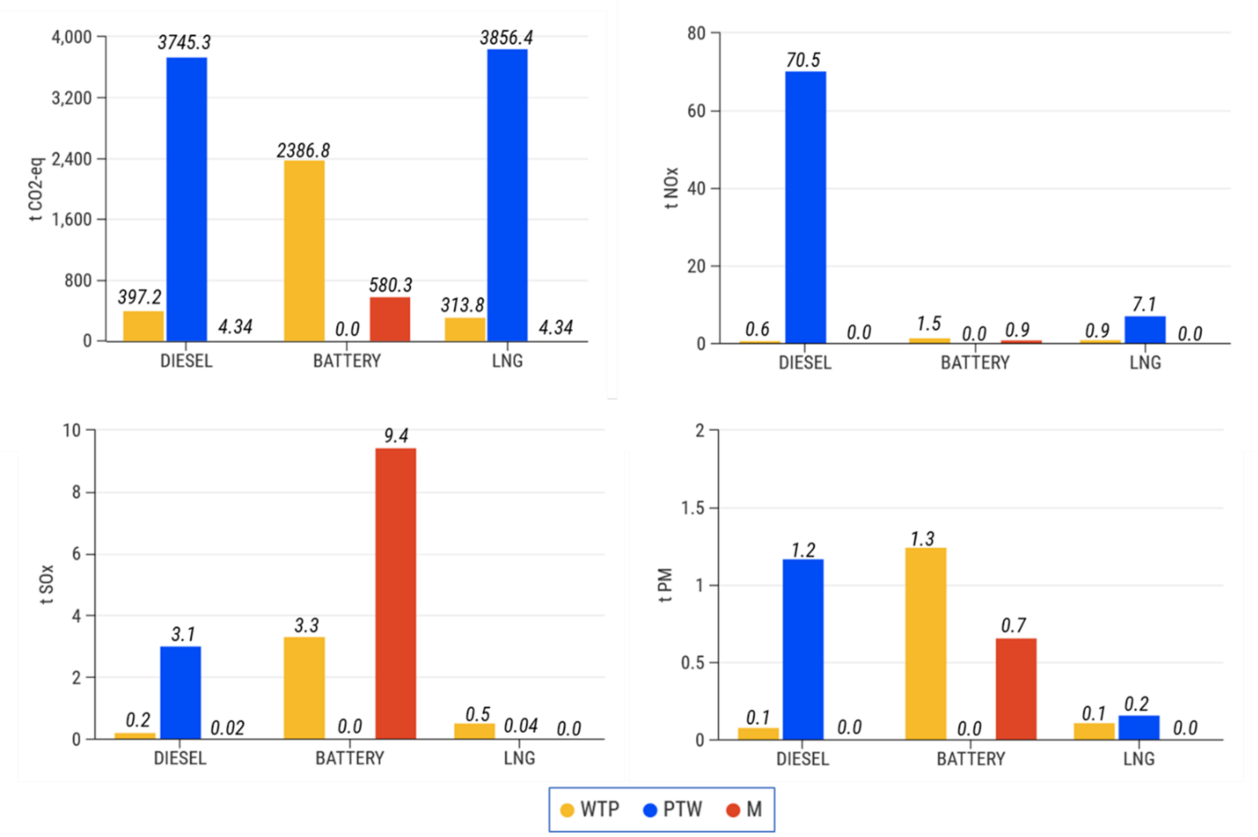


Figure 6: LCA of different power systems

It is evident that alternative energy configurations have certain benefits, but also disadvantages. LNG as fuel could mitigate harmful emissions, especially NO_X. However, diesel is still used as a pilot fuel, which adds to the value of emissions in the WTP phase. Also, an LNG-powered system requires onboard modifications, due to which it may not be the optimal solution for individual types of ships. LNG could be considered as a transitional fuel, to reduce the use of diesel and decarbonize the fleet (Prussi et al., 2021). The battery-powered configuration has already been confirmed as the most environmentally friendly option, especially in short sea shipping (Perčić et al., 2021). In the case of fishing vessels, electrification may not be the ideal power configuration since fishing operations are characterized by changes in speed, heavy loads and long voyages. Batteries could help in fishing by powering LED lights so that the use of diesel generators can be reduced and thus the impact on the environment.

5. CONCLUSION

The environmental analysis of a purse seiner operating in the Adriatic Sea is presented in this paper. Purse seining plays an important role in Croatian fisheries. A five-year data received from the Croatian Ministry of Agriculture, Department of Fisheries, gave the possibility to analyze the fuel utilization of part of the Croatian fishing fleet. The results of the LCA of the purse seiner showed that a high level of harmful emissions is released during fishing and different alternative solutions could help to mitigate the mentioned emissions. However, the required investment in these types of alternative solutions may not justify such expenses. LNG, as a diesel replacement, shows small reductions in emissions but offers a possibility to reduce fossil fuels with high concentration of carbon content, such as diesel. Batteries show the best results when talking about PTW emissions but the issues concerning battery charging and maintenance could complicate their implementation on fishing vessels. In conclusion, different alternative power options offer numerous solutions for reducing harmful emissions, but further research is needed to choose the optimal one that meets both the environmental and economic needs of fishing vessels.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Food and Agriculture (2012a). Fuel savings for small fishing vessels: A manual, http://www.fao.org/publications/card/en/c/98995c6b-bd40-56c7-bcf5-768c1d8eccc1/ (accessed 10 April 2022).

[2] Jafarzadeh S, Paltrinieri N, Utne IB, Ellingsen H. (2017) LNG-fuelled fishing vessels: A systems engineering approach. Transp Res Part D Transp Environ 2017;50:202–22. https://doi.org/10.1016/j.trd.2016.10.032.

[3] Kim, K., Kim, D.H., Kim, Y. (2021). Fisheries: A missing link in greenhouse gas emission policies in south korea. Sustain. 13, 1–10. https://doi.org/10.3390/su13115858

[4] Vladimir, N., Koričan, M., Perčić, M., Alujević, N., Hadžić, N. (2021). Analysis of environmental footprint of a fishing trawler with overview of emission reduction technologies. International Conference on Applied Energy 2021.

[5] Koričan, M., Perčić, M., Vladimir, N., Soldo, V., Jovanović, I. (2022). Environmental and economic assessment of mariculture systems using a high share of renewable energy sources. J. Clean. Prod. 333. https://doi.org/10.1016/j.jclepro.2021.130072

[6] Food and Agriculture (2021a). Trade in fisheries products: fisheries sustainability, fishing capacity, and illegal, unreported and unregulated (iuu) fishing. https://www.fao.org/publications/card/en/c/CB5411EN

[7] Food and Agriculture (2012b). Strategy for fisheries, aquaculture and climate change. https://www.fao.org/3/at500e/at500e.pdf

[8] Prussi, M., Scarlat, N., Acciaro, M., Kosmas, V., (2021). Potential and limiting factors in the use of alternative fuels in the European maritime sector. J. Clean. Prod. 291, 125849. https://doi.org/10.1016/j.jclepro.2021.125849

[9] Isaksen, J.R., Hermansen, Ø., Flaaten, O. (2015). Stubborn fuel tax concessions: The case of fisheries in Norway. Mar. Policy 52, 85–92. https://doi.org/10.1016/j.marpol.2014.10.028

[10] Parker, R.W.R., Vázquez-Rowe, I., Tyedmers, P.H., (2015). Fuel performance and carbon footprint of the global purse seine tuna fleet. J. Clean. Prod. 103, 517–524. https://doi.org/10.1016/j.jclepro.2014.05.017

[11] Basurko, OC., Gabina, G., Quincoces, I.. (2016) Fuel Consumption Monitoring in Fishing Vessels and Its Potential for Different Stakeholders. In: Presented at the Shipping in Changing Climates Conference 2016: Newcastle University, United Kingdom; https://conferences.ncl.ac.uk/media/sites/conferencewebsites/scc2016/1.1.2.pdf [accessed 23 January 2022].

[12] Basurko, O.C., Gabiña, G., Lopez, J., Granado, I., Murua, H., Fernandes, J.A., Krug, I., Ruiz, J., Uriondo, Z. (2022). Fuel consumption of free-swimming school versus FAD strategies in tropical tuna purse seine fishing. Fish. Res. 245. https://doi.org/10.1016/j.fishres.2021.106139

[13] Nhat, N.D., Tien, D.T., Van Dan, T., Quynh Tram, N.D., Lich, N.Q., Phuc, H.D., Phuoc, N.N. (2022). The effectiveness of light emitting diode (LED) lamps in the offshore purse seine fishery in Vietnam. Aquac. Fish. 1–7. https://doi.org/10.1016/j.aaf.2022.01.005

[14] Ricci, P., Trivellin, N., Cascione, D., Cipriano, G., Orlandi, V.T., Carlucci, R. (2022). Benefits and Risks of the Technological Creep of LED Light Technologies Applied to the Purse Seine Fishery. Biology (Basel). 11. https://doi.org/10.3390/biology11010048

[15] Croatian bureau of statistics. (2022). Statistical Information. https://podaci.dzs.hr/en/statistics/agriculture/fishery/ [accessed 23 January 2022].

[16] Perčić, M., Vladimir, N., Fan, A. (2021). Techno-economic assessment of alternative marine fuels for inland shipping in Croatia. Renew. Sustain. Energy Rev. 148. https://doi.org/10.1016/j.rser.2021.111363

[17] GREET software 2021 (2022). https://greet.es.anl.gov/net

[18] Leira, B. (2018). LNG as fuel on fishing vessels - Assessment of economic feasibility and environmental impact. Mar. Technol.

THE ROLE OF LOGISTICS SYSTEMS IN REGIONAL AND LOCAL SUSTAINABLE DEVELOPMENT

Milovan Kovač, Ph.D. Candidate
SnežanaTadić, Ph.D.
MladenKrstić, Ph.D.
Slobodan Zečević, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering, Logistics Department
Vojvode Stepe 305, Belgrade, Serbia
m.kovac@sf.bg.ac.rs, s.tadic@sf.bg.ac.rs, m.krstic@sf.bg.ac.rs, s.zecevic@sf.bg.ac.rs

ABSTRACT

In the last decades, the issues of sustainability and sustainable development attract much attention in expert and scientific domains. A specific issue in that field is in achieving sustainable goods flow realization. The realization of goods flows is supported with numerous logistics activities (transportation, transhipment,warehousing, goods processing, order picking, etc.) whose inadequate planning leads to serious negative effects on sustainability. Transport is a logistics activity with the most unsustainable effects that challenge the economic, environmental and social sustainability of logistics systems and processes. The planning of sustainable logistics systems is a prerequisite for the sustainable realization of goods flows and achievement of sustainable regional and local development. By promoting the intensive application of alternative transportation modes, intermodal transportation (IT) enables energy, costs and time savings, improves service quality, and so plays a key role in achieving regional sustainability. On the other hand, adequate planning of city logistics (CL) and defining of different measures, initiatives, and concepts are the prerequisites for achieving local sustainability. Having that in mind, this article explains the problems of sustainable development, their connection with the realization of logistics activities, and the key elements that enable the sustainability of logistics systems on regional and local levels. For the field of IT, that element is the Dry Port concept, while for the area of CL those elements are multiple levels of flows consolidation and the application of alternative transportation modes and alternative energy vehicles.

Keywords: Sustainability, Development, Logistics, Intermodal Transport, City Logistics

1. INTRODUCTION

Sustainable development refers to the development that satisfies the needs of the current generation without compromising the needs of future ones (WCED - The world commission on environment and development, 1987). The problems of sustainable development are an ongoing topic where the planning of sustainable logistics systems represents one of the key elements for their solving. Goods flow realization is one of the vital processes in all segments of everyday life and it represents the foundation of modern society functioning. The main support for the goods flows is an efficient realization of logistics activities. Having in mind the ever-increasing negative effects of logistics activities realization on sustainability, the planning of sustainable logistics systems is necessary. Intermodal transportation (IT) and city logistics (CL) play key roles in achieving sustainable logistics. IT represents the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes(European Conference of Ministers of Transport, 1993). CL refers to all strategies, technologies and logistics solutions that support all participants and functions of urban space, regardless of their size, number, position and boundaries, considering their individual and common interests and goals (Zečević & Tadić, 2006).

The application of IT reduces energy consumption, stimulates more rational infrastructure utilization, significantly reduces negative environmental impacts of transportation by applying large-capacity waterborne (sea and inland waterway) and rail vehicles (Lopez-Navarro, 2014). IT also retains the flexibility of road transportation in the initial and final phases of logistics chains realization (Lopez-Navarro, 2014). On the other hand, different CL concepts lead to the improvement of vehicle utilization factor and the reduction of vehicle trips, travelled distance, number of used vehicles, traffic congestions, traffic incidents, travel times, fuel consumption, CO_2 emission, etc. (Zečević & Tadić, 2006). However, the best effects are achieved through the synergy of IT and CL systems which should be considered as integral elements of a wholesome sustainable logistics system.

The goal of this article is to indicate the problems of sustainable development and focus on the importance of sustainable logistics planning for achieving regional and local sustainability. The article is organized into five sections. The next section explains the issues of sustainable development in more detail. Section 3 explains the role of logistics in achieving sustainable development with the focus set on the responsibilities of IT in achieving regional and CL in achieving local sustainability. Section 4 identifies the directions of planning sustainable IT and CL systems in the scope of its possible application within Europe. The directions are defined in accordance with existing ideas, concepts, and approaches that indicate sustainability. The last section presents concluding remarks.

2. SUSTAINABLE DEVELOPMENT

Sustainable development is more a directed journey towards changes than it is a precisely defined destination (Robinson, 2004). The society, environment, and their interaction are under constant changes, therefore sustainable development is not a fixed state of harmony but rather an evolutive process (Waas et al., 2011). Sustainable development should set the balance between economic, environmental, and social components so that they would indeed stand as pillars of that development (Mensah, 2019).

To confront the sustainability issues on a global scale, the United Nations defined in 2015 the main categories of sustainable development goals that should be achieved by 2030 (United Nations, 2016). Sustainability development goals can be classified into three groups (Fu et al., 2019): basic needs (food, water, resources, energy, ecosystems, etc.), expected goals (healthcare, equality, poverty, security, education, etc.) and sustainable planning and management (with infrastructure, urbanization, consumption, production, global partnerships, etc.). Achieving individual goals has been proven unsustainable because a complex interdependence between goals exists – the improvement on one field of sustainability often leads to unsustainability on others (Fonseca, Domingues, & Dima, 2020).

Even though some commitments in achieving sustainability exist, the world is still threatened by a crisis caused by unsustainable development (Zeng et al., 2020). Aside from some individual positive examples, the current progress is insufficient, while the achievement of sustainable development goals until the year 2030 seems impossible (Bocken & Short, 2021). Recent reports of the United Nations alarm that global warming rates are higher than expected, land degradation continues, many species are facing extinction, unsustainable consumption and production are still present, etc., which complies with the fact that the world is still far from achieving sustainability (United Nations, 2020). In 2019, the CO_2 were 50% greater compared to 2000, and almost three times greater compared to 1970 (Kurzgesagt, 2020). Sustainable development is an ongoing issue that pressurizes academics, the economy, and society as a whole (Silvestre & Ţîrcă, 2019). Numerous research attempts tried to highlight the unsustainable path of society (Lemke & Bastini, 2020). However, the research is mostly isolated in individual disciplines, institutions, and fields (Fuso Nerini et al., 2018). Encompassing and multidisciplinary approaches, which bring together all stakeholders, are required so that the sustainability issues could be treated in the right way (Liu et al., 2018).

3. LOGISTICS ROLE IN ACHIEVING SUSTAINABILITY

To achieve a sustainable future, structural transformations in all segments of everyday life are required (Sachs et al., 2019). The defined goals of sustainable development, especially those that refer to sustainable production and consumption, are contributing to the importance of logistics systems sustainability issues (Martins et al., 2019) because logistics is the foundation of global and regional supply chain realization (Qaiser et al., 2017). Logistics is a service to the global and local economy – it significantly impacts economic growth, but at the same time, the realization of logistics activities results in numerous negative effects (Baah et al., 2021). The negative effects of logistics activities realization, especially the activities of the transport subsystem, significantly contribute to the trend of unsustainable development that compromises all three pillars of sustainability. The most obvious effects on the economic pillar of sustainability are inefficient and unnecessary consumption of resources, lesser delivery reliability and accuracy, reduction in service quality and the loss of market shares, slowing down of further economic development, high goods and services prices, etc. (Tadić & Zečević, 2016). From the environmental perspective, the negative consequences of logistics activities realization are visible through the emission of air pollutants, the usage of non-renewable resources (fossil fuels), the destruction of ecosystems, and the threat of animal species extinction, waste generation, etc. (Tadić & Zečević, 2016). The transportation sector is the second largest contributor of air pollution in the European Union, and the only one whose emissions are in constant growth (Stojanović et al., 2021). Causing health problems, reduced traffic safety, noise and vibration generation, infrastructure degradation, reducing the attractiveness of the environment, traffic congestions, etc., are some of the negative effects of logistics activities realization on the social sustainability pillar (Kumar & Anbanandam, 2019; Tadić & Zečević, 2016).

Considering the current state, it is imperative to plan and develop logistics systems that will contribute to the sustainability on all three pillars – economic, environmental, and social. Sustainable logistics systems should be developed at a regional and local level. On the regional level, IT plays a key role, while on the local level, CL covers the topics of sustainable logistics.

The reorganization of existing and the planning of new logistics systems, with the aim of sustainability, is not an easy task. However, the sustainability of logistics systems could be achieved through innovations (Björklund & Forslund, 2018), internalization of externalities (Wang et al., 2017), public and private sector subsidies (Zhang et al., 2018), etc., and that sustainability could be used as a means for sustainable logistics value creation, which undoubtedly leads to competitive advantage (De Kervenoael et al., 2020).

3.1. Sustainable IT systems as support for regional sustainability

The scientific literature in the domain of IT is abundant (Caris et al., 2013), where the most covered topics refer to regulatory frameworks for stimulating IT development (Ge et al., 2020), planning of IT terminals (Tadić et al., 2019)and terminal networks (Teye et al., 2018), service network design (Tawfik & Limbourg, 2019), IT terminal location selection (Ližbetin, 2019), routing in IT (Sun, 2020), inbound/outbound operations (Benantar et al., 2020), innovations that would support IT development (Vural et al., 2020), technology selection for logistics activities realization (Krstić et al., 2019), etc. Despite the abundant scientific and expert literature, the field of IT is mostly ill-treated in practice. Some countries, such as the countries of western Europe, recognize the importance of IT, so they define the responsible bodies and institutions in their development plans, promote the usage of IT, define project funding sources, analyze the scenarios of further IT development, etc. (Tadić et al,. 2021). With the goal of promoting the usage of IT, the European Union has funded several projects in the last two decades, such as LOGIQ, PROMOTIQ, SULOGTRA, RECORDIT, PACT, Marco Polo I, Marco Polo II (Suarez-Aleman et al., 2007), etc. Still, aside from the projects and defined measures for stimulating the usage of IT, there is a lack of promising results in practice. One of the main causes is the inadequate connection between rail and inland waterway transportation modes, as alternatives for road transportation (Tawfik & Limbourg, 2019). The application of IT is mostly analyzed in the context of flow realization over long distances, it is necessary to analyze the possibilities of applying IT in CL, with the goal of planning and developing sustainable logistics systems (He & Haasis, 2019).

IT logistics networks are systems that consist of nodes (sources, transhipment points, and destinations of goods flows) and links between those nodes established through some transportation modes (Janic, 2007). Performances and sustainability of IT mostly depend on the efficiency of their elements (Tadić et al., 2021), where the key role in those roles are played by IT terminals. The development and expansion of IT networks/systems must be accompanied by the identification and prioritization of system development factors (Kumar & Anbanandam, 2020), definition of development directions (Tadić et al., 2021), identification odadequate IT terminal types (Tadić et al., 2019), their elements and structures (Krstić et al., 2019), location (Zečević et al., 2017), etc.

Lots of attention in the field of developing IT systems in seaport container terminal hinterland is set on the Dry Port (DP) concept. DP is a seaport container terminal subsystem, physically separated into the continent hinterland, with established regular shuttle connections (mainly through rail transportation) with its source seaport terminal and offers almost all services of that seaport terminal - but in its hinterland (Roso et al., 2009). The DP concept improves the performances of seaport container terminals, provides them with necessary capacities, improves the service capability of the seaport and so improves their competitiveness, which attracts greater container flow volumes (Jeevan et al., 2019)and improves the efficiency of the whole hinterland IT system. By reviewing the literature it is evident that the existing research analyzed the DP concept for different geographical areas (Abbasi & Pishvaee, 2018; Black et al., 2018; Chang et al., 2015; Tadić et al., 2021), but only in the function of seaport container terminals. The article (Tadić et al., 2021) highlights the potential sustainability of a DP concept in the function of inland waterway container terminals as a concept of efficient inland waterway integration into existing IT systems, but no existing research analyzed this concept with more detail.

3.2. Sustainable CL systems as support for local sustainability

As is the case with IT, there is a diverse body of literature in the field of CL. A large number of initiatives, measures, technologies, and CL concepts were analyzed. The research is mostly focused on the concepts of cooperation (Montecinos et al., 2020; Zečević & Tadić, 2005) and flow consolidation (Raicu et al., 2020; Tadić & Zečević, 2015), the application of alternative transportation modes (Janjević & Ndiaye, 2014; Strale, 2014), autonomous vehicles (Tadić et al., 2021) and road vehicles with alternative energy sources (Quak et al., 2016) in delivery, the development of intelligent systems and software solutions (Quereshi et al., 2014), assessment of CL initiatives (Tadić et al., 2018), the involvement of ordinary people (Castillo et al., 2018) and public passenger transport (Pimentel & Alvelos, 2018) in goods delivery, etc.

In practice, a large number of CL solutions is also applied, but their effects were mainly short-lived and limited so those projects were abandoned after a certain amount of time (Vahrenkamp, 2016). The main reason for this is not understanding the core of CL problems, partial planning, the lack of cooperation among stakeholders, and the absence of vital public funding (Van Rooijen et al., 2018; Tadić & Zečević, 2016). However, even with ill-treated CL in practice, the diversity of scientific literature in the field enables the definition of new, potentially sustainable solutions. CL solutions can be defined according to different initiatives, measures, technologies, concepts, approaches, etc., and even within one solution several different scenarios and variants can be defined (Janjević et al., 2016).

The application of IT in the field of CL, although relatively explored in the existing literature (Diziain et al., 2014; He & Haasis, 2019), is in practice present only in a few individual examples. One of the reasons for the weaker presence of alternative transportation modes (rail and inland waterway) in the field of CL is their non-competitiveness with road transportation over short distances (Strale, 2014), but also the insufficient engagement of the public sector in their funding and regulatory support (Arvidsson & Browne, 2013). However, the competitiveness of alternative transportation modes could be achieved through the concepts of flow consolidation through logistics centres (Zych, 2014). Flow consolidation attracts greater flow volumes which can enable the efficient application of IT in CL by transforming the existing systems into multi-echelon ones. In multi-echelon systems, the realization of flows is executed through different phases (levels, echelons) connected (physically and organizationally) by logistics centres (Dondo et al., 2011). The combination of multi-echelon systems with other initiatives/ technologies represents a potentially sustainable category of CL solutions (Tadić et al., 2021).

4. PLANNING AND DEVELOPING SUSTAINABLE IT AND CL SYSTEMS

Previous sections showed that the development of sustainable IT and CL systems represents the prerequisites for regional and local sustainable development. By reviewing the scientific literature and existing treatment and state of logistics, it becomes obvious that the development directions of sustainable logistics systems should be defined. The identified development directions could be the focus for implementation in underdeveloped regions that need to catch up with modern approaches and standards for achieving sustainability.

In the context of sustainable regional development, it is necessary to plan systems that would include intercontinental and regional goods flows. For the areas in the hinterland of seaport container terminals, the application of the DP concept is an obvious direction of sustainable development. Aside from the revitalization of existing IT terminals and their transformation into local DP terminals, it is necessary to develop regional DP terminals. By establishing shuttle lines on the relations DP terminals – seaport container terminals,the realization of container flows in seaport hinterland is shifted onto rail transportation. This eliminates the unnecessary engagement of road transportation in goods flow realization over long distances and the presence of a large number of road vehicles in seaport cities. To achieve better synergy in the region, it is also necessary to establish shuttle connections between DP terminals, and also to connect local IT terminals with the DP system.Such an approach would develop an encompassing IT network in the hinterland of seaport terminals and efficient realization of intercontinental flows would be enabled. (Figure 1).

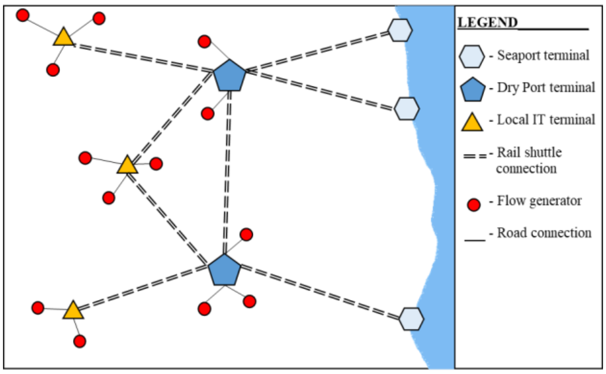


Figure 1: DP concept for intercontinental goods flows with interconnected DP terminals and local IT terminals

Having in mind that the DP concept is primarily oriented towards the realization of intercontinental flows, its application neglects regional flows whose inefficient realizations also contributes to negative effects on sustainability. In the existing systems, road transportation has the leading role in the realization of regional goods flows. To increase the involvement of IT in their realization, it is necessary to establish an adequate connection between rail and inland waterway transportation modes. This is possible by developing DP terminals in the function of inland waterway container terminals (Figure 2). On the relation DP terminals – inland waterway container terminals regular rail shuttle connections would be established. The development of DP terminals in the function of inland waterway container terminals would increase the system catchment area and larger volumes of container flows would be transferred to inland waterway transportation. The establishment of shuttle connections among DP terminals would also enable the attraction of goods flows that are incompatible with inland waterway transportation.

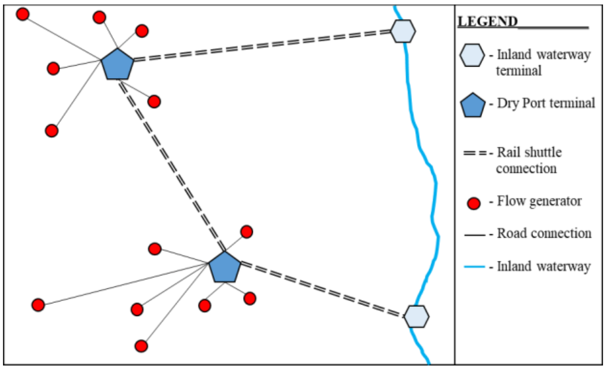


Figure 2: DP concept for inland waterway container terminals

The examined development directions through the DP concept are feasible for implementation in regions that are geographically in a favourable position for intercontinental goods flows but lack the infrastructure of an encompassing IT system. A good example of this is the Western Balkans region which lies at the coast of the Adriatic sea and could serve as a hub of nodes for the realization of intercontinental goods flows to mainland Europe. Considering the fact that the main

European hubs for intercontinental flows are in northwestern Europe, the development of efficient DP systems in southern and southeastern regions would rebalance container flows realization and give a stimulus for sustainable development of the region. The development of a DP concept in the function of inland waterway container terminals is feasible in regions with significant inland waterways, capable of catching large container flow volumes. One such region is the region of central and southeastern Europe. In such a concept, the Danube river would serve as the main logistics axis of the region, and the development of DP terminals would expand the capabilities and the catchment area of the IT network.

In the field of goods delivery in CL, road transportation is also dominant. The development of sustainable CL systems requires greater involvement of alternative transportation modes and vehicles with alternative power sources. This is possible through the application of cooperation and consolidation concepts through logistics centres. The development of adequate logistics centres on urban peripheries enables the consolidation of inbound goods flows and the economy of scale is achieved so the application of IT becomes justified. This would also enable the efficient application of regular cargo tram lines and inland waterway transportation in urban areas that lay on sailable rivers. The development of a larger number of peripheral logistics centres would enable the segmentation of the urban area into several delivery zones, where every zone would be served only by one logistics centre. By establishing regular rail connections between those logistics centres, the transfer of goods between different zones would be possible, and with it, the coverage of flow generators with all goods types as well.

Additional positive effects on urban areas' sustainability could be achieved by developing micro-consolidation centres in the delivery zone. Their development would enable the efficient application of smaller delivery vehicles and vehicles with alternative energy sources in the delivery zone. The consolidation of goods flows at the periphery of urban areas, the application of rail and inland waterway transportation for the transfer of goods to the delivery zone, and flow micro-consolidation in the delivery zone would establish the foundations of sustainable, hyperconnected CL systems (Figure 3).

Since the field of CL is mainly ill-treated in the practice, the development of sustainable CL systems is an ongoing, open topic for most urban areas. The best candidates for implementing CL concepts that include IT, logistics centres, alternative transportation modes and vehicles, are large cities that rapidly expanded themselves around their historical centre, with developed residential city zones in peripheral areas and the concentration of business activities in the city centre. Such urban areas are facing a disproportion in the demands for logistics services and the capabilities for their realization, which resulted in the inefficient and unsustainable realization of logistics activities. European examples of such cities are Budapest, Belgrade, Bucharest, Moscow, etc.

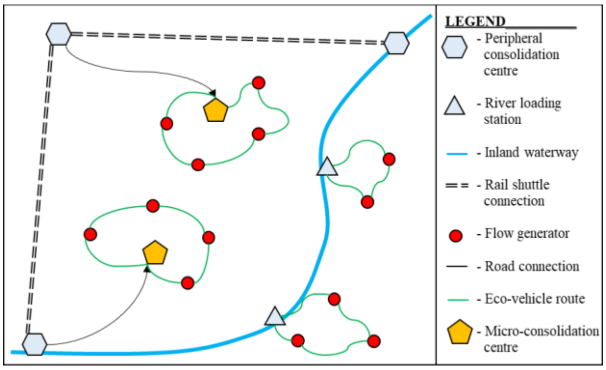


Figure 3: Consolidation of goods at the outskirts of the city and in the delivery zone with alternative transportation modes

5. CONCLUSION

The problems of sustainable development are always a trending topic in all domains. Its achievement is possible only through intensive changes and transformations of all elements of human everyday life, where the development of sustainable logistics systems has also specific importance.

This paper highlights the role of IT system planning in the context of regional sustainability, with the accent set on several potential directions for its achievement. The DP concept plays an important role in achieving sustainability in the realization of intercontinental goods flows. Furthermore, by transforming and applying the DP concept in the function of inland waterway container terminals, the efficient integration of inland waterway transportation into IT systems is enabled which provides the foundation for the sustainable realization of regional goods flows.

On the local level, sustainability could be achieved only through the planning of sustainable CL systems. Indispensable elements of sustainable CL systems are flow consolidation at the periphery of urban areas, flow micro-consolidation in the delivery zone, and the application of alternative transportation modes for connecting different categories of logistics centres.

Future research should focus on further elaboration and definition of ideas that provide the basis of sustainable logistics system development – IT and CL. It is necessary to propose frameworks for defining sustainable development scenarios of IT and to examine sustainable development directions for different geographical regions. In the domain of CL, it is necessary to define and analyze solutions that promote the intensive application of alternative transportation modes and the development of appropriate categories of logistics centresthat would enable such modal shift.

REFERENCES

[1] Abbasi, M., & Pishvaee, M. S. (2018). A two-stage GIS-based optimization model for the dry port location problem : A case study of Iran. *Journal of Industrial and Systems Engineering*, *11*(1), 50–73.

[2] Arvidsson, N., & Browne, M. (2013). A review of the success and failure of tram systems to carry urban freight: The implications for a low emission intermodal solution using electric vehicles on trams. *European Transport \ Trasporti Europei*, *54*(5), 1–18.

[3] Baah, C., Amponsah, K. T., Issau, K., Ofori, D., Acquah, I. S. K., & Agyeman, D. O. (2021). Examining the Interconnections Between Sustainable Logistics Practices, Environmental Reputation and Financial Performance: A Mediation Approach. *Vision: The Journal of Business Perspective*, *25*(1), 47–64.

[4] Benantar, A., Abourraja, M. N., Boukachour, J., Boudebous, D., & Duvallet, C. (2020). On the integration of container availability constraints into daily drayage operations arising in France: Modelling and optimization. *Transportation Research Part E: Logistics and Transportation Review*, *140*, 101969.

[5] Björklund, M., & Forslund, H. (2018). Exploring the sustainable logistics innovation process. *Industrial Management and Data Systems*, *118*(1), 204–217.

[6] Black, J., Roso, V., Marušić, E., & Brnjac, N. (2018). Issues in dry port location and implementation in metropolitan areas: The case of sydney, Australia. *Transactions on Maritime Science*, *7*(1), 41–50.

[7] Bocken, N. M. P., & Short, S. W. (2021). Unsustainable business models – Recognising and resolving institutionalised social and environmental harm. *Journal of Cleaner Production*, *312*, 127828. Elsevier.

[8] Caris, A., Macharis, C., & Janssens, G. K. (2013). Decision support in intermodal transport: A new research agenda. *Computers in Industry*, *64*, 105–112.

[9] Castillo, V. E., Bell, J. E., Rose, W. J., & Rodrigues, A. M. (2018). Crowdsourcing Last Mile Delivery: Strategic Implications and Future Research Directions. *Journal of Business Logistics*, *39*(1), 7–25.

[10] Chang, Z., Notteboom, T., & Lu, J. (2015). A two-phase model for dry port location with an application to the port of Dalian in China. *Transportation Planning and Technology*, *38*(4), 442–464.

[11] Diziain, D., Taniguchi, E., & Dablanc, L. (2014). Urban Logistics by Rail and Waterways in France and Japan. *Procedia - Social and Behavioral Sciences*, *125*, 159–170. Elsevier B.V. Retrieved from http://dx.doi.org/10.1016/j.sbspro.2014.01.1464

[12] Dondo, R., Méndez, C. A., & Cerdá, J. (2011). The multi-echelon vehicle routing problem with cross docking in supply chain management. *Computers and Chemical Engineering*, *35*(12), 3002–3024. Pergamon.

[13] European Conference of Ministers of Transport. (1993). *Terminology on Combined Transport*. European Conference of Ministers of Transport: Paris, France.

[14] Fonseca, L. M., Domingues, J. P., & Dima, A. M. (2020). Mapping the Sustainable Development Goals Relationships. *Sustainability*, *12*(8), 3359. Multidisciplinary Digital Publishing Institute. Retrieved September 18, 2021, from https://www.mdpi.com/2071-1050/12/8/3359

[15] Fu, B., Wang, S., Zhang, J., Hou, Z., & Li, J. (2019). Unravelling the complexity in achieving the 17 sustainable-development goals. *National Science Review*, *6*(3), 386–388.

[16] Fuso Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., Borrion, A., et al. (2018). Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy*, *3*(1), 10–15. Springer US. Retrieved from http://dx.doi.org/10.1038/s41560-017-0036-5

[17] Ge, J., Shi, W., & Wang, X. (2020). Policy agenda for sustainable intermodal transport in China: An application of the multiple streams framework. *Sustainability*, *12*, 3915.

[18] He, Z., & Haasis, H.-D. (2019). Integration of Urban Freight Innovations: Sustainable Inner-Urban Intermodal Transportation in the Retail/Postal Industry. *Sustainability*, *11*(6), 1749. Multidisciplinary Digital Publishing Institute. Retrieved August 29, 2021, from https://www.mdpi.com/2071-1050/11/6/1749

[19] Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment*, *12*(1), 33–44.

[20] Janjević, M., Lebeau, P., Ndiaye, A. B., Macharis, C., Van Mierlo, J., & Nsamzinshuti, A. (2016). Strategic Scenarios for Sustainable Urban Distribution in the Brussels-capital Region Using Urban Consolidation Centres. *Transportation Research Procedia*, *12*(June 2015), 598–612. Elsevier B.V.

[21] Janjević, M., & Ndiaye, A. B. (2014). Inland waterways transport for city logistics: A review of experiences and the role of local public authorities. *WIT Transactions on the Built Environment*, *138*, 279–292.

[22] Jeevan, J., Chen, S. L., & Cahoon, S. (2019). The impact of dry port operations on container seaports competitiveness. *Maritime Policy and Management*, *46*(1), 4–23. Routledge. Retrieved from https://doi.org/10.1080/03088839.2018.1505054

[23] De Kervenoael, R., Schwob, A., & Chandra, C. (2020). E-retailers and the engagement of delivery workers in urban last-mile delivery for sustainable logistics value creation: Leveraging legitimate concerns under time-based marketing promise. *Journal of Retailing and Consumer Services*, *54*, 102016. Pergamon.

[24] Krstić, M., Tadić, S., Brnjac, N., & Zečević, S. (2019). Intermodal terminal handling equipment selection using a fuzzy multi-criteria decision-making model. *Promet - Traffic & Transportation*, *31*(1), 89–100.

[25] Krstić, M., Tadić, S., & Zečević, S. (2019). Elements for defining the intermodal terminals structure. *Proceedings of the 4th Logistics International Conference (LOGIC)* (pp. 206–215). Belgrade, Serbia: Faculty of Transport and Traffic Engineering, Univeristy of Belgrade.

[26] Kumar, A., & Anbanandam, R. (2019). Development of social sustainability index for freight transportation system. *Journal of Cleaner Production*, *210*, 77–92. Elsevier.

[27] Kumar, A., & Anbanandam, R. (2020). Analyzing interrelationships and prioritising the factors influencing sustainable intermodal freight transport system: A grey-DANP approach. *Journal of Cleaner Production*, *252*, 119769. Elsevier Ltd.

[28] Kurzgesagt. (2020). Who Is Responsible For Climate Change? – Who Needs To Fix It? Retrieved from https://kurzgesagt.org

[29] Lemke, C., & Bastini, K. (2020). Embracing multiple perspectives of sustainable development in a composite measure: The Multilevel Sustainable Development Index. *Journal of Cleaner Production*, *246*, 118884. Elsevier.

[30] Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., et al. (2018). Nexus approaches to global sustainable development. *Nature Sustainability*, *1*(9), 466–476. Springer US. Retrieved from http://dx.doi.org/10.1038/s41893-018-0135-8

[31] Ližbetin, J. (2019). Methodology for determining the location of intermodal transport terminals for the development of sustainable transport systems: A case study from slovakia. *Sustainability*, *11*(5), 1230.

[32] Lopez-Navarro, M. A. (2014). Environmental factors and intermodal freight transportation: Analysis of the decision bases in the case of Spanish motorways of the sea. *Sustainability*, *6*(3), 1544–1566.

[33] Martins, V., Anholon, R., Quelhas, O. L. G., & Filho, W. (2019). Sustainable Practices in Logistics Systems: An Overview of Companies in Brazil. *Sustainability*, *11*(15), 4140. Multidisciplinary Digital Publishing Institute. Retrieved September 18, 2021, from https://www.mdpi.com/2071-1050/11/15/4140

[34] Mensah, J. (2019). Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. (S. Ricart Casadevall, Ed.)*Cogent Social Sciences*, *5*(1), 1653531. Cogent. Retrieved November 18, 2021, from https://www.tandfonline.com/doi/full/10.1080/23311886.2019.1653531

[35] Montecinos, J., Ouhimmou, M., Chauhan, S., Paquet, M., & Gharbi, A. (2020). *Transport carriers' cooperation on the last-mile delivery in urban areas*. *Transportation*. Springer US. Retrieved from https://doi.org/10.1007/s11116-020-10134-8

[36] Pimentel, C., & Alvelos, F. (2018). Integrated urban freight logistics combining passenger and freight flows - Mathematical model proposal. *Transportation Research Procedia*, *30*, 80–89. Elsevier B.V. Retrieved from https://doi.org/10.1016/j.trpro.2018.09.010

[37] Qaiser, F. H., Ahmed, K., Sykora, M., Choudhary, A., & Simpson, M. (2017). Decision support systems for sustainable logistics: a review and bibliometric analysis. *Industrial Management & Data Systems*, *117*(7), 1376–1388.

[38] Quak, H., Nesterova, N., & Van Rooijen, T. (2016). Possibilities and Barriers for Using Electric-powered Vehicles in City Logistics Practice. *Transportation Research Procedia*, *12*(June 2015), 157–169. Elsevier B.V.

[39] Quereshi, A. G., Taniguchi, E., Thompson, R., & Teo, J. (2014). Application of exact route optimization for the evaluation of a city logistics truck ban scheme. *International Journal of Urban Sciences*, *18*(2), 117–132.

[40] Raicu, S., Costescu, D., & Burciu, S. (2020). Distribution system with flow consolidation at the boundary of urban congested areas. *Sustainability*, *12*(3).

[41] Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384. Elsevier.

[42] Van Rooijen, T., Guikink, D., & Quak, H. (2018). Long-term effects of innovative city logistics measures. In E. Taniguchi & R. G. Thompson (Eds.), *City Logistics 1: New Opportunities and Challenges* (1st ed., pp. 189–208). Hoboken, New Jersey: John Wiley & Sons.

[43] Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: connecting container seaports with the hinterland. *Journal of Transport Geography*, *17*(5), 338–345. Elsevier Ltd. Retrieved from http://dx.doi.org/10.1016/j.jtrangeo.2008.10.008

[44] Sachs, J., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakićenović, N., & Rockstrom, J. (2019). Six Transformations to achieve the Sustainable Development Goals. *Nature Sustainability*, *2*, 805–814.

[45] Silvestre, B. S., & Ţîrcă, D. M. (2019). Innovations for sustainable development: Moving toward a sustainable future. *Journal of Cleaner Production*, *208*, 325–332. Elsevier.

[46] Stojanović, Đ., Ivetić, J., & Veličković, M. (2021). Assessment of International Trade-Related Transport CO2 Emissions—A Logistics Responsibility Perspective. *Sustainability* .

[47] Strale, M. (2014). The Cargo Tram: Current Status and Perspectives, the Example of Brussels. In C. Macharis, S. Melo, J. Woxenius, & T. Van Lier (Eds.), *Sustainable Logistics* (6th ed., pp. 245–263). Emerald Group Publishing Limited.

[48] Suarez-Aleman, A., Trujillo, L., & Medda, F. (2014). Short sea shipping as intermodal competitor: A theoretical analysis of European transport policies. *Maritime Policy & Management*, *42*(4), 1–18.

[49] Sun, Y. (2020). Green and Reliable Freight Routing Problem in the Road-Rail Intermodal Transportation Network with Uncertain Parameters: A Fuzzy Goal Programming Approach. *Journal of Advanced Transportation*, 7570686.

[50] Tadić, S., Kilibarda, M., Kovač, M., & Zečević, S. (2021). The assessment of intermodal transport in countries of the Danube region. *International Journal for Traffic and Transport Engineering*, *11*(3), 375–391.

[51] Tadić, S., Kovač, M., & Čokorilo, O. (2021). The application of drones in city logistics concepts. *Promet - Traffic & Transportation*, *33*(3), 451–462.

[52] Tadić, S., Kovač, M., Krstić, M., Roso, V., & Brnjac, N. (2021). The Selection of Intermodal Transport System Scenarios in the Function of Southeastern Europe Regional Development. *Sustainability*, *13*(10), 5590.

[53] Tadić, S., Krstić, M., & Brnjac, N. (2019). Selection of efficient types of inland intermodal terminals. *Journal of Transport Geography*, *78*, 170–180.

[54] Tadić, S., Krstić, M., & Kovač, M. (2021). Implementation of the dry port concept in Central and Southeastern Europe logistics network. *World Review of Intermodal Transportation Research*, *10*(2), 131–151.

[55] Tadić, S., Krstić, M., Roso, V., & Brnjac, N. (2019). Planning an intermodal terminal for the sustainable transport network. *Sustainability*, *11*(15), 4102.

[56] Tadić, S., & Zečević, S. (2015). Cooperation and consolidation of flows in city logistics. *Tehnika*, *70*(4), 687–694.

[57] Tadić, S., & Zečević, S. (2016). *Modelling city logistics concepts (in Serbian)* (1st ed.). Belgrade, Serbia: University of Belgrade, Faculty of Transport and Traffic Engineering.

[58] Tadić, S., Zečević, S., & Krstić, M. (2018). Assessment of the political city logistics initiatives sustainability. *Transportation Research Procedia*, *30*, 285–294.

[59] Tawfik, C., & Limbourg, S. (2019). Scenario-based analysis for intermodal transport in the context of service network design models. *Transportation Research Interdisciplinary Perspectives*, *2*, 100036.

[60] Teye, C., Bell, M., & Bliemer, M. (2018). Locating urban and regional container terminals in a competitive environment: An entropy maximising approach. *Transportation Research Part B: Methodological*, *117*, 971–985.

[61] Tsamboulas, D., Vrenken, H., & Lekka, A.-M. (2007). Assessment of a transport policy potential for intermodal mode shift on a European scale. *Transportation Research Part A: Policy and Practice*, *41*(8), 715–733.

[62] United Nations. (2016). *The sustainable development agenda*. Retrieved from http://www.un.org/ sustainabledevelopment/development-agenda

[63] United Nations. (2020). *Sustainable development goals report*. Retrieved from https://www.un.org/sustainabledevelopment/progress-report

[64] Vahrenkamp, R. (2016). 25 years city logistic: Why failed the urban consolidation centres? *European Transport \ Trasporti Europei*, *60*(4), 1–6.

[65] Vural, C. A., Roso, V., Halldorsson, A., Stahle, G., & Yaruta, M. (2020). Can digitalization mitigate barriers to intermodal transport? An exploratory study. *Research in Transportation Business and Management*, *37*, 100525.

[66] Waas, T., Hugé, J., Verbruggen, A., & Wright, T. (2011). Sustainable Development: A Bird's Eye View. *Sustainability*, *3*(10), 1637–1661. Molecular Diversity Preservation International. Retrieved November 18, 2021, from http://www.mdpi.com/2071-1050/3/10/1637

[67] Wang, Z., Tsai, Z., Fu, J., Zhao, L., & Yang, L. (2017). Internalization of negative external cost of green logistics and incentive mechanism. *Advances in Mechanical Engineering*, *9*(8), 1–12.

[68] WCED - The world commission on environment and development. (1987). *Our common future*. Oxford, England: Oxford University Press.

[69] Zečević, S., & Tadić, S. (2005). Cooperation models of city logistics. *Transport & Logistics*, (9), 123–141.

[70] Zečević, S., & Tadić, S. (2006). *City logistics (in Serbian)*. Belgrade, Serbia: University of Belgrade, Faculty of Transport and Traffic Engineering.

[71] Zečević, S., Tadić, S., & Krstić, M. (2017). Intermodal transport terminal location selection using a novel hybrid MCDM model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, *25*(6), 853–876.

[72] Zeng, Y., Maxwell, S., Runting, R. K., Venter, O., Watson, J. E. M., & Carrasco, L. R. (2020). Environmental destruction not avoided with the Sustainable Development Goals. *Nature Sustainability*, *3*(10), 795–798. Springer US. Retrieved from http://dx.doi.org/10.1038/s41893-020-0555-0

[73] Zhang, D., Zhan, Q., Chen, Y., & Li, S. (2018). Joint optimization of logistics infrastructure investments and subsidies in a regional logistics network with CO2 emission reduction targets. *Transportation Research Part D: Transport and Environment*, *60*, 174–190. Pergamon.

[74] Zych, M. (2014). Identification of Potential Implementation of the Cargo Tram in Warsaw: A First Overview. *Procedia - Social and Behavioral Sciences*, *151*, 360–369. Elsevier B.V. Retrieved from http://dx.doi.org/10.1016/j.sbspro.2014.10.034

ENERGY EFFICIENCY - CONTRIBUTION BY OPTIMIZING THE LAYOUT OF THE SHIP'S SWITCHBOARD

Maja Krčum, Ph.D.
Nediljko Kaštelan, M.Sc.
Marko Zubčić, M.Sc..
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
mrkcum@pfst.hr

Tomislav Peša, M.Sc.
Ministry of Defense of Republic of Croatia
Trg kralja Petra Krešimira IV 1, 10000 Zagreb, Croatia
tomopesa@yahoo.com

ABSTRACT

Efforts to reduce global greenhouse gas (GHG) emissions have significant implications for the maritime sector. Reducing global emissions requires that newly built ships become more energy efficient or that all subcomponents of ship systems improve their individual or overall energy efficiency. As a result, ship electrification, which is considered to be the most viable proposed method to achieve the emissions reduction goal, will place a large burden on the ship electrical system. The projected load will lead to improvements in all aspects of the electrical system (power generation, distribution, and consumption). This paper addresses the optimization of the distribution system, or specifically the important subcomponent, the main switchboard, through previously developed improvements, starting from the definition of the switchboard parameters, through the modification of the busbar configuration area and the implementation of novel sensor technology, to ultimately optimize the design compared to an existing solution.

Keywords: Novel technology implementation, Switchboard optimization, Energy efficiency

1. INTRODUCTION

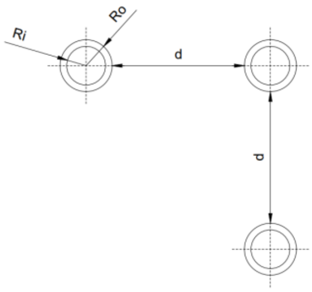
Given the global trend in electricity consumption, in which the International Energy Agency (IEA) estimates that the discrepancy caused by the COVID -19 pandemic will be overcome in 2022 and the demand for electricity will continue to increase [1]. The increased demand for electricity can also be transferred to the maritime industry, which is mainly visible through the process of electrification of ships [2]–[4] as a measure to achieve the draft greenhouse gas strategy of the International Maritime Organization (IMO) from 2018 to reduce emissions by at least 50% compared to 2008[5]. The projected increase in consumption makes it necessary to improve energy efficiency in power generation and distribution, especially in a closed system such as a ship. This paper focuses on improving the energy efficiency of the main distribution component, the medium voltage switchboard (MV), or more precisely, the individual switchgears. Switchgear design optimization consists of improvements in reducing weight and dimensions, reducing total EM losses and electrodynamic forces, reducing operating temperature to increase equipment lifetime, and introducing novel technologies. The above objectives and the optimization of the design are the subject of the Competence Centre for Advanced Mobility (CEKOM - Development of Compact Marine Medium Voltage Switch Block 21 15/17.5-"MMVSB 17.5"). The final design, taking advantage of the advances resulting from previous research within the project, will be validated by comparing the characteristics between the proposed design and an existing solution used by the project partners.

2. BUSBAR COMPARTMENT OPTIMIZATION

Considering the results obtained in [6], the analysis of the existing power consumption of large cruise ships obtained from[7] gave the electrical characteristics (rated current) of the switchgear:

- Rated voltage: 17.5 kV/15 kV (defined by the project)
- Rated current: 1600 A.

The rated current defined the busbar profiles and dimensions to be analyzed [8]. The 2-D simulation results show that the circular busbar profile configuration as shown in Figure 1 has the lowest electromagnetic (EM) losses and the lowest developed electrodynamic (ED) forces compared to the other analyzed configurations. The simulation results and busbar parameters for the mentioned configuration are shown in Table 1.



Source: Authors

Figure 1: Optimal analyzed busbar configuration

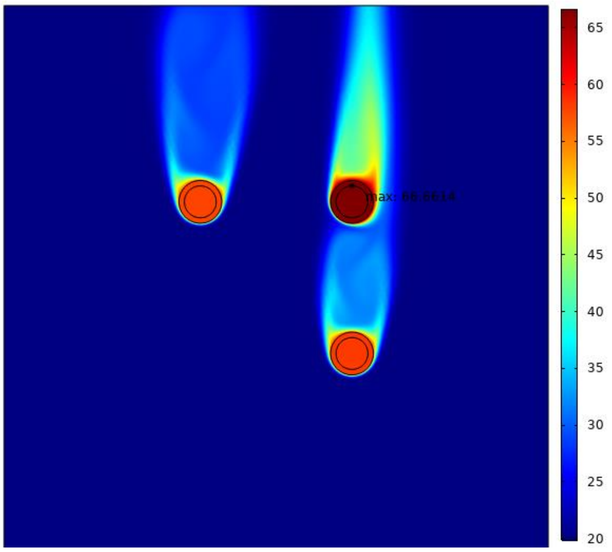
Table 1: Busbar parameters and simulation results

PARAMETERS	Outer radius Ro [mm]	31.5	
	Inner radius Ri [mm]	23.5	
	Phase-to-phase distance d [mm]	160	
	Rated current I [A]	1600	
	Frequency f [Hz]	60	
EM LOSSES	Value [W/m]	50.427	
ED FORCES	Value [N/m]	x-direction	y-direction
	Phase A	4392.88	1654.19
	Phase B	3701.59	1326.055
	Phase C	1700.34	1982.40

Source: Authors

Another advantage of optimizing the busbar space is the contribution to reducing the overall dimensions and weight of the switchgear by changing the busbar profile and spatial distribution.

Considering the results from [9], the busbar configuration was further optimized in terms of temperature rise, using the 2-D simulation, performed in COMSOL®, with the EM losses as the heat source and incorporating fluid mechanics into the simulation. Again, several configurations were analyzed, and the circular profile as shown in Figure 1 was found to be optimal, with the modification of a modelled offset of two phases to reduce the effect of mutual heating. The simulation showed that the maximum temperature of the configuration without offset is 66.66°C (Figure 2) and with the modelled offset is 57.27°C (Figure 3).



Source: Authors

Figure 2: Temperature rise result for configuration without modelled offset

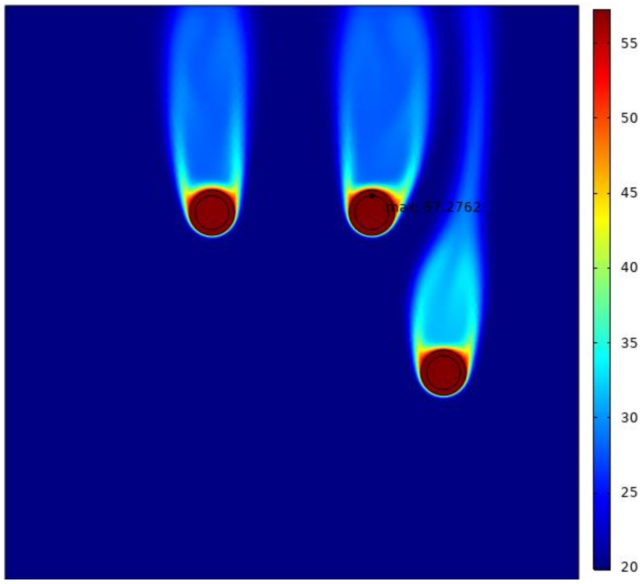


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Figure 3: Temperature rise result for configuration with modelled offset

3. IMPLEMENTATION OF NOVEL TECHNOLOGIES

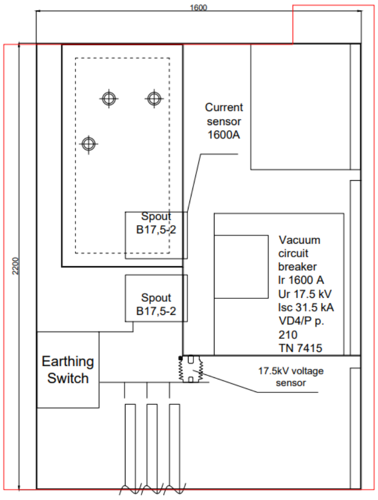
The obsolete conventional instrument transformers with their resulting drawbacks [10] have opted for the development of improved solutions to achieve the goal of maximum energy efficiency. The proposed sensors to be used are the Rogowski coil for current measurement and the resistive voltage divider for voltage measurement. The Rogowski coil operating principle is based on Faraday's Law of induction. The current passing through the conductor creates an alternating magnetic field that consequently induces a voltage on the terminals of the coil. The output voltage is proportional the rate of changing current that is measured, in order to accurately reproduce the current waveform with the voltage waveform an electronic integrator needs to be implemented. The voltage sensor is a passive device composed of resistive/capacitive components connected in a voltage divider, where the output voltage is at an adjusted voltage ratio in regard to the high input voltage. The advantages of the implementation of the aforementioned sensors in comparison to the conventional instrument transformers are [11]:

- Non-saturable as no iron core is used
- High degree of accuracy
- Personnel safety (low secondary voltages)
- Small size and weight
- Reduced losses
- Extensive dynamic range
- Environmental friendliness since less raw material is used
- Switchboard digitalization with the implementation of the IEC 61850 standard

The contribution of the sensor implementation was analyzed in both [6] and [12], resulting in a reduction in overall switchboard dimension, weight, and losses. The main improvement in energy efficiency lies in the negligible power consumption of the sensors compared to conventional ITs, as shown in [13]. With the implementation of sensors to measure temperature, humidity [14]–[16], and partial discharge [17], the design can be further extended to the concept of digital switchgear to improve overall efficiency, reliability, and safety [18] while enabling monitoring of the condition of the equipment [19] to optimize future preventive maintenance routines and further increase the life expectancy of the switchgear.

4. PROPOSED AND EXISTING SOLUTION COMPARISON

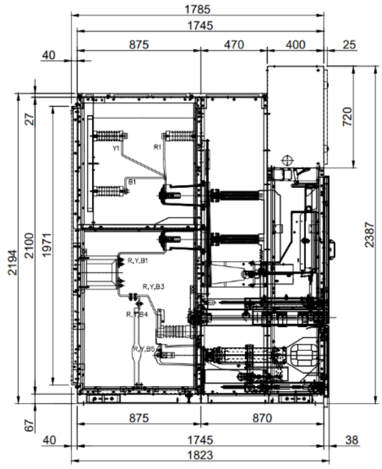
Using the previous research results, the proposed final design (which has been further modified since the previous research) is shown in Figure 4 with the existing solution outline highlighted in red, while the existing solution is shown in Figure 5. The comparison is made in the input feeder model to include both the voltage and current measurements. The optimization of each subcomponent allowed to reduce the dimensions of the switchgear (7.834% height, 30% width and 10.364% depth), the weight of the measuring devices (96.673%) and the weight of the busbars (59.426%), as well as the total losses (contribution of the busbar and the sensors). The implementation of voltage sensors allowed the elimination of the voltage measurement trolley, so that more space can be used either to implement other technologies or to further reduce the size of the design. The proposed design, with all its advantages, still meets all the technical requirements to pass the mandatory type tests and obtain the relevant certificates (which will also confirm all the research results).



Source: Authors

Figure 4: Proposed switchgear design

The proposed solution (Figure 4.) is compared to the existing switchgear solution (Figure 5.) for 17.5 kV already manufactured and in use with the project partners.



Source: Authors

Figure 5: Existing switchgear design

The improvements expressed in percentages on an example switchboard consisting of 4 incoming (with a total of 12 voltage sensors/ITs and 12 current sensors/ITs) and 14 outgoing feeders (with a total of 42 current sensors/ITs) are shown in Table 2 to summarize the improvements.

Table 2: Improvement results expressed in percentage

	Improvements
Measuring equipment weight	96.42%
Measuring equipment volume	90.57%
Measuring equipment energy consumption	100%
Overall EM losses	59.53%
Main busbar weight	59.43%
Footprint	39.83%
Length	30%
Volume	42.93%

Source: Authors

The calculated improvements, combined with the ability to digitize switchgear, will be able to meet the demands imposed by worldwide efforts to improve energy efficiency and reduce global emissions.

5. CONCLUSION

The proposed design solution, optimized compared to the existing solution, is based on the results of the research and performed simulations. The proposed design takes full advantage of the improvements made possible by the optimization of subcomponents and the implementation of novel technologies, while meeting the required technical parameters for type testing. The optimization efforts (reduction of weight, dimensions and overall energy consumption) will be highlighted within the Energy Efficiency Design Index (EEDI) of ships conceptualized by the IMO to reduce global emissions.

ACKNOWLEDGEMENTS

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REFERENCES

[1] "World Energy Outlook – Topics," *IEA*. https://www.iea.org/topics/world-energy-outlook (accessed Mar. 25, 2022).

[2] V. Bortuzzo, S. Bertagna, M. Dodero, J. Ferrari, A. Marinò, and V. Bucci, "Electrification of Vessels for Garbage Collection and Treatment in Venice Lagoon," in *2021 Sixteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, May 2021, pp. 1–6. doi: 10.1109/EVER52347.2021.9456603.

[3] J. Campillo, J. A. Domínguez-Jimenez, and J. Cabrera, "Sustainable Boat Transportation Throughout Electrification of Propulsion Systems: Challenges and Opportunities," in *2019 2nd Latin American Conference on Intelligent Transportation Systems (ITS LATAM)*, Mar. 2019, pp. 1–6. doi: 10.1109/ITSLATAM.2019.8721330.

[4] S. Anwar, M. Y. I. Zia, M. Rashid, G. Z. de Rubens, and P. Enevoldsen, "Towards Ferry Electrification in the Maritime Sector," *Energies*, vol. 13, no. 24, Art. no. 24, Jan. 2020, doi: 10.3390/en13246506.

[5] "UN body adopts climate change strategy for shipping." https://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx (accessed Mar. 24, 2022).

[6] M. Krčum, M. Zubčić, N. Kaštelan, and A. Gudelj, "Reducing the Dimensions of the Ship's Main Switchboard—A Contribution to Energy Efficiency," *Energies*, vol. 14, no. 22, p. 7567, Nov. 2021, doi: 10.3390/en14227567.

[7] "DNV GL Vessel Register." https://vesselregister.dnvgl.com/vesselregister/vesselregister.html (accessed Feb. 12, 2021).

[8] H. Gremmel, ABB-Calor-Emag-Schaltanlagen AG, and ABB-Calor-Emag-Mittelspannung GmbH, Eds., *Switchgear manual*, 10., rev. Ed. Berlin: Cornelsen, 2001.

[9] N. Kaštelan, M. Zubčić, M. Krčum, and B. Bacalja, "Temperature Rise Prediction in Three-Phase BusbarSystems - A Step in Preparation for Medium-voltageSwitchgear Type Testing," *Book of Abstracts - 1st Kotor International Maritime Conference*, p. 5, 2021.

[10] V. Proca and N. Paduraru, "Methods for non-conventional measuring sensor integration in the medium voltage electrical equipment," in *2005 IEEE Russia Power Tech*, St. Petersburg, Russia, Jun. 2005, pp. 1–6. doi: 10.1109/PTC.2005.4524774.

[11] T. Neighbours and D. Moser, "Switchgear Moves Into The Digital World," p. 8.

[12] N. Kaštelan, M. Zubčić, M. Krčum, and M. Petković, "CONTRIBUTION TO THE REDUCTION OF THE SHIP'S SWITCHBOARD BY APPLYING SENSOR TECHNOLOGY," p. 15.

[13] M. Stefanka, V. Prokop, and G. Salge, "Application of IEC 61850-9-2 in MV switchgear with sensors use," in *22nd International Conference and Exhibition on Electricity Distribution (CIRED 2013)*, Stockholm, Sweden, 2013, pp. 0103–0103. doi: 10.1049/cp.2013.0563.

[14] B. Woelke, M. Monedero, and D. Jebamony, "Application of novel sensor technology in an environmental friendly SF6 free medium voltage gas insulated switchgear pilot setup," in *VDE High Voltage Technology 2018; ETG-Symposium*, Nov. 2018, pp. 1–6.

[15] S. Wildermuth, P. Szasz, J. Gebhardt, H. Kaul, and K. Koenig, "Infrared temperature sensing in electrical equipment by low-cost IR cameras," in *VDE High Voltage Technology 2018; ETG-Symposium*, Nov. 2018, pp. 1–5.

[16] D. B. Durocher and D. Loucks, "Infrared windows applied in switchgear assemblies: Taking another look," in *2015 61st IEEE Pulp and Paper Industry Conference (PPIC)*, Jun. 2015, pp. 1–6. doi: 10.1109/PPIC.2015.7165710.

[17] L. Kumpulainen, G. A. Hussain, M. Lehtonen, and J. A. Kay, "Preemptive Arc Fault Detection Techniques in Switchgear and Controlgear," *IEEE Transactions on Industry Applications*, vol. 49, no. 4, pp. 1911–1919, Jul. 2013, doi: 10.1109/TIA.2013.2258314.

[18] H. Karandikar, T. Neighbours, and R. Pate, "The Next Phase in the Evolution of Safety by Design - Digital Switchgear," in *2019 IEEE Petroleum and Chemical Industry Committee Conference (PCIC)*, Vancouver, BC, Canada, Sep. 2019, pp. 233–240. doi: 10.1109/PCIC30934.2019.9074536.

[19] M. Budyn, H. Karandikar, and M. Urmson, "Switchgear Condition Monitoring," Oct. 2010.

THE ECOLOGY-BASED OPTIMIZATION OF TRAFFIC SIGNAL TIMING ON A DIVERGING DIAMOND INTERCHANGE

Katarina Kukić, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering
ojvode Stepe 305, Belgrade, Serbia
k.mijailovic@sf.bg.ac.rs

Aleksandar Jovanović, Ph.D.
University of Kragujevac, Faculty of Engineering
Sestre Janjić 6, Kragujevac, Serbia
a.jovanovic@kg.ac.rs

ABSTRACT

A Diverging Diamond Interchange (DDI) is a relatively new concept of the intersection with an alternative geometrical structure. This type of interchange became very popular, particularly in the United States (U.S.), since this concept reduces vehicle control delays and improves traffic safety since left-turn movements do not have any conflicts. In this paper, we examine the environmental impact of traffic on the DDI and present the optimization of an ecology-based performance index consisting of control delays and a number of stops. The mathematical model, based on the Genetic Algorithms (GA), for controlling the DDI in fixed-time control mode is developed. The number of stops on the DDI approaches is weighted with a different penalty factor (K), which depends on the percentage of heavy vehicles and cruise speed. The geometry of a hypothetical DDI has been coded into the Vissim model and used as the approaching tool for the evaluation of GA and Webster signal plans. Webster`s method, for calculation of the robust signal plans at the signalized intersections, is widely used in the field. We suppose a set of traffic demand patterns and carry out all necessary calculations. The results show the applicability of the proposed approach.

Keywords: Diverging diamond interchange, traffic signal timing, vehicles control delays, number of stops, microsimulation

1. INTRODUCTION

Traffic congestions have become a daily problem in most of the main cities in the world. The consequences of this are reflected, among others, in the increased emissions of harmful gases and economic losses. Transportation participates with 29 % in the total greenhouse gas emissions in USA cities, while global estimates are about 11 % (EPA, 2021). In particular, it was found that heavy-duty vehicles emit 71% of harmful gases, with only an 11% share in the total traffic flow (Kodjak, 2015). Also, economic losses are significant. For example, in the U.S., drivers lost an average of 26 hours due to congestion in 2020, down from 99 hours in the year before, saving the country $51 billion or $980 per driver (Pishue, 2020).

Many authors have dealt with the problems of ecology optimization of traffic signals. Robertson (1969) makes one of the first efforts to optimize fuel consumption by taking into account the number of stops at signalized intersections. Even today, Robertson`s performance index is widely in use. More recently, Stathopoulos and Noland (2003) used a microsimulation Vissim model to evaluate optimized signal plans. They showed that optimal offset value had significantly improved fuel consumption and emissions. Liao (2013) proposed an analytical fuel consumption and emissions model that account for the idling and accelerating stage of vehicles caused by stopping at a signalized intersection under saturated conditions. Another evaluation of signal timing plans, which minimizes social costs (delays, air pollution emissions and fuel consumption), can be found in the paper Peñabaena-Niebles et al. (2020). Alshayeb et al. (2021) proposed improved Robertson`s model with different values of the stop penalty factor (K) for every movement at intersections.

When critical demands are reached, optimization of traffic lights usually brings no improvements to traffic conditions. After that, there are different ways to achieve reduction of traffic congestion. Some measures in downtowns could rely on strategies such as congestion pricing, ride match and park and ride systems. In suburban areas, alternative intersection designs (AID) arise as one of few promising solutions. Common for all AID is that they reduce conflict points and delays by unconventional control of left turns (Hughes et al., 2010). On the other hand, usually more space is needed for their implementation. The best-known AIDs are Roundabout, Displaces Left-Turn Intersection, Median U-Turn Intersection, Restricted Crossing U-Turn Intersection and Quadrant Roadway. In this paper, we study one of them, the Diverging Diamond Interchange (DDI).

A Diverging Diamond Interchange (DDI) eliminates conflicts for left turns movements toward a highway, which improves safety and traffic efficiency. Several studies were relevant for the DDI in the past. Edara, et al. (2005) reported that the DDI had obtained lower delays and queue lengths for vehicles and pedestrians than conventional diamond interchange. Yang et al. (2014) developed a model for optimizing cycle length and splits under separate intersection control modes for DDIs. Claros et al. (2017) developed crash prediction models for a DDI in Missouri. They concluded that the DDI had been safer compared to a conventional signalized diamond intersection. Kukić and Jovanović (2018) developed a fuzzy logic approach to control an oversaturated DDI that brought significant benefits over the traditional fixed-time approach. Finally, Jovanović et al. (2021) investigated the performance of fuzzy logic for controlling a complex system consisting of the DDI and ramp metering in the case of oversaturated traffic conditions. The results showed that the fuzzy logic control had outperformed all other conventional control approaches.

In this paper, we address this problem of finding a fixed-time signal plan on the DDI suited for minimization of environmental impact from traffic. Genetic algorithms, a well-known metaheuristic approach, is used as a tool for solving the optimization problem. As far as we are aware, this is a novel example of optimizing the signal plans at AID.

This paper is organized as follows. A proposed methodology is given in Section 2. The numerical example is presented in Section 3. Conclusions and recommendations for future research are provided in Section 4.

2. METHODOLOGY

A problem of fixed-time control at Diverging Diamond Interchange in the case of undersaturated traffic conditions is considered.

We made an effort to get the answers to the following questions: (a) what is the best cycle length(s)? (b) what are the best green splits? The problem of designing the pre-timed signal timing plan for the DDI that we analyze in this paper could be formulated in the following way: Determine the cycle length and the green splits in such a way to minimize the Eco Performance Index on the DDI during one hour.

Generally, our methodology consists of two phases, which are present in Figure 1.

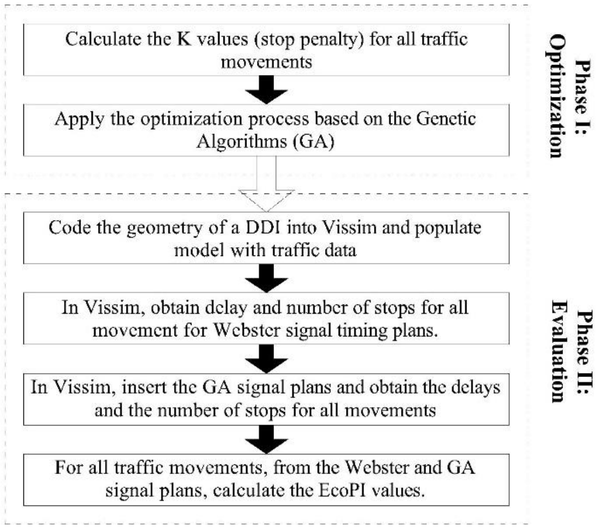


Figure 1: Proposed phases of the methodology

Phase I: Let us mark by M the set of all movements on the DDI, as $M = \{1,2,...,m\}$, where m is a total number of movements on the DDI. One of the most important parts of our methodology is a stop penalty calculation for m-th movements (K_m), which represent an ecology equivalent of delays due to stops. Let us mark by V the set of all vehicle categories on the DDI, as $V = \{1,2,...,v\}$, where v is a total number of vehicle categories on the DDI. We obtained this factor taking into consideration some of the important elements which K_m depends on, using the already mentioned study Alshayeb et al. (2021):

$$K_m = \sum_{v=1}^{|V|} p_{vm} \cdot K_{vm} \tag{1}$$

where:

p_{vm} – percentage of v-th vehicle category at m-th movement,

K_{vm} – stop penalty for v-th vehicle category at m-th movement.

$$K_{vm} = K_{vm\,def} \cdot \frac{K_{vmg\,act}}{K_{vmg\,0\%}} \cdot \frac{K_{vms\,act}}{K_{vms\,45}} \quad \forall\, v\ in\ V \tag{2}$$

where:

$K_{vm\,def}$ – default K_{vm} value,

$K_{vmg\,act}$ – actual grade value for K_{vm},

$K_{vms\,act}$ – actual speed value for K_{vm},

K_{vmg} *0%* – K_{vm} value for 0% of grade,

K_{vms} *45* – K_{vm} value for the speed of 45 mph (≈72km/h).

The default value of K_{vm} depends on the percentage of heavy vehicles in the traffic demand.

A mathematical formulation of the problem is given in the next subchapter 2.1, while some details about the GA optimization process are provided within subchapter 2.2.

Phase II: Microsimulation software Vissim (PTV Vissim, 2011) is used as a tool for evaluating signal plans obtained from Webster and GA based optimization. The evaluation parameters gained from the simulation are average delays and the number of stops for all DDI movements.

2.1. A mathematical formulation of the problem

The average delay d_m, for the *m*-th movement, can be calculated as (HCM, 2010):

$$d_m = d_{1m} + d_{2m} \quad \forall\, m \; in \; M \tag{3}$$

where:

$$d_{1m} = \frac{0.5 \cdot C \cdot \left(1 - \frac{g_m}{C}\right)^2}{1 - \left[min(1, X_m) \cdot \frac{g_m}{C}\right]} \tag{4}$$

$$d_{2m} = 900T\left[(X_m - 1) + \sqrt{(X_m - 1)^2 + \frac{4X_m}{c_m T}}\right] \tag{5}$$

where:

d_{1m} – uniform delay in the *m*-th movement [s/veh];

d_{2m} – incremental delay in the *m*-th movement [s/veh].

C – cycle length [s],

g_m – green time of the *m*-th movement [s],

X_m – volume-to-capacity ratio in the *m*-th movement,

c_m – capacity of the *m*-th movement [veh/h],

T – analysis period duration [1 h].

The capacity c_m of the *m*-th movement equals:

$$c_m = s_m \cdot \frac{g_m}{C} \tag{6}$$

where s_m is the saturation flow in the *m*-th movement [veh/h].

The average number of stops at the *m*-th movement (S_m) is calculated as (HCM, 2010):

$$S_m = 0.9 \cdot \frac{1 - \frac{g_m}{C}}{1 - \frac{q_m}{s_m}} \quad \forall\, m \; in \; M \tag{7}$$

where q_m is the vehicle demands in the *m*-th movement [veh/h].

The Ecology Performance Index $EcoPI_m$ for the *m*-th movement, can be defined as:

$$EcoPI_m = d_m + K_m \cdot S_m, \quad \forall\, m \; in \; M \tag{8}$$

The *EcoPI* for the entire DDI can then be calculated as:

$$EcoPI = \sum_{m=1}^{|M|} EcoPI_m \tag{9}$$

Let us mark by *F* the set of all phases that control the DDI, as $F = \{1,2,...,f\}$, where *f* is a total number of phases on the DDI. Then, the optimization problem is set as:

$$\min \text{EcoPI} \tag{10}$$

subject to:

$$C_{min} \leq C \leq C_{max} \tag{11}$$

$$g_{fmin} \leq g_f \leq g_{fmax} \quad \forall\, f \; in \; F \tag{12}$$

$$\sum_{f=1}^{|F|} g_f = C - L \tag{13}$$

where:

C_{min} – minimal value of variable C,

C_{max} – maximal value of variable C,

g_{fmin} – minimal value of variable g_f,

g_{fmax} – maximal value of variable g_f,

L – all-red time on the DDI.

The objective function (10), to be minimized, represents the *EcoPI* of all DDI movements. The constraint (11) defines the interval of the feasible cycle length values. The constraint (12) defines the interval of feasible green time values. The relationship between the cycle length, the green time lengths and the all-red time is described by the constraint (13).

2.2. GA optimization

GA is a widely-known metaheuristic approach that imitates the natural process of evolution. There are a lot of papers that use GA for the optimization of traffic signal signals, such as: (Park et al., 2001; Chang and Sun 2004; Liu and Chang, 2011).

The GA parameters that are used in calculations are: Crossover probability – 30%; Mutation probability – 1%; Convergence threshold – 0.01%; Maximum number of generations – 20; Population size – 20; Elitist method is included. GA is performed in the MATLAB Optimization ToolBox.

3. NUMERICAL EXAMPLE

The proposed methodology is tested on hypothetical DDI as shown on Figure 2. We mark traffic demands with capital letters A, B, C, D, E and F.

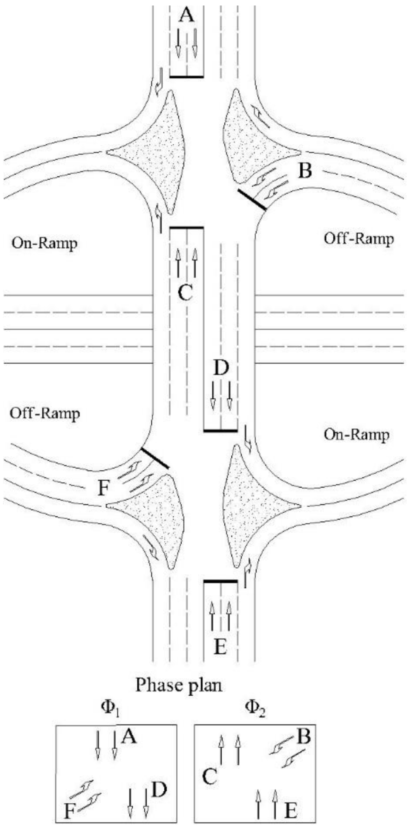


Figure 2: The layout of numerical example

The all-red time (*L*) is set to 14 s. Saturation flows (*s*) and traffic demands (*q*) are provided in Table 1. Also, the percentage of heavy vehicles (HV) and the speed of traffic demands are given in table 1.

Table 1: The relevant data for traffic demands

Traf. demand	A	B	E	F
q (veh/h)	830	480	790	520
s (veh/h)	2400	2200	2400	2200
% HV	10	3	4	9
Speed (km/h)	60	60	60	60

In this example, we simplify signal plans thus the splits (green times) depend only on traffic demands from Table 1. Consequently, traffic demands C and D follow green time defined for E and A demands, respectively. Further, we define the percentage of the left-turning vehicles on the bridge that comes from C and D demands as 20% and 25%, respectively. The right-turning vehicles are not controlled by traffic lights.

Let us assume the following geometrical characteristics in Figure 2:

- The length of the bridge is 105 m;
- The width of all traffic lines is 3 m;
- The lengths of all ramps are 200 m.

Simulation time was set to 3600 seconds, with 100 seconds of warm-up time. The number of seeds was set to 42.

3.1. Results

Firstly, we obtained *K* values for traffic demands A, B, E and F to 207, 138, 147 and 197, respectively. We compare the control delays, the number of stops and *EcoPI* values, obtained from Webster and GA signal plans. Simulation results during one hour, with a 450 s of increment, as well as cycles and splits, are shown in Table 2.

Table 2: Results

Webster signal plan: C = 82 s, g_1 = 35 s, g_2 = 33 s				
Second	# of stops HGV	# of stops all	Delay (s/veh)	PI
550	18	318	10399	65827
1000	34	655	22036	135338
1450	53	952	31777	195514
1900	74	1265	42477	260766
2350	88	1553	52269	320577
2800	106	1860	62398	383699
3250	126	2159	72649	446370
3700	147	2475	83273	510772
GA signal plan: C = 99 s, g_1 = 46 s, g_2 = 39 s				
Second	# of stops HGV	# of stops all	Delay (s/veh)	PI
550	11	290	10681	60562
1000	30	632	24139	133013
1450	44	912	34981	190708
1900	62	1235	47934	259521
2350	79	1513	58611	317655
2800	91	1810	70204	380169
3250	103	2105	81396	442050
3700	125	2427	93951	509783

Graphical representations of number of stops are provided in Figure 3. Note that abbreviation “W” within figures refers to Webster.

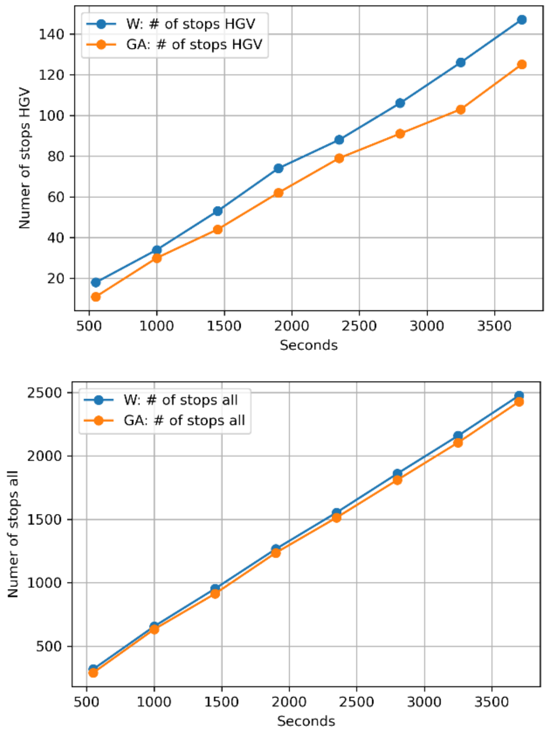


Figure 3: Number of stops

Graphical representations delay and *EcoPI* are provided in Figure 4.

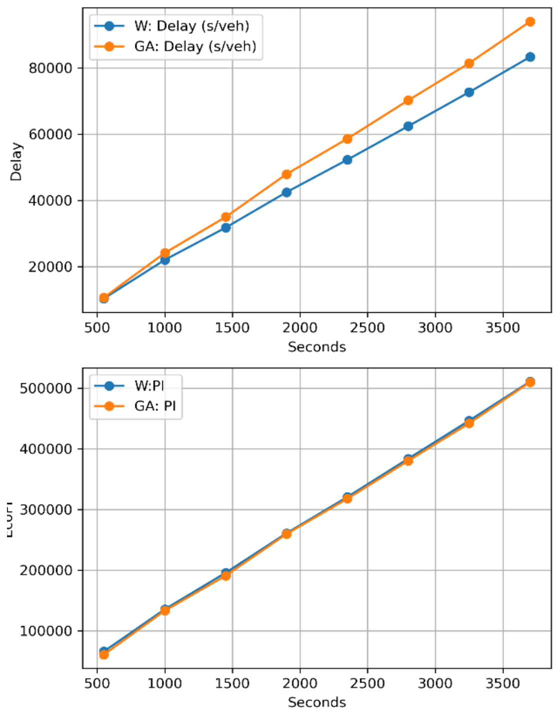


Figure 4: Delay and *EcoPI*

The corresponding heatmap, based on data from Table 2, is illustrated in Figure 5.

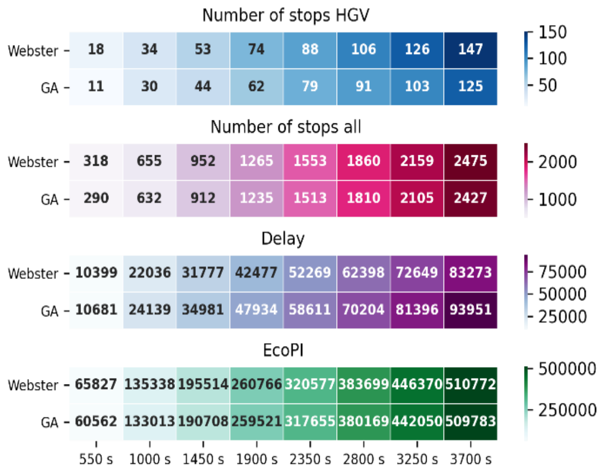


Figure 5: Heatmap for evaluation parameters

The analysis of the above results is given within the following subchapter.

Before that, it should be mentioned that Webster (Webster, 1958) has been the well-known standard approach in this kind of fixed-time signal control for the last half-century. It provides results quite well so can be used as a comparison method.

3.2. Discussion of results

The number of HV stops plays an important role in the ecology optimization of traffic signals. In the case of the GA signal plan, HV stops are lower by 17.6% than the Webster signal solution. On the entire DDI, the total number of stops has been reduced by 2% compared to the Webster signal plan.

It was expected that a higher value of the cycle may cause a higher value of delay. Thus, compared to the Webster approach, the delay in the case of GA signal plans is worse for 12.82%. Finally, the most important parameter in our study is EcoPI, where we find the improvement using the GA signal plan of 0.2%, from that obtained by Webster.

Those results show that GA signal plans, obtained from offline optimization, can be taken into consideration in this ecology-kind of the DDI signal traffic control.

4. CONCLUSION

In this paper, using microsimulation software Vissim on the DDI, we evaluate the signal plans optimized by GA. GA optimization was done in MATLAB, out of Vissim. The major objectives were to improve the number of stops of heavy vehicles and the *EcoPI* - an ecology parameter.

The results presented in this paper have shown that it is possible to improve objective parameters using GA. Compared to the classical Webster approach, we make the number of stops of heavy vehicles lower by 12.82%, while *EcoPI* is improved by 0.2%.

Based on these findings, the GA signal plans could be considered as a viable approach to execute ecology traffic control on the DDI. However, future research should take into consideration different demand patterns (levels of saturation) under different phase plans to further justify this attitude. Also, for more accuracy, the Vissim model could be calibrated with real-like data about travel time and traffic demands on the DDI.

REFERENCES

[1] Alshayeb, S., Stevanovic, A., & Effinger, J. R. (2021). Investigating impacts of various operational conditions on fuel consumption and stop penalty at signalized intersections. Int. J. Transp. Sci. Technol.

[2] Chang, T. H., & Sun, G. Y. (2004). Modeling and optimization of an oversaturated signalized network. Transp. Res. B: Methodol., 38(8), 687-707.

[3] Claros, B., Edara, P., & Sun, C. (2017). When driving on the left side is safe: Safety of the diverging diamond interchange ramp terminals. Accid. Anal. Prev., 100, 133-142.

[4] Edara, P. K., Bared, J. G., & Jagannathan, R. (2005, June). Diverging diamond interchange and double crossover intersection–vehicle and pedestrian performance. In 3rd International Symposium on Highway Geometric Design, Chicago, IL.

[5] EPA, Unated States Environmental Protection Agency. (2021). Sources of Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[6] Hughes, W., Jagannathan, R., Sengupta, D., & Hummer, J. (2010). Alternative intersections/interchanges: informational report (AIIR) (No. FHWA-HRT-09-060). United States. Federal Highway Administration. Office of Research, Development, and Technology.

[7] Jovanović, A., Kukić, K., & Stevanović, A. (2021). A fuzzy logic simulation model for controlling an oversaturated diverge diamond interchange and ramp metering system. Math. Comput. Simul., 182, 165-181.

[8] Kodjak, D. (2015). Policies to reduce fuel consumption, air pollution, and carbon emissions from vehicles in G20 nations. The International Council on Clean Transportation, (May).

[9] Kukić, K., & Jovanović, A. (2019). Fuzzy logic approach on traffic control of a Diverging Diamond Interchange in real time. In ITM Web of Conferences (Vol. 29, p. 01005). EDP Sciences.

[10] Liao, T. Y. (2013). A fuel-based signal optimization model. Transp. Res. D: Transp. Environ., 23, 1-8.

[11] Liu, Y., & Chang, G. L. (2011). An arterial signal optimization model for intersections experiencing queue spillback and lane blockage. Transp. Res. C: Emerg. Techn., 19(1), 130-144.

[12] Manual, H. C. (2010). HCM2010. Transportation Research Board, National Research Council, Washington, DC, 1207.

[13] Park, B. B., Rouphail, N. M., Hochanadel, J. P., & Sacks, J. (2001). Evaluating reliability of TRANSYT-7F optimization schemes. J. Transp. Eng., 127(4), 319-326.

[14] Peñabaena-Niebles, R., Cantillo, V., & Moura, J. L. (2020). The positive impacts of designing transition between traffic signal plans considering social cost. Transp. Policy, 87, 67-76.

[15] Pishue, B. (2020). 2020 global traffic scorecard.

[16] PTV Vissim 2011 User Manual. (2011). PTV Germany, Karlsruhe.

[17] Robertson, D. I. (1969). Transyt-a traffic network study tool. Rept No Rrl - LR -253, 43 PP, 10, London, TRRL.

[18] Stathopoulos, F. G., & Noland, R. B. (2003). Induced travel and emissions from traffic flow improvement projects. Transp. Res. Rec., 1842(1), 57-63.

[19] Yang, X., Chang, G. L., & Rahwanji, S. (2014). Development of a signal optimization model for diverging diamond interchange. J. Transp. Eng., 140(5), 04014010.

[20] Webster, F. V. (1958). Traffic signal settings (No. 39).

SURFACE WAVES AND SAFETY OF NAVIGATION ON THE ADRIATIC SEA

Nenad Leder, D.Sc.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
nenad.leder@pfst.hr

ABSTRACT

The Adriatic Sea is a semi-enclosed sea forming a distinct sub-region within the Mediterranean Sea region. It is a deeply indented gulf (*cca*. 800 km long and 200 km wide). From an oceanographic point of view, especially in terms of wind generated surface waves, the Adriatic Sea may be regarded as an enclosed sea. Most frequent surface waves in the Adriatic are generated by the bora and sirocco in the winter period, and the NW wind (maestrale) in the summer period. Characteristics of wind generated surface waves generally depend on the direction, speed and duration of predominant winds, dimensions of the area in which the winds blow (fetch) and topography of the sea bottom (sea depth), generating in the Adriatic much higher sirocco waves than those of the bora at the same wind speed and duration.
Occurrence of a fully developed model of wind waves is not typical of the Adriatic because of limited fetches. However, some instrumental measurements of surface wave elements show that during hurricane speed of sirocco winds of long fetches, wave models with maxima wave heights higher than 10 m may be developed. Results of wave measurements at four locations (North, Middle and South Adriatic) according to the Directive 2003/25/EC indicated the value of a significant wave height in the open part of the Adriatic Sea (whose exceeding probability is 10% or less), in one year period, is estimated to be H_S = 1.5 m. It was concluded that this experimental data is extremely important for the safety of navigation in the Adriatic Sea.

Keywords: wind-generated surface waves, Adriatic Sea, safety of navigation

1. INTRODUCTION

The Adriatic Sea is a semi-enclosed sea forming a distinct sub-region within the Mediterranean Sea region. There is a big contrast between western (Italian) and eastern (mostly Croatian) coastal areas regarding their bathymetry and morphology. The eastern coastal area is characterized with many islands while the east coast has only a few islets. From the climatological point of view the most important winds in the Adriatic Sea are bora and sirocco in the cold part of the year and maestrale in in the warm season. The bora and sirocco can blow with hurricane force while the maestrale is mostly weaker.

From an oceanographic point of view occurrence of a fully developed model of wind waves is not typical of the Adriatic because of limited fetches. However, during hurricane speed of sirocco winds of long fetches, wave models with maxima wave heights higher than 10 m were developed [1].

Knowledge of the elements of surface waves generated by wind is important for many activities related to the sea, such as maritime economy, shipbuilding and civil engineering. Elements of surface waves such as maximum and significant wave height, period and wavelength are extremely important for the safety of navigation at sea, and thus for the Adriatic Sea area.

Deeply aware of this fact, the European Parliament and the Council adopted Directive 2003/25/EC [2] which deals with stability requirements for ro-ro passenger ships.

The main goal of this paper is to calculate significant wave height values, to be in accordance with the definition from the Directive 2003/25/EC on specific stability requirements for ro-ro passenger ships, for the area of the Adriatic Sea.

2. STUDY AREA

Adriatic Sea is a deeply indented gulf of the Mediterranean (*cca*. 800 km long and 200 km wide) belonging to semi-enclosed seas (Fig. 1). Two big mountain ranges extend side by side with the direction of the Adriatic basin, one of them on the Balkan peninsula, and the other on the Apennine peninsula.

The southern border of the Adriatic Sea (Fig. 1) includes the area of the Strait of Otranto by a line running from the mouth of the Buttrinto River (39º 44'N) in Albania to Cape Karagol in Corfu, through this island to Cape Kephali (these two capes are in latitude 39º 45'N) and on to Cape Santa Maria di Leuca [3].

The Adriatic Sea covers an area of 138.595 km^2 [4]. Total length of the Adriatic Sea coastline (mainland and islands) is 8281 km: Croatia 6278 km (75.8%), Italy 1272 km (15.4%), Albania 406 km (4.9%), Montenegro 260 km (3.1%), Slovenia 44 km (0.5%) and Bosnia and Herzegovina 21 km (0.3%) [5]. The length of Croatian coastline is 6278 km, of which mainland coast accounts for 1880 km and coasts of islands for 4398 km. The

Croatian islands area makes the second largest archipelago in the Mediterranean: 79 islands, 525 islets, and 642 rocks and rocks awash (1246 total; [6]. There is a big contrast between western (Italian) and eastern (mostly Croatian) coastal areas regarding their bathymetry and morphology. The western coastline is relatively smooth and regular with no islands and a gentle shelf, while the eastern coastal area is characterized by many islands and a very irregular bottom increasing steeply in the offshore direction. Countless straits, passages, channels and other areas dangerous for navigation along the Croatian coast (Fig. 1) cause this area to be an exceptionally difficult and complex navigational area and therefore demands a rigid regime of navigation.

The shallowest part of the Adriatic Sea is in the Gulf of Trieste, and its deepest part in the South Adriatic Pit (1233 m; Fig. 1 [4]).

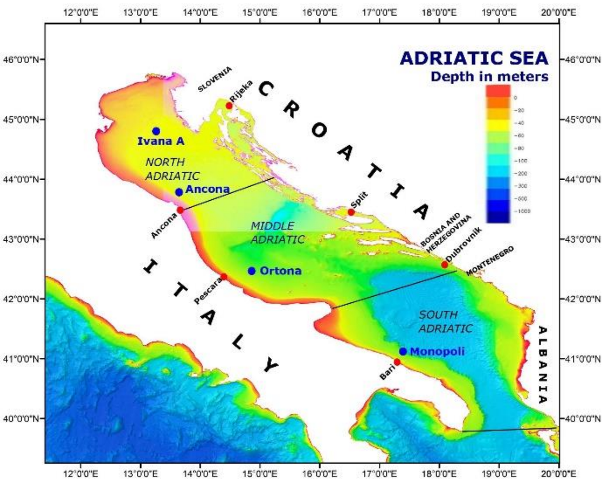


Figure 1: Bathymetric map of the Adriatic Sea. Wave measurement locations are shown with blue circles (see Table 1).

3. WINDS AND WAVES IN THE ADRIATIC SEA

Winds that blow above the Adriatic generally depend on the distribution of baric systems in a greater area. The most frequent winds are bora (NNE to ENE), sirocco (ESE to SSE) and maestrale (WNW to NW). In addition to these, there are also winds that blow from S (Ostro), SW (libeccio), W (ponente), N to NW (tramontana), E (levante), as well as land and sea breezes.

Bora is an intensive air circulation usually from NNE to ENE. It occurs when a relatively cold air accumulated on one side of a Croatian mountain range, gets across steeply falling down the mountain slopes. It is therefore a cold, strong and very gusty wind, typical of the Adriatic seaboard. The bora reaches its greatest speed in coastal areas of the east Adriatic, losing its strength toward the open sea. It rarely blows to the Italian coast, usually as a gentle to moderate breeze. The bora can reach hurricane force in the areas of mountain saddles (e.g. in the Golfo di Trieste, Senj and Makarska with bora gusts exceeding 50 m/s). On 21 December 1998 the speed of a gust on the Maslenica Bridge (north of Zadar) was measured at a record speed of 69 m/s (248 km/h). It is also the greatest wind speed ever measured in Croatia [7].

Sirocco is a warm, humid ESE to SSE wind. A cyclonic sirocco occurs when a cyclone approaches to the area of the Adriatic across the Pyrenees Peninsula, France or North Africa, or when it is developed in the area of the Tyrrhenian Sea and North Adriatic (the Genoa cyclone). An anticyclonic sirocco occurs when a low pressure area extends above western Europe, and a high pressure area above southeastern Europe. Strength and duration of a sirocco depend on the position, intensity and path of a cyclone or series of cyclones. With occurrence of a deep and slightly mobile Genoa cyclone, it may blow with gale or storm force and last for a week. A strong to gale force, persistent sirocco causes very rough and high seas in the open part of the Adriatic. Extreme sirocco speed was measured on Palagruža island (57 m/s) [7].

Libeccio (garbin) usually blows from SW. It occurs when the ridge of Azores anticyclone extends south or southwest of the Adriatic, and the centres of cyclones pass more northward of the Adriatic. With a stationary situation, it may blow for 2 days, occasionally with gale force, causing rough and very rough seas along the coast open to SW. Tramontana is a NW to N wind, usually occurring as a result of pressure gradient when cyclonic disturbances are passing north and northeast of the Adriatic, or of a rapid passing of fronts from the northwest. A strong tramontana often occurs with fair weather, depending on the distance from the cyclone centre.

Ponente blows from W, causing rough seas along west and southwest coasts of outer islands and channels of E-W direction. Levante usually blows from E, as a combination of the sirocco and bora influences.
Maestrale is a wind typical of the summer period (etesian wind). In the open sea maestrale blows from NW, but in coastal areas it is modified under the influence of land heating.

Investigations of the characteristics of surface waves generated by wind in the Adriatic Sea were most often performed by analyzing situations with extreme wave heights or by applying climatological statistics.

From an ocenographic point of view, especially in terms of wind generated surface waves, the Adriatic Sea may be regarded as an enclosed sea. Occurrence of a fully developed model of wind waves is not typical of the Adriatic because of limited fetches. However, some instrumental measurements of surface wave elements show that during hurricane speed of sirocco winds of long fetches, wave models with maxima wave heights higher than 10 m may be developed [1].

Most frequent surface waves in the Adriatic are generated by the bora and sirocco winds in the winter period, or the maestrale in the summer period. Characteristics of wind generated surface waves generally depend on the direction, speed and duration of predominant winds, dimensions of the area over the winds blow (fetch), and topography of the sea bottom (sea depth), generating in the Adriatic much higher sirocco waves than those of the bora at the same speed and duration. Maximum wave height H_{max} = 10.8 m in the open North Adriatic Sea (position IVANA A, Fig. 1) was recorded during a persistent gale force sirocco, where (significant wave height H_S = 6.0 m, mean period T = 8.5 s, mean wave length L = 112.3 m) [8]. Absolute maximum wave height in the Adriatic Sea was recorded in the South Adriatic (near Sv. Andrija islet, Dubrovnik) during the sirocco, with H_{max} = 10.87 m (significant wave height H_S = 4.75 m, mean period T = 10.0 s, mean wave length L = 156.0 m; Fig. 2) [URL 1].

By applying the theory of extreme values Leder et al. (1998) calculated maximum wave height in the Adriatic Sea which could reach the height of 14 m [8].
Cavaleri et al. (2021) suggested that freak waves are “norm in a storm” in the Northern Adriatic [9].

Figure 2: On 12 November 2019 at 16 h, Hydrographic Institute of the Republic of Croatia measured a record-setting wave in the Adriatic. This wave was recorded in the sea area of Dubrovnik near Sv. Andrija islet. Maximum wave height was Hmax =10.87 m, with significant wave height Hs = 4.75 m (sea state 6) and period T = 10 s. The wave arrived from direction Dirp = 167.1° [URL 1].

Many researchers have scientifically investigated the wave climate characteristics of the Adriatic Sea. They used different research methods: direct instrumental wave measurements, numerical modelling, remote sensing of surface waves (mostly from satellites, using different sensors) and by combining these methods.

Lončar et al. (2010) compared modelled and measured surface wind waves in two locations: open sea area in the North Adriatic and coastal chanell area in the Middle Adriatic using a quarterly time series data [10].

Wave climate of the Adriatic Sea modelled as a simulation of future scenarios was described by Benetazzo et al. (2012) [11].

Results of wave statistics for the Middle Adriatic Sea based on the World Waves Atlas data calibrated using different satellite missions and numerical wave model simulations during period of 23 years were presented by Farkas and Parunov (2016) [12].

Pomaro et al. (2017) perfomed the analysis of a 37-year long directional wave time series at the CNR-ISMAR oceanographic research tower, located in the North Adriatic [13].

24-year systematic data base obtained by satellite measurement calibration of a numerical hindcast wave model for the Adriatic Sea, was analysed by Katalinić and Parunov (2018) [14].

Two years of measured and modelled wave data in near coastal area of the Rijeka Bay were compared. Modelled wave data were simulated by the predicted forcing wind data from the atmospheric model Aladin-Hr (Lončar et al.,2019) [15].

Katalinić and Parunov (2021) [16] developed wind and wave statistical models based on the World Waves Atlas data for the entire Adriatic Sea as a whole and for 39 uniformly spaced locations across the offshore Adriatic.

It should be emphasized that in all the above papers presenting the climatological wave statistics of the Adriatic Sea, the processing of wave data as defined in Article 4 of the Directive 2003/25/EC was not applied, and it is not possible to compare them with the results of this paper.

4. DIRECTIVE 2003/25/EC

Directive 2003/25/EC of the European Parliament and of the Council deals with specific stability requirements for ro-ro passenger ships [2].
Some important facts defined in the Directive are:

- The purpose of this Directive is to lay down a uniform level of specific stability requirements for ro-ro passenger ships, which will improve the survivability of this type of vessel in case of collision damage and provide a high level of safety for the passengers and the crew;
- The SOLAS 90 damage stability standard implicitly includes the effect of water entering the ro-ro deck in a sea state of the order of 1,5 m significant wave height;
- IMO Resolution 14 of the 1995 SOLAS Conference, allowed IMO members to conclude regional agreements if they consider that prevailing sea conditions and other local conditions require specific stability requirements in a designated area;
- The significant wave heights (H_S) shall be used for determining the height of water on the car deck when applying the specific stability requirements contained in Annex I. The figures of significant wave heights shall be those which are not exceeded by a probability of more than 10 % on a **yearly basis;**
- The significant wave height (H_S) is the average height of the highest third of wave heights observed over a given period.

Therefore, according to our knowledge and experience, we suggest that methodology for calculation of significant wave height should be exactly used according to the definition written in article 4 of the Directive 2003/25/EC.

5. RESULTS

This paper will present results of the standard statistical processing of wave elemets measured at several locations in the Adriatic Sea (Fig. 1), with a time interval of measurements of about one year. Furhermore, we suggest that methodology for calculation of significant wave height should be exactly used according to the definition written in article 4 of the Directive 2003/25/EC. That means that from time series of 1-year wave measurements determined significant wave height(s) for selected station(s) have to be first put in a sequence from the its minimum to maximum value. Than, the value corresponding to the 90th percentile (meaning that 90% of the derived significant wave heights are smaller than that specific value and 10% are larger) should represent the value of significant wave height as defined in article 4 of the Directive 2003/25/EC.

In case of N-years of the significant wave heights data, a simple average value of yearly data is calculated. Significant wave heights H_s calculated according to the Directive 2003/25/EC for 4 stations in the Adriatic Sea: IVANA A (North Adriatic), ANCONA and ORTONA (Middle Adriatic), and MONOPOLI (South Adriatic) and different years are shown in Table 1. Sources of data are: IVANA A – Hydrographic Institute of the Republic of Croatia; ANCONA, ORTONA, MONOPOLI – APAT Italy (The Marine Service of Italian Agency for the Protection of the Environment) [URL 2]. Station coordinates and time intervals of measurements are shown in Table 1, also.

Table 1: Significant wave heights H_s calculated according to the Directive 2003/25/EC for 4 stations in the Adriatic Sea and different years. Sources of data: Ivana A – Hydrographic Institute of the Republic of Croatia; Ancona, Ortona, Monopoli – APAT Italy (The Marine Service of Italian Agency for the Protection of the Environment) [URL 2]

Station/Coordinates	Year	H_S (m) (DIRECTIVE 2003)
IVANA-A N 44° 44.5' – E 13° 10.2'	2009	1.2
ANCONA N 43° 49.9' – E 13° 42.6'	2000	1.2
	2001	1.4
	2002	1.0
	2003	1.4
	2004	1.3
ORTONA N 42° 24.4' – E 14° 32.2'	2000	1.1
	2001	1.4
	2002	1.0
	2003	1.1
	2004	1.2
MONOPOLI N 40° 58.5' – E 17° 22.6'	2000	1.3
	2001	1.5
	2002	1.0
	2003	1.5
	2004	1.2

Analyzing Table 1, it can be concluded that measurements of significant wave heights H_S were performed in the time interval from 2000 to 2004 (5 years) for Ancona, Ortona and Monopoli stations. Significant wave heights H_S ranged from 1.0 m (Ancona, Ortona and Monopoli) to 1.5 m (Monopoli).

Time series of significant wave heights measured at station IVANA A (sampling interval 30 min) in 2009 is shown in Fig. 3. The maximum H_S was 4.49 m, and only 6 situations with H_S greater than 3 m were recorded (0.04%).

Significant wave height H_S probability exceedens at IVANA A waverider station in 2009 is shown in Fig. 4. It can be seen that 10% of H_S are larger than 1.24 m and 0.04% are larger than 3.0 m.

On the basis of the presented results of wave measurements at four locations according to the Directive 2003/25/EC proposals, the value of a significant wave height in the open part of the Adriatic Sea (whose exceeding probability is 10% or less), in one year period, is estimated to be H_S = 1.5 m.

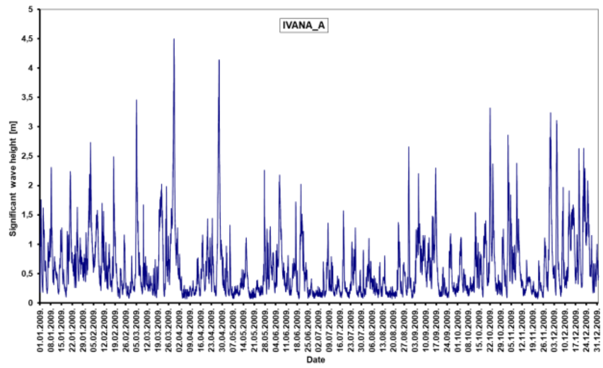


Figure 3: Significant wave heights H_S measured at IVANA A waverider station from 1 January to 31 December, 2009. Sampling interval was 30 minutes (data of the Hydrographic Institute of the Republic of Croatia).

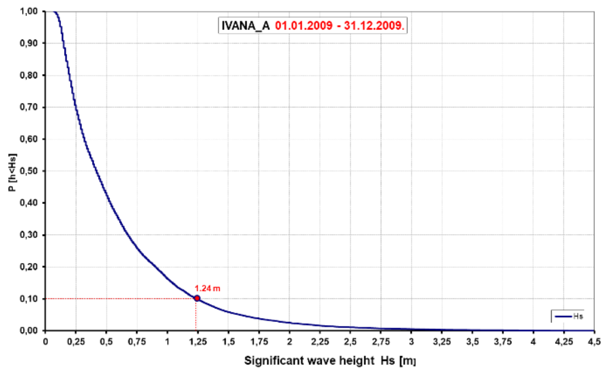


Figure 4: Significant wave height H_S probability exceedens at IVANA A waverider station in 2009. Only 10% of H_S are larger than 1.24 m.

6. CONCLUSION

The Adriatic Sea is a semi-enclosed deeply indented gulf with limiting dimensions, *cca*. 800 km long and 200 km wide. From the point of view of the analysis of surface waves generated by wind

Adriatic Sea may be regarded as an enclosed sea. Most frequent surface waves in the Adriatic are generated by the bora and sirocco in the winter period, and the NW wind (maestrale) in the summer period. Bora and sirocco can blow at extremely high speeds that are higher than 200 km/h.

Occurrence of a fully developed model of wind waves is not typical of the Adriatic because of limited fetches. However, some instrumental measurements recorded wave heights higher than 10 m during hurricane speed of sirocco winds of long fetches.

Calculation of significant wave height values, to be in accordance with the definition from the Directive 2003/25/EC on specific stability requirements for ro-ro passenger ships, was the main goal of this paper. Results of wave measurements at four locations (North, Middle and South Adriatic) according to the Directive 2003/25/EC indicated the value of a significant wave height in the open part of the Adriatic Sea (whose exceeding probability is 10% or less), in one year period, is estimated to be $H_S = 1.5$ m.

It can be concluded that this experimental value of H_S is extremely important for the safety of navigation in the Adriatic Sea.

However, it is important to point out that the Adriatic countries of Albania, Bosnia and Herzegovina, Croatia, Italy, Monte Negro and Slovenia can agree on the adoption of a larger value of a significant wave height, as many other states have done, e.g. northern European countries (Stockholm Agreement in 1996).

REFERENCES

[1] Smirčić, A. (1985). Surface waves of the open Adriatic generated by wind in the form of natural geographical properties (In Croatian), PhD Thesis, Ljubljana, 145 pp.

[2] Directive 2003/25/EC (2003). Official Journal of the European Union, L 123/25, 17.5.2003.

[3] Limits of oceans and seas (1953). International Hydrographic Organization, Special publication No.23, 3rd Edition.

[4] Adriatic Sea Pilot, Vol. 1 (2021). Hydrographic Institute of the Republic of Croatia, Split, Croatia.

[5] Leder, N., & Filipović, V. (2007). Geographical aspects of delimitation at sea and environmental features in the Adriatic, "ZERP" - gospodarski pojas, Pitanja ribarstva, zaštite okoliša i razgraničenja na Jadranu o 25-godišnjici Konvencije UN o pravu mora, Split, Croatia.

[6] Duplančić Leder, T., Ujević, T., & Čala, M. (2004). Coastline lenghts and areas of islands in the Croatian part of the Adriatic Sea determined from the topographic maps at the scale of 1 : 25 000, Geoadria 9, 5-32.

[7] Gelo, B. (2010). General and maritime meteorology (In Croatian), University of Zadar, Zadar, 614 pp.

[8] Leder, N., Smirčić, A., & Vilibić, I. (1998). Extreme values of surface wave heights in the northern Adriatic, Geofizika, Vol. 15, 1-13.

[9] Cavaleri, L., Barbariol, F., Bastianini, M. et al. (2021). An exceptionally high wave at the CNR-ISMAR oceanographic tower in the Northern Adriatic Sea, Scientific Data, 8.

[10] Lončar, G., Ocvirk, E., & Andročec, V. (2010). Comparison of modelled and measured surface wind waves (In Croatian), Građevinar, Vol. 62, 197-206.

[11] Benetazzo, A., Fedele, F., Carniel, S. et al. (2012). Wave climate of the Adriatic Sea: a future scenario simulation, Nat. Hazards Earth Syst. Sci., Vol 12, 1-12.

[12] Farkas, A., Parunov, J., & Katalinić, M. (2016). Wave statistics for the Middle Adriatic Sea, Pomorski zbornik, Vol. 52, 33-47.

[13] Pomaro, A., Cavaleri, L., & Lionello, P. (2017). Climatology and trends of the Adriatic Sea wind waves: analysis of a 37-year long instrumental data set, Int. J. Climatol., Vol. 37, 4237-4250.

[14] Katalinić, M., & Parunov, J. (2018). Wave statistics in the Adriatic Sea based on 24 years of satellite measurements, Ocean Engineering, Vol. 158, 378-388.

[15] Lončar, G., Leder, N, Duplančić Leder, T., & Carević, D. (2019). Wave Energy Disbalance as Generator of Extreme Wave Occurrence in Semi-Enclosed Coastal Waters (Example of Rijeka Bay—Croatia), Journal of Marine Science and Engineering, 7 (11):420, doi: 10.3390/jmse7110420

[16] Katalinić, M., & Parunov, J. (2021). Comprehensive wind and wave statistics and extreme values for design and analysis of marine structure in the Adriatic Sea, Journal of Marine Science and Engineering, 9:522, doi: 10.3390/jmse9050522

[URL 1] https://www.hhi.hr/en/news/record-setting-wave-measured-in-the-adriatic

[URL 2] https://www.isprambiente.gov.it/en/istitute The Marine Service of Italian Agency for the Protection of the Environment-former APAT, data base.

CONCESSIONS FOR BUS PUBLIC TRANSPORT; CHALLENGES AND IMPLEMENTATION OF THE TENDER IN THE CASE OF SLOVENIA

Marjan Lep, Ph.D.
University in Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture
Smetanova ulica 17, 2000 Maribor, Slovenia
marjan.lep@um.si

Marko Hočevar, Ph.D.
University of Ljubljana, School of Economics and Business
Kardeljeva ploščad 17, 1000 Ljubljana, Slovenia
marko.hocevar@ef.uni-lj.si

Uroš Škufca, M.Sc.
Praetor d.o.o.,
Brnčičeva 13, 1000 Ljubljana, Slovenia
uros.skufca@praetor.si

Dušan Zalar, Ph.D.
Ministry of Infrastructure, Republic of Slovenia
Langusova 4, 1000 Ljubljana, Slovenia
dusan.zalar@gov.si

Marjan Kotar
Agencija za promet d.o.o,
Cigaletova 8, 1000 Ljubljana, Slovenia
marjan.kotar@ap-ljubljana.si

ABSTRACT

Approximately 50.0 million kilometres are covered annually within the regional and intercity public bus transport in the Republic of Slovenia. The contractors of these services (concession operators) should have been selected through a call for tenders in the past, which, despite some attempts in practice, was not carried out and the concession contracts awarded based on the "actual situation" in 2003 were simply extended. In 2021, the Ministry of Infrastructure managed to carry out a call for tenders, which, according to the tenders received in December 2021, can be assessed as successful. In this paper, we summarize the key challenges of the call for tenders preparation process as well as the key steps and decisions. The methodology for balancing contradictory tendencies is explained: budgetary constraints - the limited amount of service supply, the desire to approach sustainable mobility goals - as many services as possible with (expensive) environmentally-friendly vehicles, establishing conditions for competition on the market - the fragmentation of concession lots and transparent and sustainable system management.

Keywords: Bus public transport, concessions for bus public transport, tendering bus services

1. INTRODUCTION

1.1. The situation today

Approximately 50.0 million kilometres are covered annually by buses in the framework of public intercity bus utility services (hereinafter referred to as: utility service) in the Republic of Slovenia. The year 2019 was the last year when public passenger transport services operated in full. Therefore, some of the basic data stated hereafter refers to 2019. In this year, the passenger transport service was provided by 26 transport providers who covered a total of 48.97 million kilometres (Table 1).

Table 1: Delivered services - concessionaires in regional and intercity bus services in Slovenia (2019)

Operator (short name)	Vehicle km/year	Market share
NOMAGO	16,464,462	33.62%
Arriva Štajerska	7,626,165	15.57%
ARRIVA ALPETOUR,	7,317,778	14.94%
Arriva Dolenjska in Primorska	5,101,902	10.42%
Ljubljanski potniški promet	3,483,218	7.11%
AP Murska Sobota	2,873,834	5.87%
Arriva Kam-Bus	1,826,343	3.73%
INTEGRAL BREBUS	1,235,569	2.52%
MPOV	778,433	1.59%

Operator (short name)	Vehicle km/year	Market share
Integral voznik, Novo mesto	626,585	1.28%
Others (16 operators)	1,640,604	3.35%
	48,973,274	100.00%

Source: Ministry of Infrastructure, 2019 ([9])

The public utility service discussed in this paper was funded from various sources in 2019 (Table 2).

Table 2: Financial sources of concessioned regional and intercity bus services in Slovenia in 2019

Source of income	[€]/year
Ticket sales	27,426,742
Other income (luggage, advertising...)	2,932,649
Local communities and third-party sources (companies...)	6,824,399
Subsidies granted by the state	24,281,801
Compensation	27,097,756
Total	**88,563,347**

Source: Ministry of Infrastructure, 2019 ([9])

In calculating the compensations, the Ministry of infrastructure in its capacity as a concession provider recognized the following elements and structure of the standardized cost price (Table 3):

Table 3: Standardized cost price, elements of the price and weighted arithmetic mean

Cost element	[€/km]
Fuel	0.285
Depreciation	0.208
Maintenance	0.250
Drivers	0.618
Insurance	0.033
Costs of bus stops and parking	0.138
Intermediary work	0.237
Depreciation of other fixed assets	0.034
Funding and profit	0.107
Standardized cost price	**1.91**

Source: Ministry of Infrastructure, 2019 ([9])

The contractors of these services (concession operators) should have been selected through a call for tenders in the past, which, despite some attempts in practice, was not carried out and the concession contracts awarded based on the "actual situation" in 2003 were simply extended. The call for tenders was published in 2010; however, it was not completed.

1.2. A call for tenders in 2021

In 2020, the competent ministry began the activities to prepare a new call for tenders.

In accordance with the provisions of Regulation (EC) No 1370/2007 of the European Parliament and of the Council of 23 October 2007 on public passenger transport services by rail and road and repealing Council Regulations (EEC) Nos 1191/69 and 1107/70 (hereinafter referred to as: Regulation 1370) and in accordance with the national legislation regulating this field, i.e. the Road Transport Act – ZPCP-2 (hereinafter referred to as: Road Transport Act) [1] and the Decree on the method of providing the public utility service of the regular carriage of passengers by road, on concessions for such a service and on the integrated ticketing system [2] (hereinafter referred to as: the Decree on regular passenger service), the Ministry of infrastructure must grant new concessions or rather conclude new transport contracts.

In line with the existing legislation, it is the Ministry of Infrastructure, as a sectoral body, which is responsible for the establishment of the statutory conditions for the organization, operation, funding, monitoring and implementation of the public utility service of the regular carriage of passengers (hereinafter referred to as: the regular passenger service).

Those preparing the tender documentation faced the challenge of how to meet the expectations of various stakeholders and, at the same time, to comply with clearly defined restrictions.

1.3. Key challenges of the 2021 call for tenders

Given the complications that are usually encountered when public procurement procedures are carried out in line with the Public Procurement Act and Public-Private Partnership Act, those preparing the tender documentation were in particular facing the following key challenges of the call for tender preparation process, i.e. how to balance contradictory tendencies:

- of budget restrictions, defining more or less strictly determined availability of the service, and desires to move towards the goals of sustainable mobility, having for implication the widest possible availability of the service with the most environmentally acceptable vehicles;
- of establishing the conditions for allowing a greater number of carriers to compete, leading to a fragmentation of concession lots, and the simultaneous desire for transparent and sustainable system management.

1.4. Key input data and restrictions

Those in charge of preparing the tender documentation had to deal with the following tasks imposed by the concession provider, i.e. the Ministry of Infrastructure:

- the availability of service that nowadays encompasses 50 million kilometres per year should be increased by 20% to 60 million kilometres per year;
- the increase should follow general transport policies with the increase being applied in such a way as to support rides to work and to school corresponding to 16% of the total increase in the volume of rides;
- in a manner that helps mitigate the ongoing depopulation of rural parts of Slovenia; adding rides to peripheral areas and settlements (a 4% increase);
- to also support the use of public transport funds for tourism and recreational purposes (adding rides on weekends and holidays (a 4% increase);

- the availability of services must be unified so it is "fair" for the entire state, i.e. a uniform standard of availability must be established.

2. METHODOLOGY

2.1. Legal form

To achieve the set goals, as well as the expected availability and quality of the service, while using the available public funds, an adequate form of public-private partnership had to be selected. The following forms were "at play":

- A net (concession-based) funding model covering the entire territory of Slovenia. This is the model currently in place where the carrier assumes the majority of income-related risks. This model entails direct sales of tickets or sales of tickets where the carrier obtains a part of the purchase price – the subsidy – from the subsidy provider. This model – at least in its foundation – encourages the carrier to provide the transport only when they have sufficient demand and income. There have been tendencies to cancel departures.
- The gross (public contract) model – in the entire territory of Slovenia. With this model, all (or the majority share) of income-related risks are assumed by the contracting authority (i.e. the concession provider). The latter also sells tickets on their own account, while the carrier only "generates" kilometres. The main pitfall of this approach is that the carrier is not very motivated to carry the passengers. Their primary motivation is generating as many kilometres as possible.
- A mixed system where, depending on the circumstances, a net system would be applied in some areas or along some routes, and a gross system would be applied in other areas or along other routes.

There has been heated discussion among professionals in the past about which model – net or gross – is more suitable. Some foreign practices were studied, particularly from regions in Italy, Austrian federal units, UK metropolitan regions, Ireland, Dutch regions etc. all of them with certain circumstancies (in terms of geographical scope covered, modalities involved, legal background etc) not directly comparable with the task in Slovenia. According to our estimate, both have their advantages and their considerable disadvantages. In certain areas and for certain types of rides, a gross model seems more suitable while a net model seems a better solution for others. In line with these findings, the expert team first proposed a "mixed" model, where the system operator contracts part of the services under the gross model (i.e. "it orders kilometres") and part of services under the net model (i.e. along more "interesting" routes in terms of demand). In order to implement this model, certain amendments to the Road Transport Act and the Decree on regular passenger service had to be drafted. The said amendments were drafted but were not approved when they underwent a coordination procedure among different sectors.

The first and probably the key decision was made when the gross (public contract) model, including the associated repercussions, was adopted based on the fact that even nowadays, most of the carriers' income comes from public funds.

2.2. Availability standard

The availability standard is an attempt or a basis for defining, based on some sort of a measurable piece of demographic data, the smallest volume of public passenger transport service that the state will "order" and fund.

The issue related to this task is not so much in establishing certain standards as in drafting those standards in such a way as to "contract out" exactly or approximately 60.0 million kilometres a year when such a standard is applied. The availability standard was then published as an annex to a new Decree on regular passenger service, published in 2021 [3] (hereinafter referred to as: the new Decree on public passenger service).

The Annex determines:

- the methodology for classifying municipal centres and settlements that are not municipal centres into classes of interconnection
- the standardization of days for the purposes of determining the accessibility standard
- the minimum number of connections for certain classes of interconnection

Classification of municipal centres and settlements into classes of interconnection:

Table 4: Classification of settlements into classes of interconnection

Class of interconnection	*Description*
A	Municipal centres with more than 1,000 potential passengers.
B	Municipal centres with more than 500 and up to and including 1,000 potential passengers.
C	Municipal centres with more than 200 and up to and including 500 potential passengers or settlements that are not municipal centres with more than 200 potential passengers.
D	Municipal centres with more than 100 and up to and including 200 potential passengers or settlements that are not municipal centres with more than 100 and up to and including 200 potential passengers.
E	Municipal centres with less than 100 potential passengers or settlements that are not municipal centres with more than 50 and up to and including 100 potential passengers.

Source: Annex 2 to the new Decree on public passenger service, 2021 ([3])

The new Decree on public passenger service introduces a criterion of the number of potential passengers of public passenger transport (P_i). The criterion was based on research on work and school commuting habits ([7]). The number of potential inter-municipal passengers was determined based on the "direct demand modelling" method. Given the known number of inter-municipal commuters to work and school, the target share of these routes that the commuters were to make using public means of transport was then applied. For secondary-school students this share was set at 80%, for students it was set at 50%, and for commuters to work it was set at 20%. The number of potential passengers of a municipal centre is calculated as follows:

$$P_i = \max\left((0.8 * Db_i + 0.5 * Šb_i + 0.2 * Zb_i), (0.8 * Da_i + 0.5 * Ša_i + 0.2 * Za_i) \right) \quad (1)$$

where:

Db_i means the number of secondary school students who live in municipality i and attend school outside municipality i,

$Šb_i$ means the number of students who live in municipality i and attend school outside municipality i,

Zb_i means the number of employees who live in municipality i and work outside municipality i,

Da_i means the number of secondary school students who attend school in municipality i and live outside municipality i,

$Ša_i$ means the number of students who attend school in municipality i and live outside municipality i,

Za_i means the number of employees who work in municipality i and live outside municipality i.

The number of potential passengers for settlements that are not municipal centres is calculated as follows:

$$P_i = 0.10 * N_i \quad (2)$$

where:

N_i means the number of inhabitants of settlement i.

The types of days used for the purposes of availability standards are:

DŠ business day during school hours,

DŠP business day during a school holiday,

SO Saturday,

NEP Sunday and holiday (work-free day).

In line with the above-described methodology, all the municipal centres of the Republic of Slovenia and all the remaining settlements with more than 500 inhabitants were classified into classes of interconnection.

The aforementioned Decree stipulates the minimum volume of interconnections a settlement must have for each class of interconnection (Table 5).

Table 5: Classes of interconnection and the required minimum number of connections for a settlement

Class of interconnection	*Type of day*			
	DŠ	***DŠP***	***SO***	***NEP***
A	38	30	9	9
B	24	18	5	5
C	13	10	3	3
D	10	8	-	-
E	5	4	-	-

Source: Annex 2 to the new Decree on public passenger service, 2021 [3].

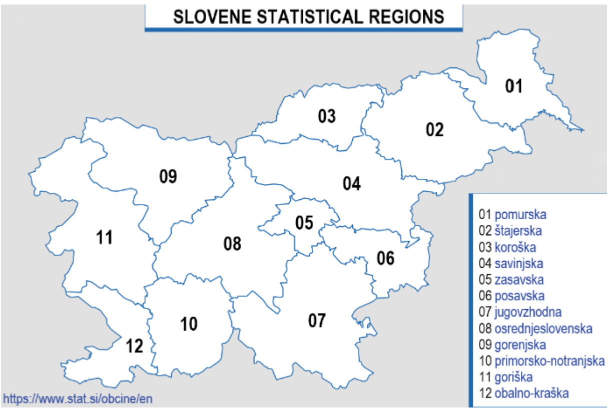
2.3. Concession areas and routes

The new Decree on the public passenger service defines the "concession lot" as one or several bundle(s) of routes for which the contractor acquires a special right, and that constitutes the smallest unit for which a concession may be granted. According to a definition in the Public Procurement Act ([6]), the set is a reasonable unit that may be contracted separately.

Even though the option of the entire territory of the Republic of Slovenia, including all the routes under the utility service (suburban, regional, inter-regional and long-distance), being contracted to one tenderer was also analysed, the decision was made to create several concession areas (hereinafter: lots). The number of concession lots was analysed using the following criteria:

- the possibility of establishing competition in the tender phase (this criterion has a tendency towards the highest possible number of tender lots),
- economies of scale (this criterion entails a slightly smaller number of concession lots),
- decreasing objective possibilities for the creation of a (monopoly) oligopoly of providers, which would put the contracting authority/concession provider who operates the system in an inferior position,
- linking the tender lots to certain regions that would make sense according to mobility patterns or have some other basis.

Based on the above, a decision was made for the tender lots to correspond to statistical regions based on the statistical data of the Statistical Office of the Republic of Slovenia (SURS). The regions of the Republic of Slovenia are shown in Figure 1.



Source: Statistical Bureau of the Republic of Slovenia, 2021 [8]

Figure 1: Statistical regions of the Republic of Slovenia

Data for the regions is shown in Table 6.

Table 6: Characteristics of the statistical regions of Slovenia.

Statistical region	Surface share	Population share
Gorenjska	10.5%	9.8%
Goriška	11.4%	5.8%
Jugovzhodna	13.3%	7.0%
Koroška	5.1%	3.5%
Obalno-kraška	5.2%	5.6%
Osrednje-slovenska	11.1%	25.3%
Podravska	10.7%	15.8%
Pomurska	6.6%	5.7%
Posavska	4.8%	3.7%
Primorsko-notranjska	7.2%	2.5%
Savinjska	11.7%	12.5%
Zasavska	2.4%	2.8%

Source: Statistical Bureau of the Republic of Slovenia, 2021 [8]

The routes, their itineraries and the volume of the required availability of the service in particular were determined based on the application of the accessibility standard from the new Decree on public passenger service, which was modified by what is known as the "actual state". The call for tenders stated the (required) volume of the service for the entire territory of the Republic of Slovenia up to the minimum (theoretical) standard, while the existing availability of the service that exceeded the minimum standard was maintained and was only reduced in exceptional cases.

Table 7: Tendered services

Statistical region	Tender [km/year]	Market share
Gorenjska	8,898,668	15.73%
Podravska	8,180,030	14.46%
Savinjska	6,756,266	11.95%
Jugovzhodna	5,654,010	10.00%
Pomurska	4,623,008	8.17%
Osrednje-slovenska*	4,553,246	8.05%
Obalno-kraška	4,483,864	7.93%
Goriška	4,401,690	7.78%
Koroška	3,307,046	5.85%
Posavska	2,215,274	3.92%
Primorsko-notranjska	1,779,556	3.15%
Zasavska	1,685,536	2.98%
	56,556,376**	100.00%

**some regional bus services integrated into the Ljubljana "extended city bus service system" were excluded from this first tender*

***with temporarily excluded Ljubljana extended city bus services, the total tendered kilometres is 59.6 million kilometres annually, which was the given limit by the ministry*

The preliminary decision on adopting the gross system made the decision of "who a certain route that runs through various regions belongs to" less difficult.

Having consulted the Competition Protection Agency (AVK), the contracting authority incorporated some safeguard measures into the public tender in order to protect competition. Thus, a restriction was added in the tender conditions under which an individual tenderer (as well as their related undertakings) may obtain no more than 55% of all the tendered kilometres under all lots in total. The contracting authority also created a better scoring system for tenders that subcontract certain parts of the services (taking into account restrictions from the new Decree on public passenger service according to which the main contractor must, given the nature of the partnership, with the concession partnership being a strictly personal relationship, provide the majority share of services). In addition, instead of the originally envisaged 8 lots, the call for tenders was divided into 12 lots.

The application of the above-described accessibility standard and other requirements to the actual commuter corridors (i.e. basic itinerary) was carried out in line with the following procedure:

- determining the existing service,
- determining potential passengers in both directions along all sections (links) of the basic itinerary; the highest is taken into consideration for further procedure,
- classifying individual sections (links) of an itinerary into classes,

- determining the number of connections of the minimum service standard (minimum accessibility standard),
- determining the tolerance – the number of connections wich are not considered as over-standard,
- determining settlements outside the basic itinerary whose connection (or at least part of it) also runs along the basic itinerary,
- determining if there are overlappings with other interconnecting, basic corridors (ie. basic itineraries,
- forming the so-called "tendered itineraries" and the volume of supply of the service for each section (link) of the investigated corridor.

An example is illustrated in the spreadsheet hereunder (Figure 2):

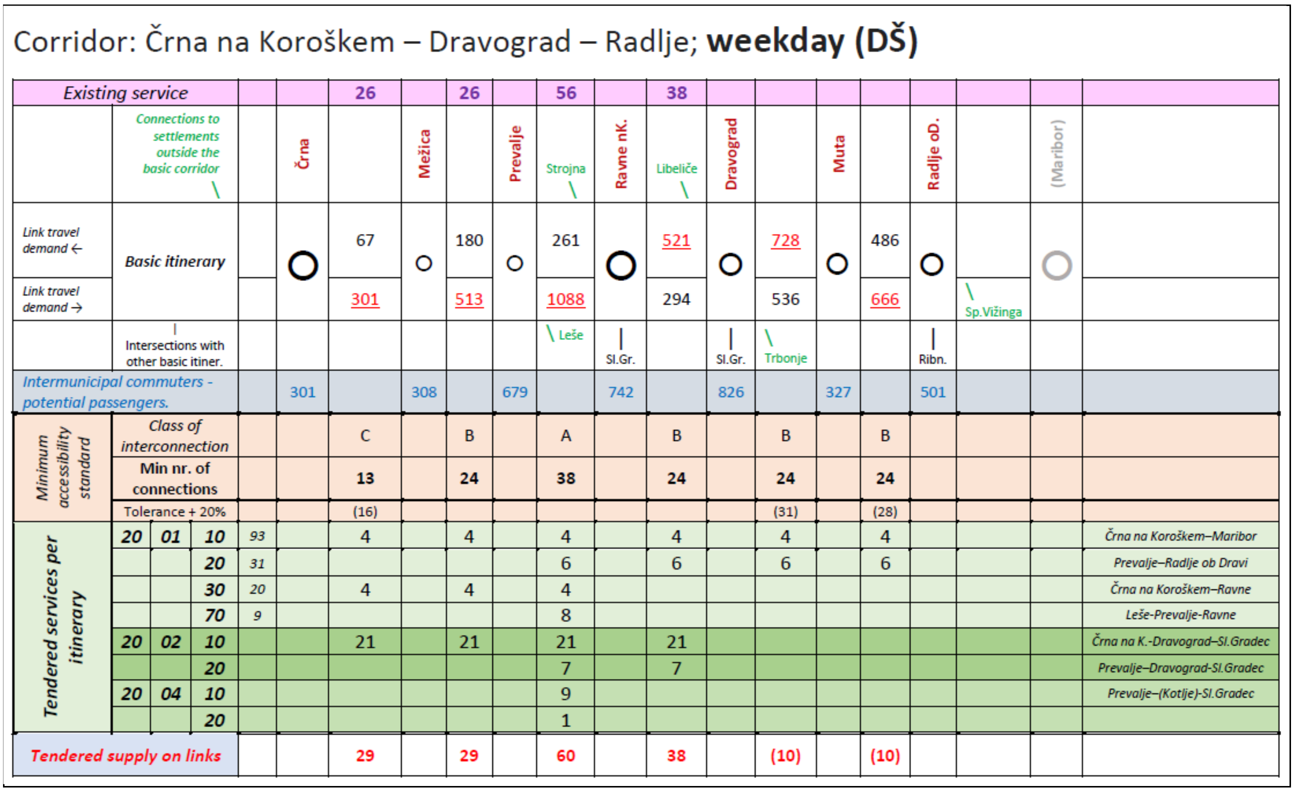


Figure 2: Application of the methodology, case study of the corridor Črna na Koroškem – Radlje ob Dravi

2.4. Criteria and conditions for recognizing the capacity of the tenderers

Apart from the mandatory grounds for exclusion and some "standard" conditions, the contracting authority only verified technical capacity (in terms of the number of available buses and number of drivers, by individual lots). The contracting authority did not decide to verify the references as this would narrow down the competition to the existing service providers. In addition, there are no economic operators on the market with sufficient capacities and without adequate references. It goes without saying that the contracting authority only took account of certain capacities for the tendered lots as it is impossible to provide transport services for different lots using the same buses and drivers.

As regards the regulatory level, the new Decree on public passenger service only determined the criterion of the economically most advantageous tender and left the contracting authority to freely determine and assess the criteria. The contracting authority could create different criteria for each lot; however, they decided to follow the same approach.

In assessing the criteria, apart from the tender price, the contracting authority took into account the elements related to social and environmental issues and above-standard services. The price criterion was weighted at 76%, though it should also be mentioned that the maximum allowed price per kilometre was defined at EUR 1.95 without VAT (this means that tenders with prices above this amount were excluded).

The rest of the criteria consisted of social criteria (i.e. the protection of small contractors) with tenderers engaging subcontractors providing a large share of the rides receiving more points. In the framework of the environmental criterion, the contracting authority awarded points to a greater number of buses complying with the EURO6 standard while they did not take into account buses below the EURO4 standard. In this regard, it should also be noted that the contractors undertook to replace all the buses that only comply with the EURO4 standard within two years from the start of service provision, and also to replace within this time limit all buses that only comply with the EURO5 standard and that are more than 12 years old.

In the framework of the above-standard services criterion, the contacting authority assessed the availability of the internet via an onboard Wi-fi network. In this context, it should be noted that literally all the tenderers had this option in their tenders for all lots.

2.5. Timeframes

With a view to limiting the monopoly of tenderers, the contracting authority envisaged the concession contracts of a minimum of 5 years with the possibility of extending them for an additional three years (i.e. 8 years maximum). This period allows stable operations for the contractors, as well as investments with an adequate rate of return in terms of time. The contracting authority also envisaged an adequate transition period allowing the contractors to start providing the services. In this context, they defined two reasonable dates for the start of service provision (according to the what is known as the big bang principle – i.e. the provision of the services under all lots shall start at the same time) which coincided with the start of the winter and summer school holidays.

3. RESULTS

3.1. Response to the tender

Having published the tender [4], the contracting authority received a large number of requests for additional clarifications. They also extended the original deadline for the submission of tenders so the potential contractors had enough time (more than four months) to prepare quality tenders.

Even though the contracting authority created as many as 12 lots (fewer lots were originally planned) in order to strengthen the competition, they only received one tender for most of the lots, which coincides with the existing situation on the market. For three lots, they received two tenders, of which one was withdrawn by the tenderer due to the above-stated restriction of 55%.

3.2. Decisions

Having issued the contract award decisions (for one lot, no one was awarded the contract), the contracting authority received three requests for review. However, at the time of drawing up this paper, the result of the review procedure is not yet known as the State Review Commission still has to make its decision.

In general, one could conclude that the contract award procedure is final for nine lots; for two lots, the contracting authority will presumably award the contract once the appeal procedure has been completed, and as regards the lot for which no contract was awarded, the contracting authority will have an option, provided the appellant party succeeds with their appeal and the tender is admissible, to either select the appellant's party tender or to opt for one of the possibilities provided for by the law (e.g. rejecting all the tenders submitted under this lot – they also have the same possibility, if applicable, for the other two lots that were the subject of the review procedure).

4. CONCLUSION AND DISCUSSION

The system that is being introduced based on the call for tenders described here has many details that are not discussed in this paper but are important components of a well-functioning system. By switching to the gross model, many tasks that were once performed by the carrier have now been assigned to the operator. In the system established by this model, the carrier is mainly motivated to "generate" as many kilometres as possible and less so to carry satisfied passengers. Partially, this risk may be mitigated by introducing a "bonus/penalty" system, in the framework of which validations are awarded meaning that the carrier is granted some sort of financial bonus for each validation (i.e. for each carried passenger) – the concession provider incorporated this into the concession contracts.

Another major set of challenges consists of what is known as integrated routes. These entail rides where one vehicle (a bus) officially performs separate transports, like school transport, that are also used by other passengers, or public transports operated by the cities, while also carrying passengers on inter-city routes and thus being entitled to charge different rates.

The next challenge consists of all public transport tenders that, according to the provisions of the new Decree, should be classified as above-standard (in terms of the volume of tendered kilometres) and that the tenderers are (to a certain extent) prepared to co-fund.

The new system also raises the question of "fair" prices for using the bus station (passenger terminals), the majority of which are owned by carriers.

All the above-described challenges, in particular those related to reaching the sustainable development goals, made the switch to the more active management of the public passenger transport (as implied by the above-described new system) a must.

REFERENCES

[1] Road Transport Act (Official Gazette of the Republic of Slovenia Nos. 6/16 – official consolidated version, 67/19 and 94/21)

[2] Decree on the method of providing the utility service of the regular carriage of passengers by road, on concessions for such a service and on the integrated ticketing system (Official Gazette of the Republic of Slovenia No. 29/19)

[3] Decree on the method of providing the utility service of the regular carriage of passengers by road, on concessions for such a service and on the integrated ticketing system (Official Gazette of the Republic of Slovenia Nos. 79/21 and 109/21)

[4] The publication of the call for tenders and tender documentation: Selection of concession operators for implementing the public utility service of the regular carriage of passengers in the Republic of Slovenia (https://www.enarocanje.si/Obrazci/?id_obrazec=408492)

[5] Public-Private Partnership Act (Official Gazette of the Republic of Slovenia No. 127/06)

[6] Public Procurement Act (Official Gazette of the Republic of Slovenia Nos. 91/15, 14/18)

[7] Gabrovec M.; Bole D.; Lep M.; Pelc S. et al. *Dnevna mobilnost v Sloveniji*. Ljubljana: Založba ZRC, 2013

[8] Statistical Bureau of the Republic of Slovenia. Available online: https://www.stat.si/statweb

[9] Ministry of Infrastructure (internal sources), 2019

ANALYSIS OF MATERIAL MOVEMENTS AT PORTS OF SV. JURAJ AND SV. KAJO CEMENT PLANTS IN PERIOD 2011-2020

Ana Macura, M.Eng
Ante Bubić, M.IT
CEMEX Croatia
F.Tuđmana 45, 21212 Kaštel Sućurac, Croatia
ana.macura@cemex.com, ante.bubic@cemex.com

ABSTRACT

Cement plants Sv.Juraj and Sv.Kajo are producing cement from the beginning of the 20th century. Both plants are based in the area under Split port authority. Cement plant's ports are considered as industrial ports used for import of materials needed for production of cement and clinker and export of produced materials. Total volume moved through Sv.Juraj and Sv.Kajo cement plant's ports make them one of the most important concession holders of Split port authority. This research paper analyses total cargo quantities of cement plants' ports in period 2011-2020 and gives a perspective of participation in total cargo movements in comparison with public cargo port - Port of Split. Total cargo movement of cement plants' ports has been analyzed considering the type of material and its participation in total movement. Furthermore, based on actual data, this paper gives an overview of possible development tendencies considering the possible market approaches and new technologies.

Keywords: Sv.Juraj plant, Sv.Kajo plant, CEMEX, Port of Split, cement

1. INTRODUCTION

There are six cement plants in Croatia by four cement producers. Three of those cement producers are producing portland cement while one is specialized in aluminate cement production.[1] CEMEX Croatia is a portland cement producing company with two cement plants located at the Croatian coastal area: cement plants Sv.Juraj and Sv.Kajo.

Cement plants Sv.Juraj and Sv.Kajo are located at Croatian coast, Kastela bay. Both cement plants are over hundred years old, Sv.Juraj cement plant started working in 1912 and Sv.Kajo cement plant started working in 1904. Both plants are integral part of CEMEX Croatia, cement producing company. For the purpose of this paper, we will use the syntagm CEMEX port when considering both ports.

CEMEX port is not a commercial cargo port, it is special purpose port used only for loading and unloading processes related to the cement and clinker production; loading of produced goods and unloading of materials needed for production. Cargoes that are referent to CEMEX port are cargoes that are cement plant products, cement and clinker, and materials needed for the production processes such as pet coke, coal, slag, and other bulk materials.

CEMEX Croatia is a holder of port concession issued by Port Authority in Split for the operative ports of Sv.Juraj and Sv.Kajo cement plants. Sv.Juraj plant is located at Kastela basin – Basin B – Waterside Sv.Juraj I and Waterside Sv.Juraj II. Sv.Kajo plant is located at Kastela basin – Basin C – Waterside Sv.Kajo.

Sv.Juraj plant port has four (4) operational berths: two berths used for loading of cement and clinker and two berths used for unloading of pet coke and other materials. Total length of the operational berths is 575 m with max depth of 8,2 m and up to 9,7 m with distancers (max vessel LOA is 120 m).[2]

Source: https://portsplit.hr/hr/kastelanski-bazen-b/ (12.04.2022)

Figures 1 and 2: Sv.Juraj port - plan and satellite image

Sv.Kajo plant port has one operational berth, used for loading of cement and clinker and for unloading of materials needed for cement and clinker production

[1] http://www.croatiacement.hr/hr/index.php (12.4.2022)

[2] https://portsplit.hr/kastelanski-bazen-b/ (28.12.2021)

process. Total length of the operational berth is 219 m with max depth of 8,2 m (vessel max LOA is 180 m).[3]

Source: https://portsplit.hr/hr/kastelanski-bazen-c/ (12.04.2022)

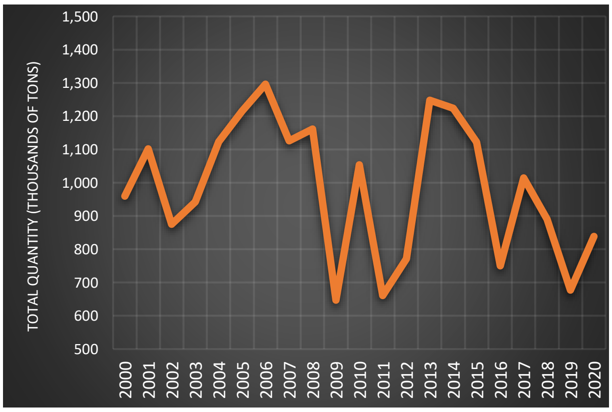
Figures 3 and 4: Sv.Kajo port - plan and satellite image

Both plants have traffic connections to the inland transport, both are situated at the state road D8 (road that connects almost all Croatian coastal cities and goes through Croatia, Bosnia and Herzegovina and Montenegro) and the connection to the highway A1 is 10 km away. Cargo rail station Solin is right next to the Sv.Kajo plant and railway goes to both plants.

The main topic of this paper is the analysis of the material volumes at CEMEX port, technical details such as operational machinery, warehouse, and transport possibilities were not considered in this paper.

2. VOLUMES MOVED AT SV. JURAJ AND SV. KAJO PORTS

The start of the material movement analysis took into consideration the total volumes moved through the cement plants' ports and comparison with the Split area total cargo volume moved and comparison with total annual volumes of some other Croatian ports.



Source: Internal documentation CEMEX Croatia, made by authors

Graph 1: Total volume at CEMEX port 2000-2020

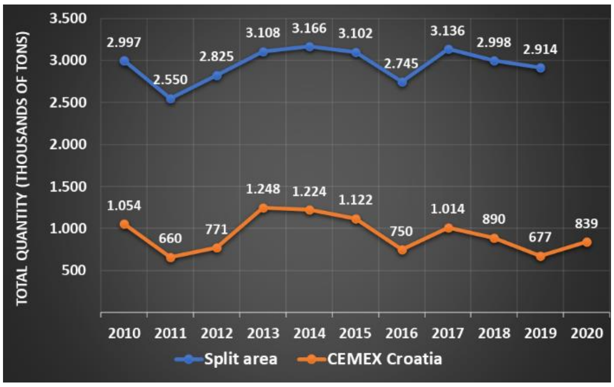
Graph 1. shows the total volume moved through CEMEX port in the period of 21 years. It presents the total movements of the volumes throughout the cement plants' ports and gives an indication of the commercial aspect and cargo movements in the area.

The periods of 2004-2008 and 2013-2015 had peaks of total moved volumes with the maximum of 1,3 million tons in year 2006 (maximum in the first millennial decade was in year 2006, the maximum in the second decade was in year 2013 with 1,25 million tons).

Years with the lowest volumes of moved volumes were 2009, 2011 and 2019, all below 700 thousand tons.

As presented in the graph, there is a major decrease in moved volume between the one of the peak periods and the year with record minimum. Record minimum was in year 2009 with 647 thousand tons of moved volume which followed the peak period of 2004-2008. The decrease of total volume in year 2009 in relation to year 2008 was 44%. Total volume in year 2010 recovered to be over 1 million tons which is an increase of 38% from the previous year. That volume drop can possibly be in correlation with the global financial crisis in 2008 but that analysis is not the purpose of this paper. The data presented in this paper could be valuable to extend the research considering the external reasons of influence to the volume flow and total volumes in ports of cement plants.

Year 2019 with total of 677 thousand tons of total volume of moved material is the 3rd lowest year in the analyzed period. The next year, year 2020, showed an 24% increase of the total volume moved resulting in 852 thousand tons of total volume of moved material.



Source: www.portsplit.hr(15.01.2022) and internal documentation CEMEX Croatia, made by authors

Graph 2: Total volume at Split area and CEMEX port 2010-2020

Graph 2. presents the total volume moved in the area under the jurisdiction of Port Authority Split (the data for Split area for 2020 was not available). Total volume in Split port area covers the total volume moved through areas within the competence of Port Authority Split (6 basins in total, two of which are considered as CEMEX port)[4]. The graph shows that volume moved through CEMEX port represents a significant part of

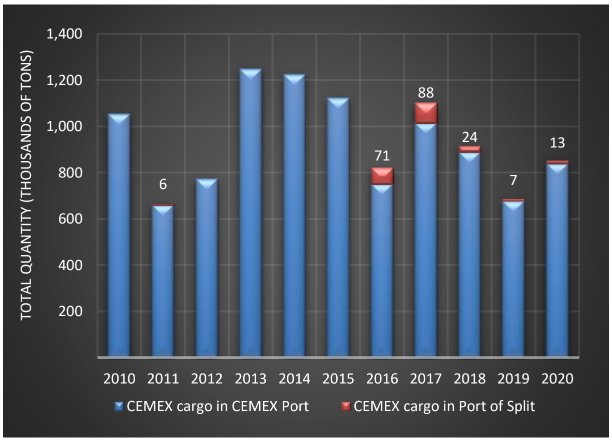
[3] https://portsplit.hr/kastelanski-bazen-c/ (28.12.2021)

[4] https://portsplit.hr/en/split-port-authority/ (28.12.2021)

total volume in Split area making CEMEX port one of the largest port concession holders in the area.

It is evident from the data presented that peaks in total volume moved in Split area correspond to the peaks of total volume moved in CEMEX port. The period of 2013-2015 had yearly volumes over 3 million in total as well as the year 2017 (record year 2014 with maximum volume of 3,2 million tons).

Record year for CEMEX port in analyzed period was 2013 and the total volume of that year represented 40% of the total cargo volumes moved in Split area. In 2014, the record year for Split area, CEMEX port represented 39% of the total cargo volumes moved in Split area. In average, in the analyzed period, CEMEX port represents 32% of the total volume of moved cargo in area under the jurisdiction of Port Authority Split. That is a significant fact due to the area consists of 6 basins of which one basin is a public cargo port[5].



Source: Internal documentation Port of Split and internal documentation CEMEX Croatia, made by authors

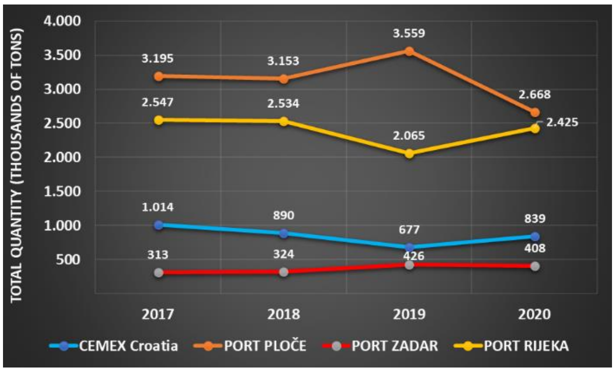
Graph 3: Total volume moved for CEMEX at Split area 2010-2020

CEMEX Croatia sometimes, due to the port restrictions of CEMEX port, uses the public port, Port of Split, for unloading operations and storage of material.

Materials for which CEMEX had used public port are cement, slag, and pet coke. The cooperation started in 2016 and has continued each year since then (6 thousand tons as an exemption in 2011). The maximum volume in the analyzed period was 88 thousand tons moved through public port for CEMEX in year 2017, which represented 9% of the total CEMEX volume moved by vessels that year.

The biggest vessel that ever entered the Split area was unloaded in November of 2021 at Port of Split (public port) for the account of CEMEX; m/v Omishima Island unloaded 40 thousand tons of slag. Record size vessels continued when m/v GDF Suez North Sea arrived at public port in January 2022 with 40 thousand tons of slag for CEMEX.

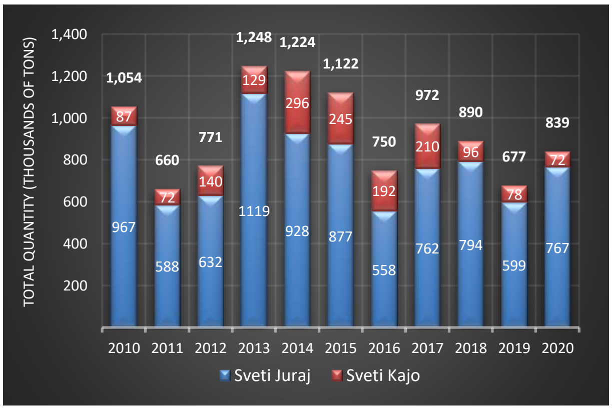
To give some more perspective of the significance of CEMEX port in comparison to other Croatian ports, the analysis of annual volumes has been made as presented in the Graph 4. Port of Ploče and Port of Rijeka are the biggest Croatian ports, and it is evident that CEMEX port has lower annual volumes then them but still having the bigger annual volume than Port of Zadar. Although CEMEX port is not a public port and it is limited to the certain type of materials, the total volume moved through the port position it as a port that generates a considerable volume in the Adriatic cargo movements.



*Source: **Error! Hyperlink reference not valid.**www.port-authority-zadar.hr(20.04.2022), www.lukarijeka.hr(20.04.2022) and internal documentation CEMEX Croatia, made by authors*

Graph 4: Total volume at CEMEX port, Port Ploče, Port Zadar and Port Rijeka 2017-2020

As previously stated, ports of two cement plans, Sv.Juraj and Sv.Kajo make CEMEX port. Graph 5 shows the comparison of material movements in both cement plants' ports. It is evident that Sv.Juraj port has a major part of moved volume, volumes moved through Sv.Kajo port almost never excide the quarter of the total volume of CEMEX port (the exception is year 2016 where Sv.Kajo had 26% of the total volume).



Source: Internal documentation CEMEX Croatia, made by authors

Graph 5: Total volume moved at Sv.Juraj and Sv.Kajo ports 2010-2020

The record volume of Sv.Kajo port in the analyzed decade was 296 kt in 2014 which represented 24% of total volume of CEMEX port that year. Record percentage of volume moved through Sv.Kajo port in

[5] https://portsplit.hr/en/vranjicko-solinski-bazen/ (28.12.2021)

comparison to the total volume was in year 2016, 26% of total volume was moved through Sv.Kajo plant. Sv.Kajo port had the lowest tonnage moved in 2011 and 2020 (72 kt) which represented 11% of total volume in 2011 and 9% of total volume in 2020 moved in CEMEX port. In period from 2012 to 2017 volumes moved through Sv.Kajo port were significant and over 100 kt (2014, 2015 and 2017 over 200 kt).

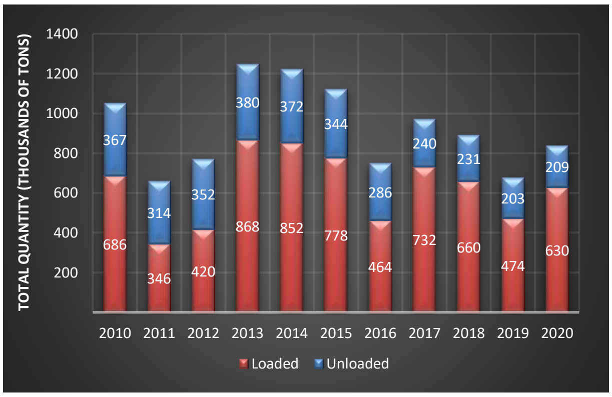
The record volume in Sv.Juraj port was in year 2013 which was the record year for CEMEX port in the analyzed decade; 90% of the total volume has been moved through Sv.Juraj port that year in total of 1.119 kt. Years with the lowest volumes moved through Sv.Juraj ports were 2011, 2016 and 2019; all below 600 kt of total moved volume. The range of total volume moved through Sv.Juraj port is from 550 kt to 1.250 kt which is quite indicative in showing the fluctuating and volatile aspect of the cement producing market.

3. MATERIALS AT SV. JURAJ AND SV. KAJO PORTS

Ports of Sv.Juraj and Sv.Kajo cement plants are both operative ports with material movement which can be considered as the type of the material (product and materials needed for production) as well as the materials shipped, and materials received.

Graph 6 divides the materials and volumes as per the loaded (shipped) and unloaded (received) materials. Cement plant products represent loaded materials (cement and clinker) and materials needed for production represent unloaded materials (pet coke, coal, slag, etc).

In years 2011 and 2012 unloaded volumes were very close to loaded volumes (unloaded volumes represented 48% and 46% of total volume in CEMEX port). In all other years in the analyzed period unloaded materials represent between 25% and 38%. Considering the entire analyzed decade average, loaded materials represent 67% and unloaded materials 33% of the total volume. The simple conclusion of this data is that there is a significant difference between loaded and unloaded volumes. This shows a commercial and supply chain aspects of the port; having more volumes sold and distributed then received for production purposes.



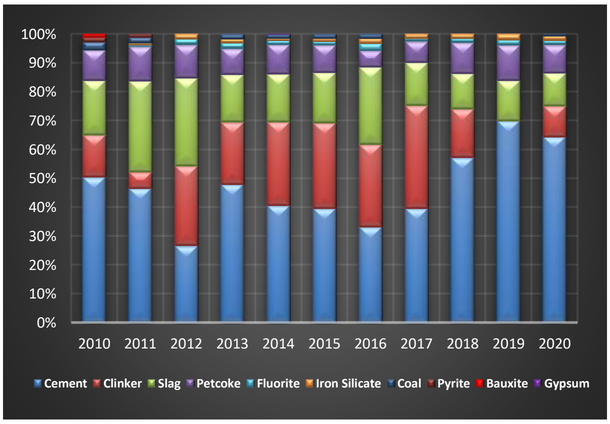
Source: Internal documentation CEMEX Croatia, made by authors

Graph 6: Comparison of loaded and unloaded total volume at CEMEX port 2010-2020

Further analysis by materials represents the specific share of each material represented by percentage of total volume.

Four materials represent major part of all materials in CEMEX port; cement, clinker, slag, and pet coke in average represent 96% of all volume moved through Sv.Juraj and Sv.Kajo ports (their share throughout the period 2010 - 2020 is in range from 94% to 98%).

Cement is a solid material and final product of cement plants. Cement cargos account for about 5% of the world's dry bulk trade.[6] Cement has the biggest share of all materials at CEMEX port in all years except 2012 (that year slag volume represented 30% of all materials while cement volume represented 27%). Cement share in the analyzed decade has a range from 27% (2012) of total volume to 70% of total volume (2019). In average, cement volume represents 47% of total volume in CEMEX port. Major part of cement moved through CEMEX port is bulk cement, bagged cement represents only 3% share of the total volume of cement moved by vessels (bagged cement refers to palletized bagged cement and cement bagged and packed in slings).



Source: Internal documentation CEMEX Croatia, made by authors

Graph 7: Share of each material in total volume at CEMEX port 2010-2020

[6] https://www.hartmann-ag.com/en/business_area/pneumatic_cement_carriers.php (20.04.2022)

Clinker is a solid material and intermediary product of cement plants. It comes in second place considering the average total share in volume of materials moved through CEMEX port in the analyzed period; average share is 20%. Its share varies from 0% (2019) to 36% (2017) throughout the analyzed years. Clinker in CEMEX port is only manipulated as bulk material, designated mainly for export shipments to 3rd parties.

Slag (GBFS – granulated blast furnace slag) is a solid material which is used as a raw material in cement and clinker production process. Analyzed period average share for slag in CEMEX port is 19%; yearly range is from 12% (2017 and 2020) to 31% (2011). Slag in CEMEX port is only manipulated as bulk material and unloaded by shore cranes. The slag volume in Split area ports is larger when considering the volumes moved through public port.

Pet coke (commonly used as an abbreviation for petroleum coke) is a solid material used in cement production process. Pet coke volume remains at almost the same level throughout the decade; yearly range from 6% to 12% generating an average of 10% share in volume of materials moved through CEMEX port in the analyzed period. Pet coke in CEMEX port is only manipulated as bulk material. The pet coke volume as cargo in Split area ports is larger when considering the volumes moved through public port.

All other materials presented in the graph represent the minor share of the total volumes moved through CEMEX port; 4% share of the average of total volume in the analyzed period.

4. VESSELS AT SV. JURAJ AND SV. KAJO PORTS

Port restrictions as well as the shore loading/unloading equipment limit the size of the vessels that can berth at CEMEX port. Depending on the specific berth in CEMEX port, volume per cargo of one shipment can be in range from 500 t to 25.000 t.

Type of vessels calling the Sv.Juraj and Sv.Kajo ports are general cargo vessels and pneumatic cement carriers.

Cement carrier is a bulk carrier provided with a cement loading and discharging system.[7] Cement carriers are loaded by gravity or by pressure from the silo, pneumatic cement carrier is a self-discharging type of vessel, equipped with own compressors and pumps.[8]

The analysis of vessels at CEMEX port has been made considering the size of the vessels and not the materials or destinations of the shipments. Some further analysis considering the final destinations, material and markets would have more commercial aspect of the cement market business which is not the topis of this paper.

Source: (authors)

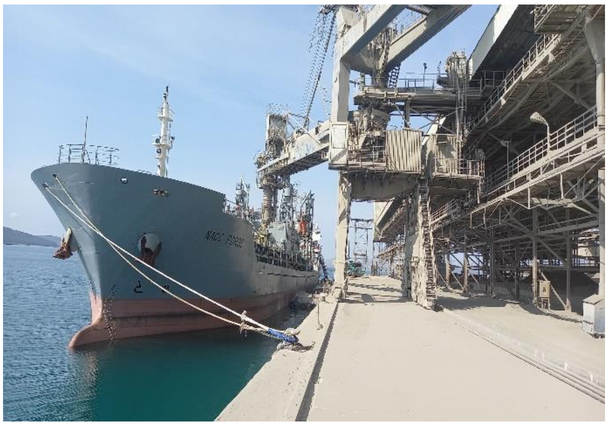
Figure 5: Unloading of general cargo vessel at Sv.Juraj plant using shore crane

Average size of the vessel that calls to CEMEX port in the analyzed period is in range from 2.374 t to 5.905 t, while average vessel size of the entire analyzed period is 3.760 t.

Maximum size of the vessel each year exceeds 17.000 t. The record size vessel of the analyzed period at CEMEX port was in Sv.Juraj plant in year 2018, m/v Harriet loaded 23.542 t of clinker for export to Americas.

Average number of vessels calling at CEMEX port is 255 vessels per year (in range from 190 vessels in 2015 to 318 vessels in 2010). Majority of the vessels are smaller size vessels with cargo volume up to 5.000 t per shipment, they represent the average share of 78% of all vessels in analyzed period (in range from 57% in 2015 to 93% in 2012).

Total number of vessels indicates that the specialized port of cement plants is a quite busy port, more than half of the days in the year with at least one vessel in the port.

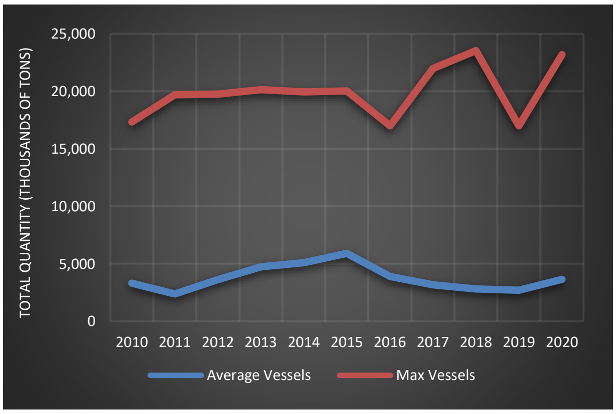


Source: (authors)

Figure 6: Loading of pneumatic cement carrier vessel at Sv.Juraj plant

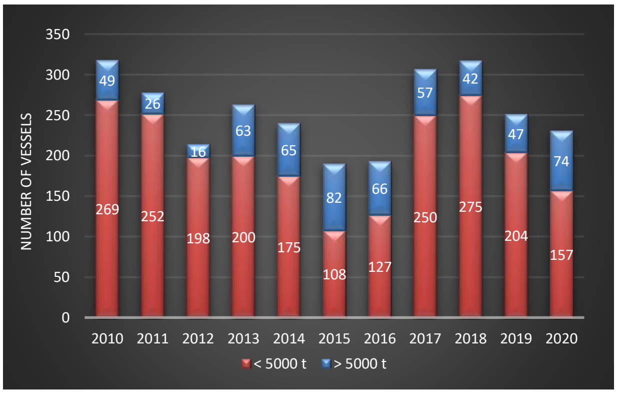
[7] Jurišić, P., Parunov, J. (2021). Structural aspects during conversion from general cargo ships to cement carriers

[8] https://www.hartmann-ag.com/en/business_area/pneumatic_cement_carriers.php (20.04.2022)



Source: Internal documentation CEMEX Croatia, made by authors

Graph 8: Cargo volume per vessel at CEMEX port 2010-2020



Source: Internal documentation CEMEX Croatia, made by authors

Graph 9: Vessels with cargo volume per shipment below and over 5000t at CEMEX port 2010-2020

5. CONCLUSION

Sv.Juraj and Sv.Kajo ports continue to play a significant role at the area under the jurisdiction of Port authority of Split. Although CEMEX port is a specialized port used only for loading and unloading materials directly connected to the cement production process, total volume of cargo moved through CEMEX positions that port at a significant place on Croatian Adriatic map of ports.

Total volume of materials moved through CEMEX port can be an indication of the operational and commercial plans and certainly serves as a significant part of the supply chain of the cement producing company.

Due to the significant part of the volume, cement is one of the major materials moved in the cargo traffic at Split area. Other materials used in cement production process also play an important role in the total cargo movements in the area, especially considering the usage of public port and the arrival of the bigger vessels.

Paper ''Traffic analysis of the ports of Sv.Juraj and Sv.Kajo cement plants'' was published in 2011 with the traffic analysis of the cement plants' ports for the first millennium decade. The conclusions of that paper included the reference to the bagged cement having a small share of the total volume manipulated through the ports and the suggestion has been made to make additional efforts in diversification of materials loaded at cement plants' ports. The material movement analysis of the following decade in this paper showed also a very small share of bagged cement in opposite to the bulk materials loaded in the cement plants' ports. The materials between those two decades did not change, and their share in the total material movement followed the production process.

So, the question arises; what could be the next steps in the development of cement plant ports? The answer is not a simple one, it is closely connected to the commercial plans of the cement producing company as well as the operational investment plans. Also, any change in the port must be made with the cooperation of Split Port Authority, the institution that has jurisdiction for the port area. Nevertheless, some suggestions can be made.

One possible approach could be increasing the size of the average vessels loaded at the cement plants as well as the maximum vessels that can berth the ports. Those plans depend on the commercial plans of the cement producing company and port infrastructure projects.

Second suggestion is diversification of the materials moved through the ports to include the packed goods. Those possible plans also depend on the commercial and procurement plans and cement plant infrastructure projects.

Suggestions have been made not considering the strategic plans of the cement producing company as well as the plans that Port Authority has in relations to the improvement of the Split port area.

At the end, this paper has shown an overview of the volumes and materials, all movements at CEMEX port throughout the last decade. It can be used as a base and data source for possible other research; either cargo movements in Croatia, cement plant ports, or any other topic related to this subject.

The authors will continue to track and analyze the material movements at cement plants' ports, the plan is to have a useful and detailed data base starting from the year 2000. Two papers have already been written based on this database and hopefully there will be some more.

REFERENCES

[1] Macura, A., (2011). Traffic analysis of the ports of Sv.Juraj and Sv.Kajo cement plants. Suvremeni promet: časopis za pitanja teorije i prakse prometa ,31 (pp 124-131), Zagreb, Croatia, Hrvatsko znanstveno društvo za promet

[2] Jurišić, P., Parunov, J. (2021). Structural aspects during conversion from general cargo ships to cement carriers, Brodogradnja/Shipbuilding/Open access, Volume 72 Number 2

[3] www.cemex.hr

[4] www.croatiacement.hr

[5] www.portsplit.hr

[6] www.luka-ploce.hr

[7] www.port-authority-zadar.hr

[8] www.lukarijeka.hr

[9] www.hartmann-ag.com

[10] www.en.wikipedia.org

SITUATIONAL AWARENES FROM THE MASTER POINT OF VIEW AND IMPORTANCE OF FACTORS THAT INFLUENCE IT

Mislav Maljković, M.Eng, Ph.D. Student
Srđan Vukša, M.Eng.
Pero Vidan, Ph.D.
Toni Meštrović, M.Eng.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, 21000 Split, Croatia
mmaljkovi@pfst.hr; svuksa@pfst.hr; pvidan@pfst.hr; tmestrovic@pfst.hr;

ABSTRACT

Situational awareness is knowing your surroundings well at all times. It is a prediction of how incoming situations will affect your vessel. It is critical for all navigators on the bridge watch because everyone must be aware of their surroundings at all times, understand them, and then act properly. Proper situational awareness requires the use of all available resources, our senses and navigational aids. Lack of or inadequate situational awareness has been identified as one of the most significant human factors in accidents. Good bridge team management consists of sharing observations and interpretations with other officers and ratings. We must never assume that other officers saw or understood the situation as well as you did. Master and watchkeeping officer's perspectives on situational awareness may differ due to cultural differences and officer disinterest when the Master is in command. Some officers come from a culture where orders from higher ranks are unchallengeable and therefore are afraid to challenge a higher-ranking officer, especially Master. Therefore, the Master must encourage all officers and ratings to participate in the leadership of the bridge team, as this constantly improves situational awareness. Sharing information and constantly "talking the talk" will ensure that everyone is alert and ready to act in the next situation. A convincing establishment of safety awareness on board can only succeed if all crew members are actively involved. A survey was conducted on the importance of situational awareness and the factors that influence it. Reliability analysis was performed by calculating the Cronbach's alpha coefficient.

Keywords: Situational awareness, Master, Officers on watch, Bridge Resource Management, Human factor

1. INTRODUCTION

Situational awareness is one of the most important human safety factors aboard ship. It is considered critical to successful decision making in a variety of situations. It relates to the protection of human life, marine pollution, collisions, grounding, fire, and explosions. Lack of situational awareness has been identified as one of the major contributing factors to accidents in the maritime industry. Situational awareness can be limited due to:

- fatigue,
- distraction,
- stressful situations,
- high workloads,
- lack of alertness,
- poorly presented information,
- forgetting key information,
- commercial pressure,
- poor mental models,
- inadequately designed equipment,
- lack of training and familiarization with the equipment,
- short period for familiarization and handover,
- lack of training and education [1]- [4].

Situational awareness means being aware of your surroundings at all times. Due to the large amount of information an officer must process, it is not easy to select the important information. A big help in understanding the surrounding better is the sophisticated vessel equipment. The problem is the human factor, which must be familiar with or understand the ship's equipment. Inadequate knowledge and understanding of ship systems and equipment can lead to fatalities. Therefore, seafarers should be familiarized with the proper use of vessel equipment under various and changing conditions. Ship operators must have sufficient knowledge of the required equipment, its capabilities and limitations to avoid and prevent accidents at sea. New modern and complex technologies and automated systems are being introduced very quickly in the shipping industry. It is very difficult to keep up with this new, rapidly growing technology. It is of utmost importance that seafarers receive education and training on the equipment used on board [1]. Understanding the working environment on a ship is necessary to design equipment that meets the actual needs of seafarers in all environments. This is why ship ergonomics and user-friendly equipment are so important. Designing technology can be a challenge to working safely and efficiently on board. In the maritime industry, the design of marine equipment is not standardized and can vary from ship to ship.

As a result, seafarers often have to familiarize themselves with equipment they were not previously familiar with shortly after embarkation. They must do this as soon as possible, which causes stress and fatigue and reduces situational awareness [1], [2]. The handover is usually short and insufficient because time is short in ports. It depends on the training background of the officer, with the same or similar ship and/or equipment [3]. Crew changes on board are completed very quickly due to commercial pressures, leaving no room for proper handover and familiarization with the equipment.

2. SITUATIONAL AWARENESS AND USE OF MODERN TECHNOLOGIES

Situational awareness from the Master's and officer's point of view may be different. It also depends on the age of the seafarers. Twenty years ago, there was not much interaction between people and modern technologies, but today the situation has changed rapidly with the advent of modern technology. Before modern technology became prevalent on ships, officers relied more on visual lookout and the use of RADAR. Nowadays, officers rely on modern technology and the use of ECDIS and forget about visual observation. Visual observation is still the most important aspect for situational awareness, but the new generation of officers has grown up with modern technologies and simply forgets about "looking through the window", not because they are not trained to do so, but because it is simply their way of understanding navigation and the situation around them. On the other hand, there is another problem with "older Masters" who cannot keep up with the rapidly growing modern technologies. Some Masters have difficulty operating ECDIS and other sophisticated equipment that is being adopted with ease by the younger generation. The positive aspects of modern technologies include reducing workload and fatigue in environments not suitable for humans, improving human performance limits, and handling routine tasks more accurately. The problems with modern technologies include lack of manual skills, ineffective equipment monitoring, equipment overload, overlying on equipment, failure of equipment and poor situational awareness. Electronic navigation has been introduced on ships to improve safety through better situational awareness, but bridge watch standards have been eroded due to various factors [5], [6]. The recent accident in which the MT "Atina" collided with the oil/gas platform SP-57B was the result of poor bridge watch standards. The Master had poor or no situational awareness due to commercial pressure, short handover, lack of familiarization with bridge equipment, fatigue, stress, and poor bridge watch standards [7].

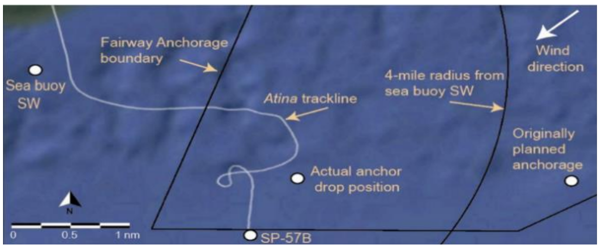


Figure 1: Mt "Atina" route taken from VDR data [7]

Most officers do not have practice in maneuvering the ship and steering because the ships operate on autopilot. Officers rely on bridge equipment without checking the situation with all available reliable sources, forgetting visual observation. The result is poor situational awareness, the consequences of which can be catastrophic. Modern integrated bridge systems provide all the data required for navigation from all available sources (AIS, VDR, GPS, RADAR, ECDIS), which are of utmost importance for situational awareness [8]. Officers must monitor and understand the information from the sources and use this collected information for situational awareness to make timely decisions. Despite integrated navigation systems and modern technologies, many accidents still occur. The most common reason is the reduction in the number of crew members on board due to the increase in modern technologies [9]. The result is increased workload, fatigue and stress, which overall significantly reduces situational awareness despite all the available technologies. Modern technology and traditional navigation aspects (visual observation, hearing, etc.) must complement each other. One of the primary roles of the officer of the watch (OOW) is to safely navigate the ship and keep it on the planned course. He is the one who decides on the course of action to avoid collisions. OOW must have adequate skills to implement the COLREGs (International Regulations for Preventing Collisions at Sea) [9]. It is of paramount importance for the Master to do everything possible to ensure that the OOW achieves satisfactory situational awareness. This can be achieved by an open approach to the officer, with knowledge, a sense of responsibility, and willingness to help.

3. FACTORS WHICH DECREASE SITUATIONAL AWARENESS AND SHARED SITUATIONAL AWARENESS

Most accidents at sea, such as groundings and collisions, are due to fatigue followed by stress. When navigating at sea, the proper action must be taken at the right time to avoid dangerous situations. The bridge team should use modern technology on the bridge and visual observation to decide when to take proper action. When the OOW is under stress, his or her awareness of the surrounding is reduced or ignored, and he or she may fail to take the proper actions to avoid an accident. The OOW must process a given amount of available information in a given amount of time, using all available resources (ARPA, ECDIS, AIS, VHF, etc.). Under stress, the time to gather such useful information is shortened, officers are unable to manage the situation, and the consequences are poor or delayed decisions that lead to errors that can contribute to accidents [10], [11]. Safety is of paramount importance in the shipping industry, which is why the shipping industry is making more efforts to address fatigue on board. A broader definition of fatigue is the subjective experience of a person who is forced to continue working after reaching a point where they are certain they can no longer perform the task efficiently.

Adequate manning on board is critical to managing fatigue, stress and increase situational awareness. That is, there must be enough personnel on board so that the work can be distributed wisely without overburdening anyone. This is a very difficult task today, as shipping companies are reducing crew and attributing this to modern technologies on board. But they all forget or refuse to acknowledge that with the advent of technology, onboard management has increased significantly and that this, along with other factors, is the main reason for fatigue and stress onboard, which have a significant negative impact on situational awareness [12], [13].

The concept of shared situational awareness has emerged in the military industry as a basis for new ideas in the organization of military personnel. The term Shared Situational Awareness is not defined, but it is possible to create a definition and develop objective approaches for studying processes in which shared situational awareness is created. Shared situational awareness in the military industry means providing a clear, accurate, common, and relevant picture of the battlefield to commanders at all levels and reducing potential human casualties [14]. Shared situational awareness could be used in the maritime industry as part of bridge team management on the navigation bridge. Individual situational awareness is different from group situational awareness. Individual observation and understanding of the situation, task, and objectives can sometimes differ significantly from the understanding of other bridge team members. Individual situational awareness is based on the idea of knowing what is going on - what might happen - what the options are. Individual situational awareness is a personal characteristic of each individual. It depends on our cultural background, education and experience. The limitations of our senses are particularly important to situational awareness because some people are better observers than others, and this trait affects an individual's ability to develop situational awareness. Shared situational awareness differs from individual situational awareness in that it involves a number of individuals trying to form a shared picture of the situation. In any given situation, these individuals have their own individual situation awareness that exists in their minds. They need to share their individual situation awareness with all team members so that they can create a shared situation awareness to best accomplish the task. To create shared situational awareness, team members must develop individual situational awareness of the situation to be managed, share their individual situational awareness with other team members, and develop a common (shared) situational awareness. Building shared situational awareness is very easy because we do it all the time based on our experience and knowledge. However, when we build situational awareness to share with others, to create shared situational awareness, the individual situational awareness must be based on a common foundation such as knowledge, experience, and assumptions. The other element, sharing individual situational awareness, is essentially each individual communicating effectively with other team members. The third element in building shared situational awareness is the interaction of the various individual mental models of the situation. The Master should encourage all officers to share their situational awareness because communication is critical to the management of the bridge team [14]- [18]. The Masters and officers have different perceptions of situational awareness, which can be for a number of reasons. When the Master is on command, some officers are relaxed and have a poor perception of situational awareness and do not participate in the management of the bridge team, especially if the officers are from culturally different countries where they do not question the Master or the authority of higher ranks. The Master must encourage all officers to participate in the leadership of the bridge team and challenge him each time they feel it is necessary. In addition, the Master must explain to each officer what he expects of him during the navigation watch. Since good bridge team leadership and management consists of sharing observations and interpretations with other officers and ratings, the Master must encourage officers and ratings to share their perspectives, even if they have less experience than the Master. Their individual situational awareness and the Master's individual situational awareness form a group or shared situational awareness of the current situation so that a timely and accurate response to the situation is possible. It is important to share information or simply "talk" to reduce stress due to fatigue and other related factors. Constant "talking" on the bridge and sharing information keeps everyone awake and alert, especially the Master. Silence, i.e. poor communication is the most dangerous thing on the bridge and we must always try to avoid it.

4. METODOLOGY

The questions presented in this study are the second part of a situational awareness survey conducted in 2021. The first part of the survey was presented in the article "Situational Awareness - Key Safety Factor For The Officer Of The Watch" [8]. This part of the survey shows the importance of modern technologies, shore and shipboard training, and the use of training simulators to maintain the required level of situational awareness. 94 deck and engine officers of various age groups and different ship types participated in the survey. Importance was rated with scores from 1 - 5, where 1 was not important and 5 was very important. The questions are:

1. How important is the experience gained at sea to achieve a high level of situational awareness?
2. Rate the importance of training (shore, shipboard, STCW, and specific training) in achieving a high level of situational awareness.
3. Evaluate the importance of navigation/maritime practices and the use of training simulators at maritime schools, academies, and training centers in achieving a high level of situational awareness.
4. Evaluate the importance of modern technologies and ship autonomy in improving officer's situational awareness.
5. Evaluate the importance of situational awareness as a key safety factor for officers and ship crews.

Reliability analysis was performed by calculating Cronbach's alpha coefficient. The Cronbach's alpha coefficient evaluates the internal consistency of the questionnaire. The alphas can range from 0 to 1.0, as shown in Figure 2.

Cronbach's alpha	Internal consistency
α ≥ 0.9	Excellent
0.9 > α ≥ 0.8	Good
0.8 > α ≥ 0.7	Acceptable
0.7 > α ≥ 0.6	Questionable
0.6 > α ≥ 0.5	Poor
0.5 > α	Unacceptable

Figure 2: Cronbach's alpha consistency [19]

Internal consistency measures how well all questions in a scale are correlated with each other, and high correlations between items indicate that all questions measure the same factor of interest [20].

The reliability test in this study uses the Cronbach alpha formula to calculate scale data at multiple levels [21]:

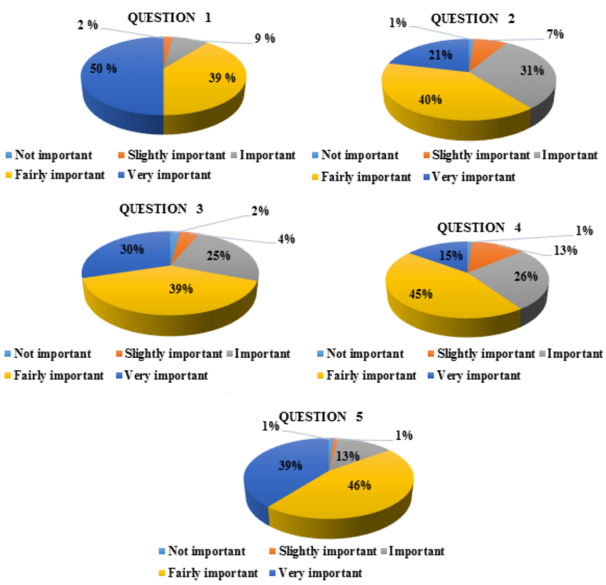
$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K}\sigma_{Y_i}^2}{\sigma_X^2}\right) \qquad (1)$$

where α is Cronbach's alpha coefficient, K is number of items/questions, $\sum_{i=1}^{K}\sigma_{Y_i}^2$ is number of variants of the item and σ_X^2 is number of total variances.

5. SURVEY RESULTS, CRONBACH'S ALPHA TEST AND DISCUSSION

From the survey results, we can conclude that situational awareness is an important factor for all deck and engine officers, regardless of age or seagoing experience. All candidates agreed that situational awareness is quite important or very important in shipping and that experience at sea, training on board and ashore, training simulators, and the use of modern technologies increase the situational awareness of officers on board. 71% of the respondents were deck officers, which is very important because most accidents on board, such as collisions and groundings, are due to poor or no situational awareness on the part of deck officers. Question number one indicates that experience gained at sea is very important in achieving a high level of situational awareness. For question number two, only 21% of respondents believe that training (shore, shipboard, STCW, and specialized training) is important to achieving a high level of situational awareness. This could be due to the fact that no shore or shipboard training can replace the practical skills learned on the ship. To this conclusion can be added question number three, in which respondents consider simulators to be very important for situational awareness at 30%. In question number four, respondents do not consider modern technologies and ship autonomy to be very important in improving officer's situational awareness. This could be because visual observation is still the most important aspect of situational awareness. 39% of respondents in question number five consider situational awareness to be a very important safety factor for officers and ship's crews.

The results of the survey are shown in Figure 3.



Source: Authors

Figure 3: Survey results

Reliability analysis was performed by calculating the Cronbach's alpha coefficient, as shown in Table 1.

Table 1: Cronbach's alpha analysis results

GP 1	GP 2	GP 3	GP 4	GP 5	GP 6
0.79	0.62	0.74	0.82	0.82	0.87

Source: Authors

For the 6 groups, the Cronbach's alpha coefficient was calculated as follows:

- Group 1 (GP 1) - All respondents,
- Group 2 (GP 2) - Top 4 Officers (Masters, Ch. Eng., Ch. Off. and 1 A/E,
- Group 3 (GP 3) - Masters and Ch. Eng.,

- Group 4 (GP 4) - Junior Officers,
- Group 5 (GP 5) - Engine Officers and,
- Group 6 (GP 6) - Deck Officers.

Table 1 shows that the internal consistency of the survey conducted is good. All respondents recognized the importance of situational awareness and asked about the factors that influence it. For GP 2 and 3, the consistency is questionable or acceptable. The reason could be the small number of respondents and the difference in perception of situational awareness between Masters and Ch. Eng. Training and education on simulators for engine officers is more complex and engineers (Ch. Eng.) do not recognize this as an important factor in improving situational awareness.

6. CONCLUSION

There is no doubt that situational awareness in the maritime industry is one of the key factors in preventing accidents and generally one of the most important aspects of safety. Officers who have a high level of situational awareness can very easily find a solution to a situation with the help of modern technologies. The survey found that all deck and engine officers consider situational awareness to be one of the most important safety aspects in shipping and agree that training on board and ashore, as well as the use of modern technologies, help to achieve a high level of situational awareness. Despite very good results of ship officers in terms of situational awareness, shipping accidents still occur. The International Maritime Organization (IMO) has addressed this problem through numerous conventions, rules and regulations, but unfortunately the organizations cannot keep up with the rapidly growing maritime industry. The introduction of modern technologies on ships led to a reduction in the number of crew members but an increase in management, which increased the workload. And this could be one of the factors negatively affecting situational awareness. The main goal of shipping companies is profit, without regard to safety, which pushes crews to the limit of exhaustion. Poor training and education, short handover and familiarization, failure to follow the ship's matrix can lead to serious accidents at sea. The future problem for shipping companies is the rapidly growing demand for natural gas carriers (LNG ships). This fast-growing demand is not easy to meet, and it takes time to find qualified ship personnel. Cruise lines were the hardest hit by the COVID pandemic, and many seafarers lost their jobs and had to find work on merchant ships. However, the demand on merchant ships are completely different, and seafarers must undergo additional training for new employment. Qualified personnel cannot be trained as fast as the demand for new ships increases. And that is always a burning issue in the shipping industry. The shipping industry will certainly continue to grow in the coming years, and with it the demand for seafarers. Great attention must be paid to training seafarers with modern technologies. Familiarizing seafarers with modern technologies while reducing the number of crew members is not the best solution, because seafarers will have to keep an eye on several things at the same time, which could lead to fatigue and increased stress, which in turn could have disastrous consequences. Shipping companies and maritime organizations need to work together and find the best way to ensure safe and efficient operations at sea.

REFERENCES

[1] T. Bielić, N. Hasanspahić, and J. Čulin, "Preventing marine accidents caused by technology-induced human error," *Pomorstvo*, vol. 31, no. 1, pp. 33–37, 2017, doi: 10.31217/p.31.1.6.

[2] H. P. Berg, "Human Factors and Safety Culture in Maritime Safety (revised)," *TransNav, Int. J. Mar. Navig. Saf. Sea Transp.*, vol. 7, no. 3, pp. 343–352, 2013, doi: 10.12716/1001.07.03.04.

[3] P. Vidan, T. Dlabač, and G. Jerković, "Familiarisation Aboard Ships of Croatian and Montenegrin Officers," *Trans. Marit. Sci.*, vol. 4, no. 2, pp. 113–118, 2015, doi: 10.7225/toms.v04.n02.002.

[4] P. Vidan, S. Vukša, and T. Dlabač, "Practice of and attitudes toward familiarisation on board: Survey of Croatian and Montenegrin maritime officers," *Brodogradnja*, vol. 69, no. 3, pp. 97–110, 2018, doi: 10.21278/brod69306.

[5] K. Pazouki, N. Forbes, R. A. Norman, and M. D. Woodward, "Investigation on the impact of human-automation interaction in maritime operations," *Ocean Eng.*, vol. 153, pp. 297–304, 2018, doi: 10.1016/j.oceaneng.2018.01.103.

[6] P. N. Hansen *et al.*, "COLREGs-based situation awareness for marine vessels - A discrete event systems approach," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 14501–14508, 2020, doi: 10.1016/j.ifacol.2020.12.1453.

[7] NTSB, "Contact of Tanker Atina with Oil and Gas Production Platform SP-57B," 2021.

[8] H. Jaram, P. Vidan, S. Vukša, and I. Pavić, "Situational Awareness – Key Safety Factor For The Officer Of The Watch," in *Pedagogika-Pedagogy*, 2021, vol. 93, no. 7s, pp. 225–240, doi: 10.53656/ped21-7s.20situ.

[9] B. K. Taha Talip TÜRKİSTANLI, "Training situational awareness and decision making for preventing collision at sea," *Mersin Univ. J. Marit. Fac.*, vol. Vol. 1, Is, no. March, pp. 10–16, 2019.

[10] G. A. Psarros, "Comparing the navigator's response time in collision and grounding accidents," *Proc. Int. Conf. Offshore Mech. Arct. Eng. - OMAE*, vol. 3, 2015, doi: 10.1115/OMAE201541001.

[11] B. K. Towns, "Situational Awareness in the Marine Towing Industry Boris," Rochester Institute of Technology, 2007.

[12] M. J. Akhtar and I. B. Utne, "Human fatigue's effect on the risk of maritime groundings - A Bayesian Network modeling approach," *Saf. Sci.*, vol. 62, pp. 427–440, 2014, doi: 10.1016/j.ssci.2013.10.002.

[13] G. A. Psarros, "Bayesian Perspective on the Deck Officer's Situation Awareness to Navigation Accidents," *Procedia Manuf.*, vol. 3, pp. 2341–2348, 2015, doi: 10.1016/j.promfg.2015.07.381.A. Nofi, "Defining and Measuring Shared Situational Awareness," in *PloS one*, vol. 5, 2000, p. 76.

[14] P. P. Perla, M. Markowitz, A. Nofi, C. Weuve, J. Loughran, and M. Stahl, *Gaming and Shared Situation Awareness*, no. November. 2000.

[15] H. Sandhåland, H. Oltedal, and J. Eid, "Situation awareness in bridge operations - A study of collisions between attendant vessels and offshore facilities in the North Sea," *Saf. Sci.*, vol. 79, pp. 277–285, 2015, doi: 10.1016/j.ssci.2015.06.021.

[16] H. Seppänen and K. Virrantaus, "Shared situational awareness and information quality in disaster management," *Saf. Sci.*, vol. 77, pp. 112–122, 2015, doi: 10.1016/j.ssci.2015.03.018.

[17] N. A. Stanton, P. R. G. Chambers, and J. Piggott, "Situational awareness and safety," *Saf. Sci.*, vol. 39, no. 3, pp. 189–204, 2001, doi: 10.1016/S0925-7535(01)00010-8.

[18] STATS-U, "How do we assess reliability and validity?," *September 27*, 2020. https://sites.education.miami.edu/statsu/2020/09/27/how-do-we-assess-reliability-and-validity/.

[19] E. Zarei, I. Mohammadfam, M. M. Aliabadi, A. Jamshidi, and F. Ghasemi, "Efficiency prediction of control room operators based on human reliability analysis and dynamic decision-making style in the process industry," *Process Saf. Prog.*, vol. 35, no. 2, pp. 192–199, 2016, doi: 10.1002/prs.11782.

[20] I. Lestari, A. Maksum, and C. Kustandi, "Mobile learning design models for State University of Jakarta, Indonesia," *Int. J. Interact. Mob. Technol.*, vol. 13, no. 9, pp. 152–171, 2019, doi: 10.3991/ijim.v13i09.10987.

PETRI NET MODEL OF AHTS/PSV SUPPLY VESSEL AND CREW BOAT USABILITY IN NORTH ADRIATIC ON GAS FIELD IVANA

Toni Meštrović, M.Sc..
Danko Kezić, Ph.D.
Mislav Maljković, M.Sc.
Marina Laušić, Mag. Math.
University of Split, Faculty of Maritime Studies,
Ruđera Boškovića 37, 21000 Split, Croatia
tmestrovi@pfst.hr, danko.kezic@pfst.hr, mmaljkovi@pfst.hr, msarac@pfst.hr,

ABSTRACT

The demand for gas is increasing every day in all European countries. Therefore, the number of gas production platforms is also increasing. In Croatia, the most important gas field is 'Ivana', located in the northern Adriatic Sea. In this paper Petri nets and 'Yasper' tool are used to simulate the dynamic process of supply and operation of vessels. The simulation depends on the wind and wave conditions in the northern Adriatic Sea and the type of work performed by the supply vessel and crew boat in cooperation with the Ivana gas field. The input data are: Sea state and wind conditions in the northern Adriatic near the Istria peninsula, fuel consumption, type of vessel operation, distance between the port of Pula and the Ivana gas field, and the number of daily departures of vessels from the port. The report presents a model of discrete events in the process of supplying the Ivana gas field, leaving the Port of Pula until the completion of the works around the Ivana gas field and returning to the Port of Pula. The report can provide information about the usability of the vessels and the approximate costs of the supply vessels and crew boat on a voyage from the port of Pula to the Ivana gas field and back.

Keywords: Supply vessel, crew boat, petri net, process model, gas field Ivana

1. INTRODUCTION

The gas industry and the search for gas fields is an extremely important industry. Gas fields located at sea must provide all the necessary material for the search and exploitation of gas from the mainland. The most convenient way to supply platforms is by supply ships that bring everything they need from the mainland, which is one of the most expensive factors in the gas industry's logistical supply chain. In most cases, the vessels are not owned by the gas companies and are rented for a specific period of time. The number of vessels used in a gas field depends on the type of work and the number of platforms in the field. The use of vessels is also influenced by weather conditions and the state of wind and waves.

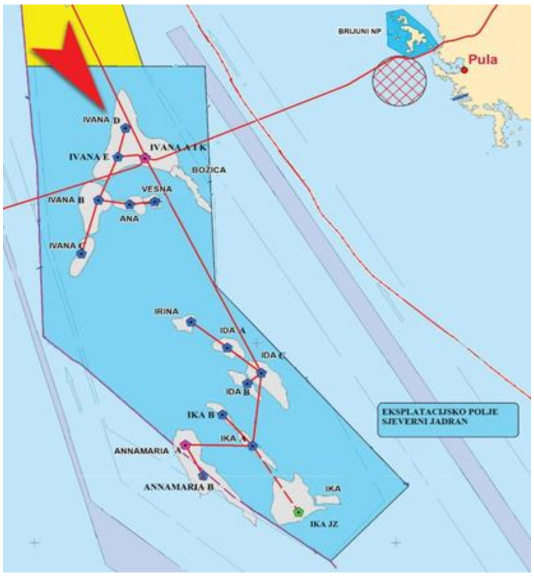
There are several gas fields in the Republic of Croatia, the most important of which is the "Ivana" gas field. It is located near the port of Pula and vessels travel daily between the port and the platforms on the gas field.

In this paper we present a model created with the help of Yasper tools in Petri nets. In the model we included 4 vessels that supply the platforms on the Ivana gas field. The input data are the consumption of the vessels and the state of wind and waves. Based on the input data, the model processes the data and provides us with output data such as the daily cost of the vessels, the number of voyages that were not made due to weather conditions, and the usability of the vessel. The model also contains data on the duration of the works and calculates the time needed to travel to the gas field and back to the port of Pula.

The model can be applied to any gas or oil field, it is only necessary to take into account the weather conditions, the type of work around the platforms in the field, the number of vessels, the consumption of the vessels and the distance of the field from the port.

2. GAS FIELD “IVANA”

The gas field "Ivana" is located in the northern Adriatic Sea and is about 26 nautical miles away from the port of Pula, or if we convert into kilometers, 48.152 km. It is extremely important for the gas supply of the Republic of Croatia. Normally, four vessels work on it, namely two supply vessels and two crew boats. The platform "Ivana" is located on the Ivana gas field, and besides the Ivana field in the northern Adriatic, there are the following fields: Ida, Ika, Anamaria, Ana, Izabela, Vesna, Marica and Katarina. Most of these fields have platforms and are supplied by ships from the mainland.



Source: https://www.zvono.eu/foto.php?foto=140996&z=

Figure 1: Croatian gas fields in Northern Adriatic

Research in these areas began in the 1960s. In 1968, the history of hydrocarbon exploration in the entire Croatian part of the Adriatic Sea began when the seismic survey vessel "Vez (Baltus & Rubbers, 1999)" carried out the first exploration [2]. The Ivana gas field was discovered in 1973 with the well 'Jadran -6' [3]. By 2000, 116 wells were drilled and 75.000 km of 2D seismic exploration was conducted [4].

Source: https://www.zvono.eu/foto.php?foto=140997&z=9089

Figure 2: Platform „Ivana"

3. VESSELS IN THE SUPPLY OF THE "IVANA" GAS FIELD

To operate from remote locations, offshore drilling and production platforms require various types of support services provided by specialized vessels. Examples of such vessels are Anchor Handling Vessels, Offshore Supply Vessels (OSVs), Crew Boats and Standby/Rescue vessels [5]. The number of vessels depends on the size of the field and the number of platforms located in a field. For the "Ivana" gas field, 4 vessels, two crew boats, one AHTS and one OSV are in operation. The ships operate between the port of Pula and the gas field and we have included them in the model.

3.1. Crew boat

Crew boats transport crew from platform to shore and from shore to platform. They are much smaller than supply vessels and do not carry large cargo, but only smaller pallets of cargo. The most important feature of these vessels is their speed. Newer generation crew boats, called Fast Supply Vessels (FSV) can also carry very limited amounts of supplies and as such are often used for emergency or time sensitive deliveries of supplies in addition to transporting crews [5].

Source:http://www.brodospas.net/Flota/CREWBOAT/Junak/tabid/155/Default.aspx

Figure 3: Crew boat „Junak"

In our model we included the crew boat "Junak" (Figure 3), which sails on the route between the Ivana gas field and the Port of Pula. Based on the survey of the consumption of the crew boat in 2014, the owner of the "Brodospas" provided the average consumption of the crew boat "Junak". The ship normally sails at a speed of twenty knots and we have included this speed and consumption in the model (Table 1).

Table 1: Average consumption of crew boat

SPEED Kn	CONSUMPTION lit/h
15.9	230.5
18	327.6
20	422.7
22	518.6
23.2	590.3

Source: „BRODOSPAS "fuel consumption

3.2. Supply vessels

Basically, supply vessels are used to transport supplies back and forth between the supply base and the facilities [6]. Cargo is transported both ways because the platforms do not have much storage space and cargo not needed on the platform is transported back to the mainland to the warehouses. The demand on the rigs can be divided into six different cargo categories: Deck cargo, bulk cargo, mud, brine, diesel, and water [7]. Supply vessels are not as fast as crew boats, but have a much larger deck for a variety of cargoes and have large tanks in which they carry oil and water to the platform.

The basic division is into AHTS (Anchor Handling Vessels) and OSV (Offshore Supply Vessels), so we have included them in the model. The main difference is in the work, because AHTS have a large winch with which they can lift the anchors of the platform and thus move them.

Source:http://www.brodospas.net/Fleet/ANCHORHANDLINGTUGSUPPLYVESSELS/BrodospasAlfa/tabid/150/Default.aspx

Figure 4: Supply vessel „Brodospas Alfa "

In the model we have included the supply vessel "Brodospas Alfa" (Figure 4), which operates on the route between the port of Pula and the Ivana gas field. Based on the orders executed in the model, the fuel consumption is entered. (Table 2). The consumption data comes from a survey conducted by Brodospas, the owner of the supply vessel.

Table 2: Average consumption of the supply vessel "Brodospas Alfa"

TYPE OF WORK	CONSUMPTION lit/h
Working with anchors	1500
Navigation	950
Work under platform	650
Navigation near platform	370

Source: „BRODOSPAS "fuel consumption

4. STATE OF WIND AND WAVES IN THE NORTH ADRIATIC

The Adriatic Sea is a small adjacent sea of the Mediterranean. Its northern part, which is the shallowest, extends deep into the European continent [8].

In this area, the most common winds are the bora and the jugo. The Jugo, the wind from the southeast direction, generates the largest waves.

Measurements and analyzes show that waves with significant wave heights of more than 4 meters are possible in the Adriatic Sea [9]. The largest wave measured in the Adriatic Sea was recorded from a platform in the northern Adriatic and had a wave height of 10.8 meters [10].

Table 3: Scale of sea conditions in the Adriatic

Beaufort scale	WMO	H- Wave height	%
0	0	-	10
1	1	1.6	24.6
2	2	2.7	
3	3	3.7	43.0
4		4.6	
5	4	5.4	17.2
6		6.2	
7	5	6.9	4.2
8		7.6	
9	6	8.3	1.0
10		9.0	
11	7	9.7	0.01
12		10.4	

Source: Maritime encyclopedia

These values are consistent with the analysis of significant values of sea state in the work of Leder [10], in which a maximum significant wave height of 8.57 m was calculated for the northern Adriatic by applying the extreme value theory based on measured data from platforms in the northern Adriatic. The table shows that only slightly more than 1% of the waves are larger than 8.3, and the most frequent waves are between 3.7 m and 4.6 m high.

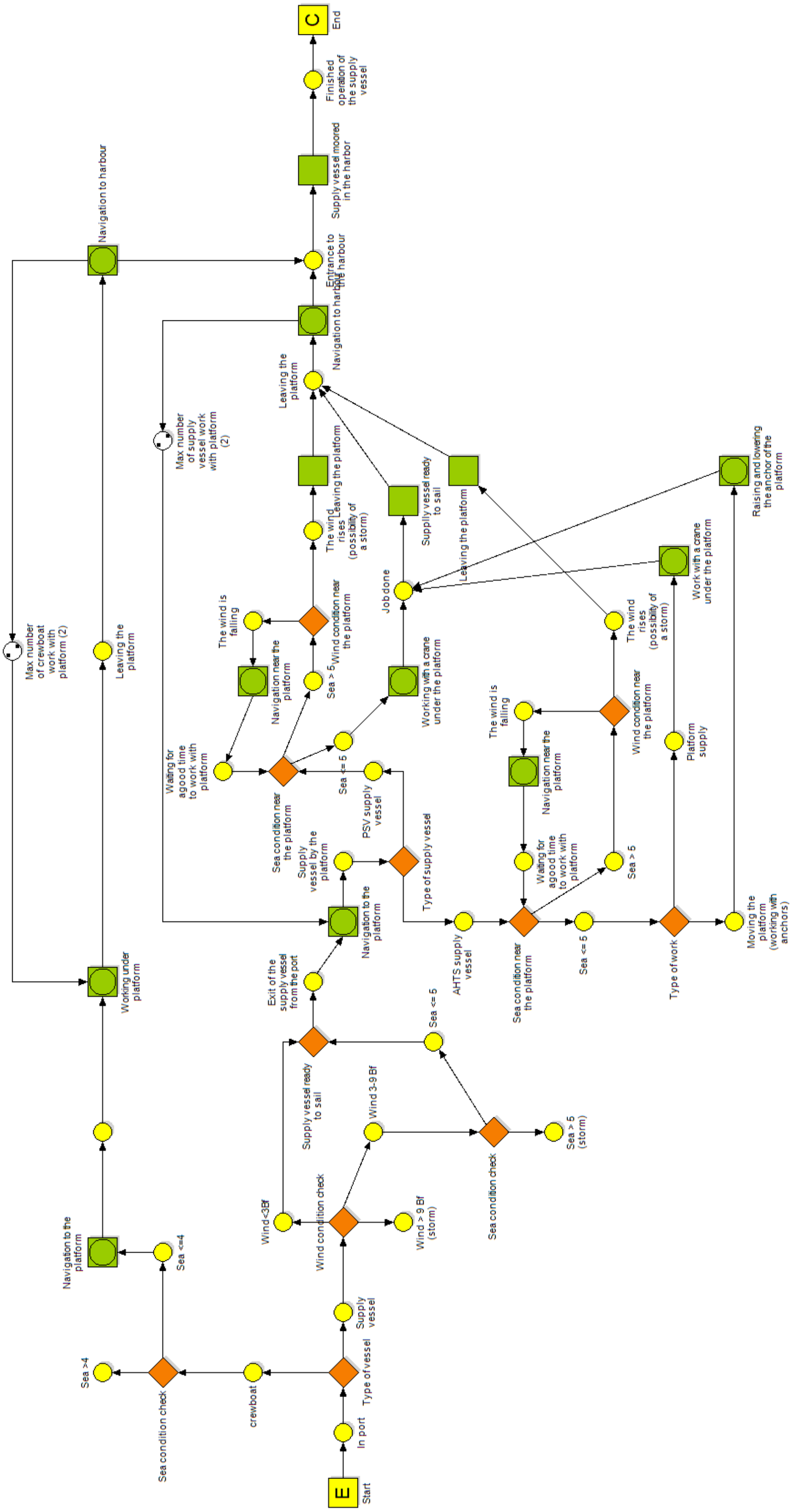
Within the model, we included sea state in four places and wind state in three places with the values given in the table. We entered the data from the percent column into the model.

5. PETRI NET MODEL

Petri nets are a graphical method for modeling dynamic systems to analyze their behavior under various conditions. They are named after their inventor, Carl Adam Petri, and are mainly used for modeling, simulation and analysis of dynamical systems with discrete events [11]. Definition a Petri net consists of a place, a process step, and an arc. Arcs go from place to process step or vice versa, never between places or between process steps.

We used colored Petri nets for the model. Their advantage is the different colors within the model, which make the model visually more beautiful. The main reason for the great success of this type of mesh models is that they have a graphical representation and a well-defined semantics that allows formal analysis [12].

The production scheduling problem is to assign tasks to limited resources over a period of time and to sequence the operations to meet system constraints and optimize performance criteria. One approach to this problem is to use Petri nets in conjunction with other methods [13].



Source: Author – Yasper

Figure 5: Petri net model

We created the model using the Yasper modeling tool. Yasper puts the modeling of Petri nets in the hands of business analysts and software architects. They can specify systems in familiar terms (XOR choice, workflow, cases, roles, processing time, and cost) and directly run manual and automatic simulations with the resulting models to analyze correctness and performance [14].

Our model (Figure 5.) describing the process of supplying the Ivana gas field with supply vessels and crew boats can be divided into two parts. In the first part, we include the number of vessels in the model that supply the Ivana gas field. We included 4 vessels in the model, two crew boats, one AHTS and one OSV. We assume that the number of daily departures is 4, i.e. every 6 hours. The model contains the restriction that no more than two vessels can be on the platform at the same time. Then we consider wind and waves, i.e. the percentage of wind and waves at sea between Pula and Ivana gas field. The crew boat does not sail if the sea state is greater than 4. The supply vessels sail out of the port when the wind is less than 3 and stay in the port when the wind is greater than 9. When the wind is greater than 3 and less than 9, the sea state is checked. If the sea state is greater than 6, the supply vessels stay in port, and if the sea state is less than 6, they put to sea. The data on wind and waves were included in Table 3.

The second part of the model relates to voyage to and from the gas field and the type of work that the supply vessels do near the gas field platforms. The distance between the Ivana gas field and the port of Pula is 26 nautical miles. For the fuel price, we applied $ 1.0249 per liter, which corresponds to the price of 3.2.2022 [15]. In the model, we considered that the crew boat travels to the gas field at a speed of 20 knots and the supply vessels travel at 13.3 knots. For the work around the platform, we included data on the consumption of the supply vessels (Table 2) and the crew boat (Table 1). Using the model for the supply vessels, we again check the wind and wave conditions near the platform. If the sea state is greater than 5, the supply vessels cannot operate near the platform. For the voyage from the Ivana gas field to the port of Pula, we considered the same data as at the beginning of the model for the voyage to the gas field.

6. RESULTS

The time period in the model is 720 hours or one month. We chose a period of one month because the vessels used to supply the platform are usually rented for months. The simulation sent 121 events in 721.3 times and ran a simulation of 107 events (Table 3). This showed that 14 events were not completed and 13 ships did not sail to the platform due to weather conditions. One vessel remained in the model as if it were standing on a platform. Of the 13 ships that did not set sail due to bad weather, 11 were crew boats and 2 were supply vessel. Since we simulated 4 voyages per day, this gives an average of slightly less than three bad weather days per month for a crew boat voyage to the Ivana gas field and half a day for a supply vessel voyage. If we convert the data into percentages, we arrive at the data that the weather affects the crew boat 18.33% and the supply vessels 3.33%.

The data we have obtained would be more accurate if we had the ability to include weather conditions for each season, or better yet, if we had weather conditions on a monthly basis. There would certainly be fewer days in the summer when shipping would be affected, but there would certainly be more days in the winter.

Table 3: Number of departures

Time elapsed	#generated	#completed
721.3	121	107

Source: Author – Yasper

Fuel costs average $3966.48 per voyage from port of Pula to Ivana gas field and return. The average time for one trip is 6.1 hours (Table 4).

Table 4: Work time and costs

Work time	Cost
6.1	3996.48

Source: Author – Yasper

In the model we have considered that two hours of work are done on the platform, and the results are based on these values. If you look only at the results of the crew boat (Table 5), its voyage takes on average 4.6 hours and the fuel cost is $1265.18 per voyage. Its tasks are not as demanding and its fuel consumption is lower, so the cost is below average.

Table 5: Work time and costs of crew boat

Work time	cost
4.6	1265.18

Source: Author – Yasper

Fuel costs for supply vessels vary and are highest when the AHTS operates with anchors along the platform in the field and are $6469.78 per voyage. Such a voyage takes 7.91 hours (Table 6).

Table 6: Work time and costs of supply vessel

Work time	Cost
7.91	6769,78

Source: Author – Yasper

7. CONCLUSION

In this paper we present a model in Petri nets using Yasper tools, with which we simulated the process of operation of supply ships and crew boats on the Ivana gas field. In the model we included the state of wind and waves in the Adriatic Sea and the consumption of vessels operating on the Ivana gas field. The data was researched for vessels that have been operating on the gas field for years, so we tried to get the most relevant model results. The results we obtained are approximations and provide us with data on vessel consumption as a function of the influence of wind and waves and how much wind and waves affect navigability. Several repeated runs of the model always give an average of 10% of the voyages influenced by wind and waves. We have also presented the obtained results to the employees of these vessels, who said that they agree with the results and that they are very similar to the actual events in the port of Pula and the Ivana gas field. This confirms the correctness and functioning of the model. The model can also be used for other gas and oil fields and vessels working there.

The daily rental rates for supply vessels are extremely high, and all users can easily use the model to get approximate figures that can help in the decision and price of supply vessels, both for ship owners and oil companies renting supply vessels. The plan is to continue to develop the model and try to develop a safer and better model that simulates the operation of supply vessels to help an industry that has been in a lot of trouble in recent years. This model relates only to the consumption of the vessels. The model could be developed further toward the cost of crewing and maintaining the vessels. These costs would increase the amount of money and thus more accurately identify the true cost of operating the vessels on the supply platform.

REFERENCES

[1] Živković, V. (2015):Production platforms of exploitation field North Adriatic (Proizvodne platforme eksploatacijskog polja Sjeverni Jadran), DiplomaThesis, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, 46 p. (in Croatian, with the English summary).

[2] Malvić T., Đureković M., Šikonja Ž., Čogelja Z., Ilijaš T., Kruljac I.,(2011). Exploration and production activities in northern Adriatic Sea (Croatia), successful joint venture INA (Croatia) and ENI (Italy), NAFTA 62 (9-10) 287-292 (2011).

[3] Malvić T., Velić J.,Režić M., (2016) Geological probability calculation of new gas discoveries in wider area of Ivana and Ika Gas Fields, Northern Adriatic, Croatia. RMZ – M&G | 2016 | Vol. 63 | pp. 127–0138.

[4] Malvić T., Velić J., Cvetković M., Vekić M., Šapina M. (2015). Definition of new Pliocene, Pleistocene and Holocene lithostratigraphic units in the Croatian part of the Adriatic Sea (shallow offshore) Geoadria 20/2 (2015) 85-108.

[5] Barret, D. (2005) The Offshore Supply Boat Sector, Sector Note, New York, USA: Fortis Bank

[6] Aas, B., Halskau Sr, Ø., & Wallace, S. W. (2009). The role of supply vessels in offshore logistics. Maritime Economics & Logistics, 11(3), 302–325.

[7] Fagerholt, K. (2000). Optimal policies for maintaining a supply service in the Norwegian Sea. Omega, 28(3), 269–275.

[8] Leder N., Morović M. (1996).Ecological study of gas fields in the northern Adriatic 2. Climate characteristic, ACTA ADRIAT: 37 (1/2) 9-15, 1996.

[9] Katalinić M.,Parunov J. (2014) Review of climatic conditions in the Adriatic Sea, 21st symposium Sorta 2014.

[10] Leder N., Smirčić A., Vilibić I. (1998) "Extreme values of surface wave heights in the Northern Adriatic". Geofizika 15 (1998), p. 1–13.

[11] Zurawsk, R., Zhou, M. C. (1994). Petri Nets and Industrial Applications: A Tutorial, IEEE Transactions on Industrial Electronics, Vol. 41, No. 6, p. 567-583.

[12] Jensen, K. (1997). Colored Petri Nets. Basic Concepts, Analysis Methods and Practical Use, Monographs in Theoretical Computer Science, vol 1-3, Springer-Verlag, Berlin 2nd corrected printing, Germany.

[13] Tuncel, G., & Bayhan, G. M. (2006). Applications of Petri nets in production scheduling: a review. The International Journal of Advanced Manufacturing Technology, 34(7-8), 762–773.

[14] Kees van Hee, Olivia Oanea, Reinier Post, Lou Somers and Jan Martijn van der Werf,(2006), Yasper: a tool for workflow modeling and analysis. Proceedings of the Sixth International Conference on Application of Concurrency to System Design (ACSD'06)

[15] https://www.ina.hr/ [Accessed 3rd February 2022]

USERS' PERCEPTION ON MICROMOBILITY VEHICLES AND INFRASTRUCTURE IN THE REPUBLIC OF SERBIA

Branko Milovanović, Ph.D.
Sreten Jevremović
Predrag Živanović, Ph.D.
Ana Trpković, Ph.D.
Slaven Tica, Ph.D.
Stanko Bajčetić, Ph.D.
Andrea Nađ, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, Belgrade, Serbia
b.milovanovic@sf.bg.ac.rs, s.jevremovic@sf.bg.ac.rs, p.zivanovic@sf.bg.ac.rs, a.trpkovic@sf.bg.ac.rs, slaven.tica@sf.bg.ac.rs, s.bajcetic@sf.bg.ac.rs, andrea@sf.bg.ac.rs

ABSTRACT

Micromobility vehicles' characteristics such as environmental friendliness, ease of use, autonomy, as well as potentially lower transport costs and greater efficiency than traditional modes of transport (public transport and passenger cars) have increased the attractiveness of these vehicles further accelerating their global expansion. Regulation, infrastructure, vehicle characteristics are just some of the current issues that have been raised with the increasing usage of micromobility vehicles. Also, the transition of traditional transport modes users to use new mobility options, at the same time their needs, habits and requirements are changing, which further complicates the situation. To define the requirements of users and potential users for micromobility vehicles and infrastructure, within the project "Micromobility vehicles" for Republic of Serbia - Traffic Safety Agency, research (survey) was conducted on a sample of 1,002 respondents. This paper aims to present the most important results of the survey related to the requirements of users and potential users in terms of characteristics, infrastructure and additional conditions for the usage of these vehicles in the Republic of Serbia. The research determined that the respondents would continue to use or switch to the use of micromobility vehicles if there were clear regulations and adequate infrastructure. Also, certain restrictions such as the mandatory use of protective helmets, reflective clothing and speed limits would not reduce the use of these vehicles, which significantly helped to understand the general attitudes of society regarding the issue of micromobility vehicles. Research and results of this project can be used as a basis for defining measures to improve current regulations, in order of adequate treatment of micromobility vehicles in the territory of the Republic of Serbia.

Keywords: Micromobility, Vehicle, Infrastructure, Users, Potential users

1. INTRODUCTION

Flexibility, dynamism and adaptability are the basic characteristics of a modern urban space that is constantly evolving and adapting to the intensive needs and requirements of its inhabitants. Urban transport system with its performance, technology, quality, costs and impact on the environment, represents one of the important factors influencing the functioning of modern cities, their economy, social relations, quality of life, etc. In a broader context, the urban transport system is one of the key elements influencing the convenience of living in cities.

The impact of micromobility vehicles on the market and transport system is significant. Since 2010, 207 million trips have been made by micromobility vehicles in the United States [1]. Thereof, 136 million trips were realized in 2019, which is about 60% more trips than in 2018 [2]. Some research shows that micromobility market will reach a value between 200 and 300 billion dollars by 2030 [3].

Micromobility practically represents a mode of personal transport, where the realization of transport needs is enabled only to those users who own a means of transport or users who are in direct contact with its owner. The main focus of the micromobility market is the realization of short distances trips.

The classification of micromobility vehicles in Europe is based on Regulation (EU) No 168/2013 of the European Parliament and the Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles [4] and European standards EN 15194:2017 [5] and EN 17128:2020 [6].

New micromobility services can be one of the effective measures in the process of sustainable and innovative transport development. The micromobility vehicles (e-bikes, e-scooters, segways, e-skates, etc.) are easy to use, environmentally friendly, in some situations faster than the traditional passenger transport system (public passenger transport system and passenger car). They allow users fast and cheap transport, as well as complete autonomy of movement, thus can reduce the traffic volume on the street network and conventional public transport systems. In a broader context, this technology can reduce the pressure on the entire urban transport system.

Micromobility vehicles integration into urban transport systems implies consideration of all regulatory, spatial, traffic, economic and other possibilities and limitations. In addition to the above, the indicators that should not be omitted are the attitudes and demands of users and potential users on this issue. Taking into account that the users are the main consumers of certain services or products, it is very important to analyze the attitudes and demands of all participants who are directly and/or indirectly affected by the change.

The subject of this paper is to show the requirements of users and potential users towards the micromobility system in the Republic of Serbia. This paper aims to present the results of users' and potential users' attitudes regarding activities that have an impact on micromobility vehicles usage in the Republic of Serbia.

This research is structured as follows: first, the introductory chapter is presented, and then section 2 gives a review of the research methodology. Section 3 provides the results and discussion regarding users' and potential users' characteristics, travel characteristics and impact of certain activities on micromobility vehicles use, while at the end we give some important concluding remarks.

2. THE RESEARCH METHODOLOGY

During 2020, we have conducted a pilot survey of user requirements - an online user survey. This pilot has provided the necessary guidelines on which user requirements to focus on. The main survey on the requirements of users and potential users for micromobility vehicles and infrastructure was done in 2021. The survey was conducted on a sample of 1,002 respondents.

The research method of micromobility users and potential users survey was an online interview in Google Forms. The representativeness of the sample was achieved by an adequate selection of cities and municipalities to which the survey form was forwarded by the Traffic Safety Agency. Moreover, the survey was advertised on certain websites and through social networks with a spatial sampling of target groups. This approach enabled residents of all municipalities and cities in the Republic of Serbia to give their opinion on micromobility vehicles.

The survey determined the basic characteristics of users (gender, age, work status, municipality/city, etc.), travel patterns (purpose, frequency of use, travel length, etc.), type and characteristics of vehicles, conditions and restrictions (possession of a license, use of a protective helmet, insurance, speed limit, etc.), infrastructure characteristics, the impact of the Covid-19, safety and security aspects, as well as preferences and basic reasons for using certain micromobility options.

The most important results of the survey related to the requirements of users and potential users are presented in the next chapter.

3. RESULTS AND DISCUSSION

3.1. Sample characteristics and travel patterns

In the total sample, 68% were males, while the remaining 32% were females. Respondents aged 36 to 45 have the largest share (32%), as well as respondents aged 26 to 35 (31%). Respondents aged 19 to 25 and persons aged 46 to 55 participated in the sample with 16% and 14%, respectively. Employees with a share of 69% are the most represented category, while other categories have a much lower share - students (13%), occasionally employed persons (10%) and unemployed persons (5%). Pensioners (2%) and pupils (1%) have the smallest share in the sample. 86.4% of respondents own a passenger car, and a very large percentage of respondents own a bicycle (69.8%). 14.7% of respondents own a motorcycle, 6.8% own an e-scooter, while 2.9% own an e-bicycle or some other micromobility vehicle.

Distribution of e-scooter users according to the type of vehicle ownership shows that 56% of them own an e-scooter, while 40% of users rent an e-scooter. Among e-bike users, 37% own an e-bike while 57% rent one. A large number of users of other micromobility vehicles rent this type of vehicle, i.e. 62% of them. 27% users of these vehicles stated that they own one of the other types of vehicles.

Micromobility vehicles are used for various trip purposes, but, interestingly, 24.6% of respondents use micromobility vehicles daily to go to/from work/school. For the purpose of visiting, the largest percentage of respondents (25.4%) use micromobility vehicles several times a month. The situation is similar for shopping trips, where 15.4% of respondents use micromobility vehicles several times a month. For recreation trips, an equal percentage of respondents use micromobility vehicles several times a week (18.5%) and daily (18.5%). Finally, the largest percentage of respondents (24.6%) use micromobility vehicles daily for recreation.

When it comes to the use of infrastructure, the largest number of respondents use e-scooters on pedestrian paths/sidewalks (56.2%), while 26.2% of respondents use e-bikes and other vehicles for micromobility. The share of e-bikes is significantly higher on bicycle paths/lanes (44.6%), while e-scooters are used similarly to on pedestrian paths/sidewalks. The smallest number of respondents (17.7%) stated that they use other micromobility vehicles on bicycle paths/lanes. The traffic lanes are mostly used by e-scooters (50%) and e-bikes (43.1%) users, and just 18.5% of other micromobility vehicles users.

The next chapter presents the results of users' and potential users' attitudes regarding activities that have an impact on micromobility vehicles usage.

3.2. The factors of micromobility vehicles usage

To define the impact of different factors on micromobility vehicles usage, eight activities are given within the research form (Speed limit, Mandatory use of a protective helmet, Mandatory vehicle registration, Compulsory vehicle insurance, Mandatory use of reflective clothing and lights, Prohibition of movement in the pedestrian zone, Prohibition of movement on the sidewalk, Prohibition of movement on the bicycle path). The respondents were asked to select the degree of influence for each activity. We use a five-step impact scale: it would completely distract me, it would probably distract me, I'm not sure (neutral), it probably wouldn't distract me and it wouldn't completely distract me.

According to the results shown in the Figure 1, it can be concluded that mandatory vehicle registration would completely deter 56.2% of users, which is the highest percentage of all activities. A slightly lower percentage of users, 53.1% of them, said that compulsory vehicle insurance would completely distract them from using micromobility vehicles. A large number of users would completely stop using micromobility vehicles if the bicycle path is banned for them - 48.5%.

On the other hand, the mandatory use of a protective helmet wouldn't completely distract 33.8% of users from micromobility vehicle use, and if we add to this 29.2% of those who said that they wouldn't probably dissuade from using a protective helmet, it can be concluded that 63% of users would still use micromobility vehicles if the use of a protective helmet was mandatory.

Also, the mandatory use of reflective clothing and lights would not completely distract 29.2% of users from micromobility vehicles use, while 26.2% said they would probably not be distracted, which represents a total of 55.4% of users. Interestingly, the speed limit would not completely distract 23.8% of users from micromobility vehicles, and 29.2% of users would not be dissuaded, which is a total of 53%.

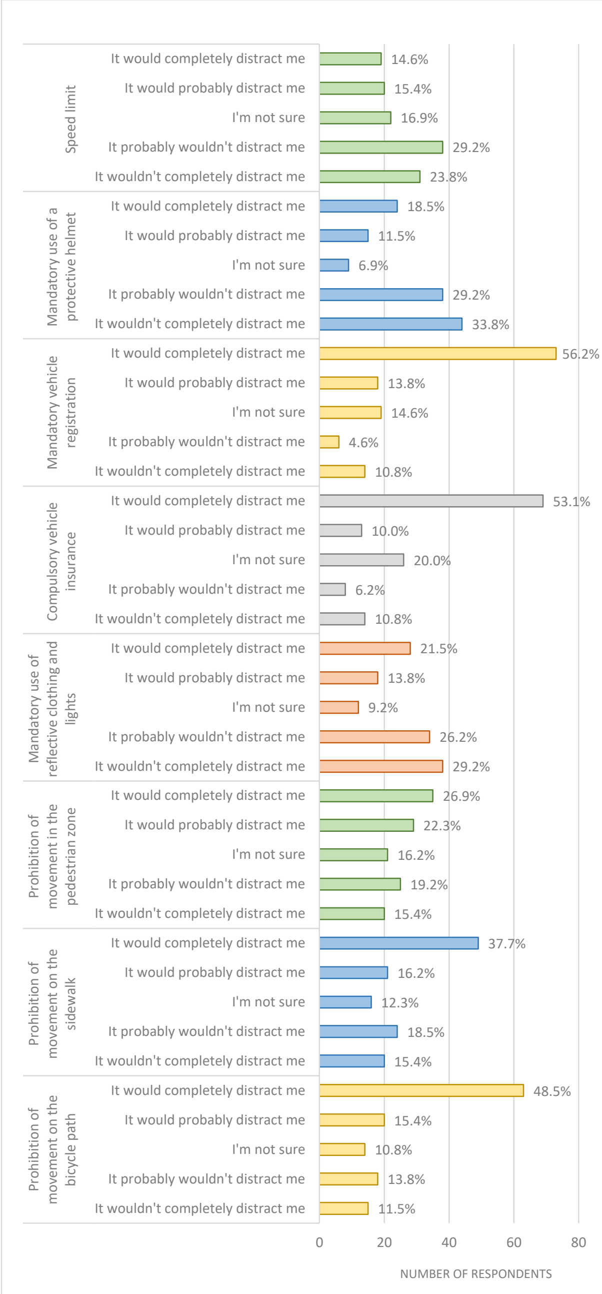


Figure 1: Impact of certain activities on micromobility vehicles usage - users

Unlike Serbia in France, the greatest impact on the reduced micromobility vehicles use, primarily e-scooters would occur in the case of introducing a measure of mandatory use of a protective helmet (71% of users would reduce the use of e-scooters), mandatory parking (63%) and speed limits (58%) [7]. Almost the same results as in France were obtained in a study conducted in New Zealand, but in this case, the most negative answers were related to the ban of micromobility vehicles use on sidewalks, as many as 83% of users said they would use e-scooters less often in the event of the ban [8].

Based on the presented results, it can be concluded that each country and each city individually exhibits specific requirements and needs of users in terms of micromobility vehicles. The diversity of requirements only indicates the need to regulate the issue of micromobility vehicle use at the local level in accordance with the specifics of the area, infrastructure and user characteristics.

On the other hand, for potential users of micromobility vehicles, eleven activities were defined for which they expressed a degree of impact in a similar way as users (It doesn't completely affect, It doesn't affect, I'm not sure (neutral), It affects, It completely affects) (Figure 2).

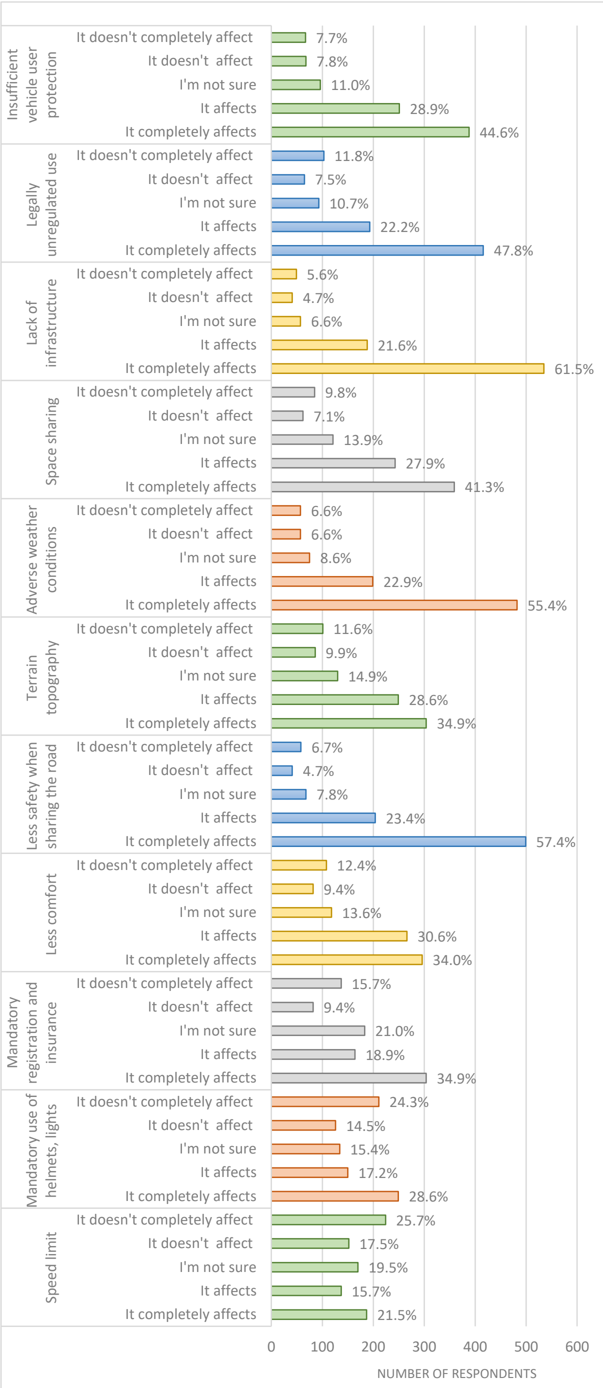


Figure 2: Impact of certain activities on micromobility vehicles use – potential users

Based on the results shown in the figure, it can be concluded that 44.6% of potential users agree that insufficient protection of micromobility vehicle users completely negatively affects their willingness to use these vehicles, which was expected given the high level of users safety perception. 47.8% stated that the unregulated use of these vehicles has a completely negative impact. This result is also expected given the inability of users to manage their behaviour in accordance with current regulations, for example: where to drive, how fast, how they can use certain zones (areas), how to park vehicles etc.

As many as 61.5% of potential users agree that the lack of adequate infrastructure has a completely negative impact on their willingness to use micromobility vehicles, while 41.3% stated that space-sharing has the same impact. In general, shared spaces are very specific areas, which can largely deter users from using them if they are not adequately designed. Having in mind the behaviour and cultural heritage of the people in this area, the obtained results are expected. In fact, the most receptive option for both potential and current users is to have a separate (physically separate) infrastructure for micromobility vehicles. On the one hand, this solution provides a high level of safety, but is rarely used due to the high density of buildings in urban areas, i.e. lack of space, larger financial investments, etc., so in most cases it is necessary to find an alternative which would be the optimal choice between physically separated infrastructure and sharing the road with other motor vehicles.

More than half of the potential users, 57.4% of them, stated that lower safety when sharing the road with motor vehicles completely negatively affects their willingness to use micromobility vehicles, while 55.4% stated that adverse weather conditions have the same impact.

These results are of great importance given that adequate infrastructure is one of the main prerequisites for the use of micromobility vehicles. In this particular case, potential users are users whose defined preconditions and planned improvement of regulations determine the willingness to use these vehicles. In this regard, when proposing changes to existing regulations, it is important to take into account the views of potential users who may represent a significant percentage of vehicle users for micromobility in the future.

Terrain topography, less comfort, mandatory vehicle registration and compulsory vehicle insurance completely negatively affect potential users' willingness to use micromobility vehicles, but not to such an extent as previously described activities.

It is interesting to note that potential users regarding mandatory use of protective helmets and lights on the vehicle, as well as speed limit, have divided attitudes (from 14 to 29%).

4. CONCLUSIONS

Based on the results of research on the characteristics and requirements of users and potential users to the micromobility system in the Republic of Serbia, it can be concluded that they differ greatly from the requirements of users in other countries, such as France and New Zealand. This indicates the fact that it is necessary to design micromobility systems "tailored" to specifics of cities and areas, as well as users and potential users, not according to pre-established procedures because there is no universal solution for organizing such a complex system.

The general conclusions that can be obtained based on the presented results are: users of micromobility vehicles want a high level of safety with as few situations as possible in which have to share the infrastructure with other users. Adequate infrastructure is a basic prerequisite for the use of these vehicles, and additional obligations and requirements such as: mandatory vehicle registration and insurance, would deter potential users from using micromobility vehicles.

The presented results, on the one hand, clearly indicate the activities that should be carried out in order to maintain the number of active users, but also encourage a certain number of potential users to use these vehicles. On the other hand, the results also indicate the measures that must be taken to ensure the basic preconditions for the use of these vehicles, such as infrastructure capacity and adequate regulations.

The future of micromobility, to a large extent, also depends on the public sharing services of these vehicles, especially if there is a possibility of integration with the public transport subsystem. Having in mind that public transport in Belgrade participates with about 50% in the modal share, it can be concluded that there is already a good basis for the integration of the mentioned types of transport. This aspect is especially important if we take into account the population density and construction in the area of Belgrade, especially in the central zone (the old part of the city). In that sense, different user categories are given the opportunity to access the use of micromobility vehicles and realize their movements with, for example, an e-bike or e-scooter, instead of a passenger car. Given the good experiences of world cities, this can be especially important in university areas where there are many pedestrians whose movements are usually realized on shorter distances. In this sense, the services of public e-bikes and e-scooters can prove to be adequate alternatives to passenger cars or taxis. In this sense, a very important step which will have to be considered is the detailed planning and design process of the micromobility stations, which can greatly affect the cost-effectiveness and use of the mentioned public service.

In general, large differences between cities in terms of available infrastructure, terrain topography, spatial possibilities, and above all the requirements of users and potential users indicate that the issue of micromobility should be treated in accordance with all these specifics at the local level, respecting all interested sides equally. Only in this way the active integration of micromobility into the existing urban city systems can be ensured, which will consequently provide a convenient, efficient, safe and accessible transport options for all users equally.

REFERENCES

[1] Governors Highway Association (2020). Understanding and Tackling Micromobility: Transportation's New Disruptor. Washington DC United States.

[2] National Association of City Transportation Officials (NACTO). (2019). Shared Micromobility in the US. United States.

[3] Reed, T. (2019). Micromobility Potential in the US, UK and Germany. Kirkland, WA United States.

[4] European Parliament and the Council of the European Union (2013). Regulation (EU) No 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles.

[5] European Committee for standardization (2017). "Safety standard adapted for Electrically Power Assisted Cycles (EPAC) - EN 15194.

[6] European Committee for standardization (2020). Light motorized vehicles for the transportation of persons and goods and related facilities and not subject to type-approval for on-road use - Personal light electric vehicles (PLEV) - Requirements and test methods - EN 17128.

[7] 6t-bureau de recherche (2019). Uses and Users of Free-floating Electric Scooters in France. France.

[8] Lo, D., Mintrom, C., Robinson, K. & Thomas, R. (2020). Shared micromobility: The influence of regulation on travel mode choice, N. Z. Geog., 76 (2), 135–146.

A CONCEPTUAL FRAMEWORK FOR MAAS SCHEME INDICATORS

Mehdi Moeinaddini
Institute of Computer Science, University of Tartu
Narva mnt 18, 51009 Tartu linn, Tartu, Estonia
mehdi.moeinaddini@ut.ee

Zohreh Asadi-Shekari
Universiti Teknologi Malaysia,
Skudai, Johor, Malaysia
aszohreh2@live.utm.my

Attila Aba
Domokos Esztergár-Kiss
Budapest University of Technology and Economics
1111 Budapest Műegyetem rakpart 3., Budapest, Hungary
aba.attila@kjk.bme.hu, esztergar@mail.bme.hu

ABSTRACT

Mobility as a Service (MaaS) is a quickly developing paradigm implemented in several cities. A wide range of indicators including individual users, policymakers, and stakeholders should be defined for MaaS as a multidimensional solution. Currently, there are some indices that measure the readiness of cities for MaaS, but most of these consider solely a few indicators thus being not comprehensive. In this paper, a framework for a comprehensive MaaS scheme is introduced. The first phase of the research includes the identification of the key factors considering the infrastructure, technology, users, policies, and integration. Afterward, assessment methods are provided to measure each indicator. In the final phase, a framework for the indicators considering the weights and the scores is created. Based on the framework, experts, urban planners, and mobility providers can evaluate the readiness level of cities, identify problems, suggest improvements, and design new solutions.

Keywords: Mobility as a Service, framework, indicators

1. INTRODUCTION

Mobility as a Service (MaaS), as one of its primary definitions states, is a system that includes different mobility services provided by mobility operators. [18] MaaS Alliance [34] defines Maas as a single on-demand mobility service that consists of various integrated mobility services. Some studies focus on the MaaS benefits. For example, Jittrapirom et al. [24] propose that MaaS might be used as a tool to acquire feedback, which can improve the system. MaaS Alliance [34] concludes that users can have better access to mobility-related information and fewer problems with ticketing by using the proposed single MaaS platform. Moreover, MaaS might trigger the shift of travel behaviour towards sustainable travel modes, which has environmental benefits. [25]

While preparing a roadmap for MaaS in Helsinki, Heikkilä [18] highlights such important factors as social change, technological advances, and paradigm change. To these factors, Rantasila [43] adds the operational regulations and the need for new legislation. Kamargianni et al. [27] conduct a feasibility study for MaaS in London and propose an information and communication technology (ICT) integration of the information and cooperation between the different stakeholders. Giesecke et al. [15][13] focus on the end-users' perspective, which is one of the main sustainability aspects that needs to be considered when implementing MaaS. Karlsson et al. [29] investigate the stakeholders' – rather than the users' – willingness to join MaaS. Other researchers focus on possible market growth scenarios, while Stopka et al. [49][44] explore the users' willingness to pay. More recent studies (e.g., [20], [33]) examine the barriers and the level of integration.

Furthermore, there are some proposed indices related to MaaS. For example, Kamargianni et al. [25] recommend an index to measure the level of mobility integration. A MaaS maturity index is developed by Goulding and Kamargianni [17] to measure the readiness of cities for MaaS implementation. The operators' openness and willingness to data sharing, citizens' interests, services, and ICT infrastructure are the main components of the MaaS maturity index.

Most indices focus on a few indicators; thus, there is a need to have a comprehensive framework of indicators, which takes a wider look at MaaS as a multidimensional solution affecting individual users, policymakers, and stakeholders.

This paper introduces a conceptual framework that can be used as a foundation for this comprehensive framework. To do this, section 2 focuses on the MaaS related factors. Identifying these factors is very useful to have a comprehensive framework. The proposed conceptual framework is presented in section 3 and finally, the discussion and conclusions are summarized in section 4.

2. THE MAAS READINESS-RELATED FACTORS

2.1. Infrastructure

To have a successful MaaS service, a city needs to offer different transport modes. [32] Public transport should be the focus to make MaaS in line with the initial sustainability-related benefits. Additionally, those mobility options that complement public transport, like micro-mobility, are essential parts of MaaS to provide door-to-door travelling. [3] To grant spatial (e.g., suburban areas) and temporal (e.g., night-time) coverage, on-demand and shared transport is needed, as well. [32], [47] Table 1 summarizes the MaaS mobility-related infrastructure that is necessary as well as the proposed assessment methods.

Table 1: The MaaS mobility-related infrastructure

Mobility infrastructure	Proposed assessment method
Walking	Enough and safe walking facilities in the city [5]
Bikes and e-bikes	Enough and safe cycling facilities in the city [6]
Scooters and e-scooters	Enough and safe scootering facilities in the city [52] [21]
The availability of micro-mobility	Enough rental facilities for bikes, e-bikes, scooters, or e-scooters in the city
Parking for micro-mobility	Enough parking facilities for bicycles and scooters in the city
Public transport coverage	Public transport covers most of the destinations in the city [35]
Public transport frequency	The frequency of the public transport is acceptable for most of the routes in the city [16] [2]
Public transport reliability	Public transport is reliable for most of the routes in the city [11] [12] [53]
Public transport safety	Public transport is safe for most of the routes in the city
Public transport security	Public transport is secure for most of the routes in the city
Public transport information	Enough information is provided for public transport users in the city [19] [37] [54]
Taxi and online taxi	Taxis are accessible for most of the destinations in the city [22]
Demand Responsive Transport (DRT)	DRT is available for most of the low-demand areas in the city [40] [30]
DRT for elderly and mobility-impaired people	DRT is available for the elderly and mobility-impaired people in the city [38]
Carsharing	Easy access to carsharing for short periods of time in the city
Carpooling	Easy access to carpooling for a journey in the city
Shared on-demand public transport	Easy access to sharing a van, a minibus, or a bus for a journey in the city
Park and ride (private transport)	Easy to find the park and ride facilities for most of the transit stations in the city
Congestion (private transport)	The level of congestion for most of the major roads during peak hours in the city

2.2. Technology

Another essential part of MaaS is ICT. Nowadays, there are more than 60,000 travel Apps on Google Play, [32][32] but for the users, it is difficult to find integrated travel planners. MaaS uses a joint digital channel for planning, booking, and paying for the different mobility options. [45] Therefore, the ICT-related infrastructure can play an important role in making the cities ready for MaaS. [3] Kamargianni et al. [27][26] focus on ICT and define it as one of the MaaS feasibility-related factors in London. Kamargianni and Matyas [26] introduce ICT as one of the most important MaaS ecosystem components, and as proposed by Goulding and Kamargianni [17], it is among the MaaS maturity index-related factors, as well. Table 2 summarizes the necessary MaaS ICT-related infrastructure as well as the proposed assessment methods.

Table 2: The MaaS ICT-related infrastructure

ICT infrastructure	Proposed assessment method
Mobile and Internet	Mobile phones and Internet access available to most people
Travel planner for public transport	Easy to find a suitable travel planner app for public transport in the city
Multimodal travel planner	Easy to find a suitable multimodal travel planner app in the city
Payment for public transport	Enough online payment options for public transport in the city
Payment for multimodal journeys	Enough online payment options for multimodal journeys in the city

2.3. Users

The current travel behaviour and the attitudes towards different travel options are among the user-related factors that can affect MaaS. [15] Pendyala et al. [41] observe a repetitive nature in travel behaviour. Other studies focus on travel behaviour as a deliberation process. [7] Another approach to travel behaviour-related studies is the habit approach [13] [14]. Karlsson et al. [28] highlight the considerable impact on private car usage while examining the potential of MaaS. Mobility without owning a car is in line with the effect of MaaS, which breaks private car dependence as proposed by Jittrapirom et al. [23]. MaaS can provide an opportunity for the users to consider integral mobility solutions, and it is important to shift from ownership to access-based mobility.

The Smile pilot as a MaaS platform is tested by over 1000 pilot users in Vienna, and the results indicate a reduction in private car usage in the case of 21% of the respondents. [44] For UbiGo participants in Sweden, this reduction is 44%. [28] MaaS provides fewer positive attitudes towards private cars and more positive approaches towards alternative modes. [48] The current modal split and attitudes towards different travel options can be considered important factors in rating the MaaS readiness. Table 3 summarizes the assessment methods for the current modal split and the attitudes towards the different travel options.

Table 3: The modal split and the attitudes towards the different travel options

Users-related factor	Proposed assessment method
Walking rate	Modal split-related data
Cycling rate	Modal split-related data
Public transport usage	Modal split-related data
Private car usage	Modal split-related data
Attitude towards walking	Attitudes towards transport modes [4]
Attitude towards cycling	Attitudes towards transport modes [4]
Attitude towards public transport	Attitudes towards transport modes [4][4]
Attitude towards private cars	Attitudes towards transport modes [4]

2.4. Policies

On an organisational level, MaaS is an integration of public and private operators by using a MaaS provider, where the trips need to be complementary. [1] One example of a complimentary trip can be the usage of public transport and then micro-mobility for the last mile. Therefore, in addition to the required providers and policies, the collaboration between the providers is an important organizational MaaS-related factor. Kamargianni et al. [27][26] propose cooperation among the stakeholders, which is one of the MaaS feasibility-related factors in London. Moreover, Karlsson et al. [29][28] emphasize the importance of cooperation to avoid the technical problems related to information, payment, and infrastructure as well as the issues related to trust and the distribution of resources. Authorities and policymakers might have key roles in providing policies that enhance the collaboration between the different stakeholders and providers. [10] Rantasila [43][35] emphasizes the needs for MaaS-related operational regulations and new legislation. In addition to the cooperation, policies and regulation enhancements are among the important factors allowing MaaS. [39][39] Other important aspects of cooperation in the MaaS ecosystem are data sharing and data providers. [26] Li and Voege [32][32] highlight the importance of data sharing, and they consider data security and privacy as the pre-conditions for MaaS. The providers' openness and data sharing are among the MaaS maturity index-related factors proposed by Goulding and Kamargianni [17][16]. Table 4 summarizes the proposed assessment methods for the MaaS organizational-related factors.

Table 4: The proposed assessment methods

Stakeholders and policymakers	Proposed assessment method
Policies for active travel options	Sufficient supportive local policies for active travel modes [50] [8] [42]
Policies for shared mobility	Sufficient supportive local policies for shared mobility [50] [36]
Policies for public transport	Sufficient supportive local policies for public transport [30] [51]
Policies for MaaS	Sufficient supportive policies for MaaS [45]
Micro-mobility providers	The number of micro-mobility providers and their level of integration
Shared mobility providers	The number of shared mobility providers and their level of integration
Public transport providers	The number of public transport providers and their level of integration
MaaS providers	The number of MaaS providers and their levels of integration
Collaboration	Collaboration between the different mobility providers
Data sharing	The level of exchanging data between various mobility providers and third parties [9]
Data security and privacy	Suitable policies to protect security and privacy for individual-related data [9][9]

2.5. Integration

Considering the MaaS concept, the level of integration plays an important role in providing a single on-demand mobility service. Lyons et al. [33] introduce operational integration, informational integration, transactional integration, and cognitive user effort as the different aspects of integration necessary for MaaS. The operational integration provides door-to-door travel options with low interchange needs. The informational integration creates a one-stop interface for the required travel information, while the transactional integration provides one platform for booking and payment. Finally, the cognitive user effort combines all the mentioned aspects to promote MaaS as a better option than private cars. Sochor et al. [46][44] define the integration of information, the integration of booking and payment, the integration of the service offer, and the integration of the societal goals as the four levels of integration for MaaS. Table 5 summarizes the proposed assessment methods for the MaaS-related integration levels.

Table 5: The MaaS-related integration levels

Integration	Measurement
The integration of information	Integrated information provided for a multimodal journey
The integration of booking and payment	Integrated booking and payment options provided for a multimodal journey
The integration of the mobility options	Integrated mobility options provided for a multimodal journey
The integration of mobility and other services	Integration between mobility and other services in the city

3. A FRAMEWORK FOR THE MAAS SCHEME INDICATORS

Figure 1 presents a framework applied to establish the MaaS Scheme Indicator (MSI). To identify those indicators that significantly affect the proposed MSI, the required infrastructure and facilities need to be determined. Accordingly, in addition to the required infrastructure and facilities, MaaS-related studies addressing the users' needs require reviews to select the indicators most suitable for the proposed MSI. This first step, which includes a comprehensive literature review to find the effective indicators, is presented in the first part of current paper. However, it should be noted that the list of the effective indicators can be modified after applying the next steps (presented in the proposed framework), which include examining the experts, citizens, and local authorities' opinions by using the related interviews and questionnaires.

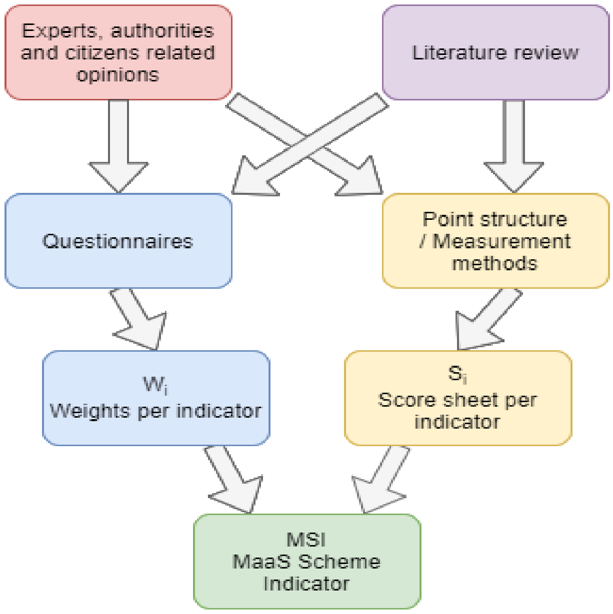


Figure 1: A framework for MSI

As each indicator has a unique effect on MSI, they have specific coefficients or weights. The effectiveness of each indicator can be identified by its weight. The importance of an indicator for the users and the experts might be used to calculate the weights. A survey needs to be designed to collect the required data for this step. The respondents indicate the importance of each indicator. The participants are selected in such a way that the population quotas in terms of gender and age are respected. By using the data of this survey, a structural equation model (SEM), in particular a confirmatory factor analysis (CFA), needs to be developed to determine the weight (i.e., importance) of each indicator. The factor loadings of the CFA model serve as weights.

CFA can be used to determine the relationships between observed variables and latent variables (underlying factors like walking, cycling, etc.). To do this, a path diagram that is a structural equation model (SEM) can be applied. This diagram includes observed variables, latent variables, and error terms. The results of CFA can be used to identify the weight of each latent variable and observed variable. The resulting factor loading values can be used as weights to estimate the proposed MSI.

Another important step is determining the score of the indicators. Comparing the conditions of an indicator with its ideal conditions allows the determination of its score ranging from 0 to 1 after normalization (1 indicating that the ideal conditions are met and 0 presenting a complete mismatch). In this step, the most important point is to provide logical instruction to be able to measure the current situations objectively. Therefore, providing logical measurement methods is one of the crucial challenges in this step.

Currently, there are various measurement methods for different travel options that can be used for the indicators' scores. For example, pedestrian and bicycle levels of services have been established to measure enough and safe walking and cycling facilities in the city (e.g., [16-17]).

To make MSI easily understandable, an MSI percentage (MSI%) might be defined. This value is the percentage of the existing value compared to the maximum MSI value that might be obtained. The latter maximum MSI occurs when all scores are equal to 1. Based on the MSI%, various MSI classifications can be proposed. Typically, six classes ranging from A to F are defined in index studies. Class A represents a high rating for MaaS readiness. Class B shows that the readiness is acceptable, but minor improvements are required. Class C demonstrates that more improvements are demanded, and a rating below class C indicates that serious improvements are needed. The proposed MSI can be applied to evaluate the MaaS readiness in the different cities. This evaluation can be used to find problems and to suggest improvements, in addition to rating the readiness.

4. DISCUSSION AND CONCLUSION

Suitable and enough infrastructure and facilities should be provided to make the cities ready for MaaS. Accordingly, practical and comprehensive MaaS scheme indicators are needed to evaluate the cities and to propose some necessary improvements. Most previously introduced MaaS readiness indices consider a limited range of effective indicators. Furthermore, the methodology of previous studies is very subjective, and in most of them, the importance or weights of the related indicators are missing. Therefore, this study proposes a new framework of comprehensive MaaS scheme indicators to fulfil the needs for considering various indicators extracted from a wide range of literature and interviews. Moreover, the framework recommends the use of objective rating systems to avoid subjectivity.

Although this study solely focuses on MaaS, in further research, the readiness for other innovative mobility solutions, such as connected vehicles, might be evaluated by using a similar process. Furthermore, adding more indicators to include the effects of other innovative mobility solutions on MaaS can be an interesting approach for further studies. In order to be able to use the proposed index with other scales, such as regional scales, it might be modified by considering the changes of the indicators and the recalculation of the weights. Future research works might develop the proposed index in the form of software to acquire an easier calculation process. The proposed index can be applied by urban designers and planners as well as by mobility providers for designing new solutions in addition to the improvement of the existing conditions.

The current literature on MaaS related indicators mainly focuses on the technical activities, data processing, payments, standardization, and offering consulting. However, to have a comprehensive understanding of new ideas and solutions like MaaS, the important initial step is a comprehensive framework for assessment analysis. This comprehensive framework needs to include a wider range of indicators to provide a more comprehensive assessment. Therefore, in the elaborated framework, additional key indicators are suggested based on the current literature that can encourage or discourage MaaS as well as including experts, authorities, and citizens related opinions.

Looking at MaaS as an innovative solution from the viewpoint of the mobility providers, the proposed MSI can be used to find existing barriers, where identifying the barriers can be the initial step to propose innovative solutions by the mobility providers and MaaS operators. Moreover, identifying the barriers and the required activities can be used to reduce innovation costs in addition to encouraging collaboration and enhancing the management quality of the process. The proposed framework that includes a comprehensive list of effective indicators can ultimately provide the necessary information about the complementary components that are needed for the MaaS development.

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REFERENCES

[1] Aapaoja, A., Eckhardt, J., Nykänen, L., & Sochor, J. (2017). MaaS service combinations for different geographical areas. Montreal, Canada: Proceedings ITS World Congress 2017.

[2] Agrawal, K., Suman, H. K., & Bolia, N. B. (2020). Frequency Optimization Models for Reducing Overcrowding Discomfort. Transportation Research Record, 2674(5), 160-171.

[3] Arias-Molinares, D., & García-Palomares, J. C. (2020). Shared Mobility Development as Key for Prompting Mobility as a Service (MaaS) in Urban Areas: The Case of Madrid. Case Studies on Transport Policy, 8, 846–859.

[4] Arroyo, R., Ruiz, T., Mars, L., Rasouli, S., & Timmermans, H. (2020). Influence of Values, Attitudes towards Transport Modes and Companions on Travel Behavior. Transportation Research Part F: Traffic Psychology and Behaviour, 71, 8–22.

[5] Asadi-Shekari, Z., Moeinaddini, M., Aghaabbasi, M., Cools, M., & Zaly Shah, M. (2019). Exploring Effective Micro-Level Items for Evaluating Inclusive Walking Facilities on Urban Streets (Applied in Johor Bahru, Malaysia). Sustainable Cities and Society, 49, 101563.

[6] Asadi-Shekari, Z., Moeinaddini, M., & Zaly Shah, M. (2015). A Bicycle Safety Index for Evaluating Urban Street Facilities. Traffic Injury Prevention, 16(3), 283-288.

[7] Bamberg, S., Ajzen, I., & Schmidt, P. (2003). Choice of Travel Mode in the Theory of Planned Behavior: The Roles of Past Behavior, Habit, and Reasoned Action. Basic and Applied Social Psychology, 25(3), 175-187.

[8] Bloyce, D., & White, C. (2018). When Transport Policy Becomes Health Policy: A Documentary Analysis of Active Travel Policy in England. Transport Policy, 72, 13–23.

[9] Callegati, F., Giallorenzo, S., Melis, A., & Prandini, M. (2016). Data security issues in MaaS enabling platforms. Bologna, Italy: Proceedings International Forum on Research and Technologies for Society and Industry.

[10] Chang, S. K. J., Chen, H., & Chen, H. (2019). Mobility as a Service Policy Planning, Deployments and Trials in Taiwan. IATSS Research, 43(4), 210-218.

[11] Chen, X., Yu, L., Zhang, Y., & Guo, J. (2009). Analyzing Urban Bus Service Reliability at the Stop, Route, and Network Levels. Transportation Research Part A: Policy and Practice, 43(8), 722-734.

[12] Diab, E. I., Badami, M. G., & El-Geneidy, A. M. (2015). Bus Transit Service Reliability and Improvement Strategies, Integrating the Perspectives of Passengers and Transit Agencies in North America. Transport Reviews, 35(3), 292-328.

[13] Gardner, B. (2009). Modelling Motivation and Habit in Stable Travel Mode Contexts. Transportation Research Part F: Traffic Psychology and Behaviour, 12(1), 68-76.

[14] Gärling, T., & Axhausen, K. W. (2003). Introduction: Habitual Travel Choice. Transportation, 30(1), 1-11.

[15] Giesecke, R., Surakka, T., & Hakonen, M. (2016). Conceptualising mobility as a service: A user centric view on key issues of mobility services. (11). Espoo, Finnland: 2016 Eleventh International Conference on Ecological Vehicles and Renewable Energies *(EVER)*.

[16] Gkiotsalitis, K., & Cats, O. (2018). Reliable Frequency Determination, Incorporating Information on Service Uncertainty when Setting Dispatching Headways. Transportation Research Part C: Emerging Technologies, 88, 187–207.

[17] Goulding, R., & Kamargianni, M. (2018). The mobility as a service maturity index: Preparing the cities for the mobility as a service era. (pp. 16-18). Vienna, Austria: 7th Transportation Research Arena.

[18] Heikkilä, S. (2014). Mobility as a service -a proposal for action for the public administration case Helsinki. Master Thesis, Espoo, Finnland: Aalto University.

[19] Hensher, D. A., Stopher, P., & Bullock, P. (2003). Service Quality - Developing a Service Quality Index in the Provision of Commercial Bus Contracts. Transportation Research Part A: Policy and Practice, 37, 499–517.

[20] Hesselgren, M., Sjöman, M., & Pernestål, A. (2020). Understanding User Practices in Mobility Service Systems: Results from Studying Large Scale CorporateMaaS in Practice. Travel Behaviour and Society, 12, 318-327.

[21] James, O., Swiderski, J., Hicks, J., Teoman, D., & Buehler, R. (2019). Pedestrians and E-Scooters, An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. Sustainability, 11(20), 5591.

[22] Jiang, S., Chen, L., Mislove, A., & Wilson, C. (2018). On Ridesharing Competition and Accessibility, Evidence from Uber, Lyft, and Taxi. (pp. 863-872) Lyon, France: The Web Conference (WWW 2018).

[23] Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-González, M., & Narayan, J. (2017). Mobility as a Service: A Critical Review of Defintions, Assessements of Schemes and Key Challenges. Urban Planning, 2(2), 13-25.

[24] Jittrapirom, P., Marchau, V., van der Heijden, R., & Meurs, H. (2020). Future Implementation of Mobility as a Service (MaaS): Results of an International Delphi Study. Travel Behaviour and Society, 21, 281–294.

[25] Kamargianni, M., Li, W., Matyas, M., & Schäfer, A. (2016). A Critical Review of New Mobility Services for Urban Transport. Transportation Research Procedia, 14, 3294-3303.

[26] Kamargianni, M., & Matyas, M. (2017). The business ecosystem of mobility as a service. Washington DC, USA: Proceedings 96th Transportation Research Board Annual Meeting.

[27] Kamargianni, M., Matyas, M., Li, W., & Schäfer, A. (2015). Feasibility study for mobility as a service concept for London. London, UK: UCL Energy Institute Report.

[28] Karlsson, I. C. M., Sochor, J., Aapaoja, A., Eckhardt, J., & König, D. (2017). Deliverable 4. Impact assessement MAASiFiE project, funded by CEDR.

[29] Karlsson, I. C. M., Sochor, J., & Strömberg, H. (2016). Developing the "Service" in Mobility as a Service: Experiences from a Field Trial of an Innovative Travel Brokerage. Transportation Research Procedia, 14, 3265–3273.

[30] Kent, J. L., Mulley, C., & Stevens, N. (2020). Challenging Policies that Prohibit Public Transport Use: Travelling with Pets as a Case Study. Transport Policy, 99, 86–94.

[31] König, A., & Grippenkoven, J. (2020). The Actual Demand Behind Demand-Responsive Transport, Assessing Behavioral Intention to Use DRT Systems in Two Rural Areas in Germany. Case Studies on Transport Policy, 8, 954–962.

[32] Li, Y., & Voege, T. (2017). Mobility as a Service (MaaS): Callenges of Implementation and Policy Required. Journal of Transportation Technologies, 7(2), 95–106.

[33] Lyons, G., Hammond, P., & Mackay, K. (2019). The Importance of User Perspective in the Evolution of MaaS. Transportation Research Part A: Policy and Practice, 121, 22–36.

[34] MaaS Alliance (2017). White paper: Guidelines and recommendations to create the foundations for thriving MaaS ecosystem.

[35] Magalhães, M. T. (2016). Spatial Coverage Index for Assessing National and Regional Transportation Infrastructures. Journal of Transport Geography, 56, 53–61.

[36] Meng, L., Somenahalli, S., & Berry, S. (2020). Policy Implementation of Multi-Modal (Shared) Mobility: Review of a Supply-Demand Value Proposition Canvas. Transport Reviews, 40(5), 670-684.

[37] Mulley, C., Clifton, G., Balbontin, C., & Ma, L. (2017). Information for Travelling: Awareness and Usage of the Various Sources of Information Available to Public Transport Users in NSW. Transportation Research Part A: Policy and Practice, 101, 111–132.

[38] Neven, A., Braekers, K., Declercq, K., Wets, G., Janssens, D., & Bellemans, T. (2015). Assessing the Impact of Different Policy Decisions on the Resource Requirements of a Demand Responsive Transport System for Persons with Disabilities. Transport Policy, 44, 48–57.

[39] Nikitas, A., Kougias, I., Alyavina, E., & Tchouamou, E. N. (2017). How Can Autonomous and Connected Vehicles, Electromobility, BRT, Hyperloop, Shared Use Mobility and Mobility-as-a-Service Shape Transport Futures for the Context of Smart Cities? Urban Science, 1(4), 36.

[40] Papanikolaou, A., & Basbas, S. (in press). Analytical Models for Comparing Demand Responsive Transport with Bus Services in Low Demand Interurban Areas. Transportation Letters.

[41] Pendyala, R., Parashar, A., & Muthyalagari, G. (2001). Measuring day-to-day variability in travel characteristics using GPS data. Washington DC, USA: Proceedings 79th Annual Meeting of the Transportation Research Board (TRB).

[42] Pooley, C. G., Horton, D., Scheldeman, G., Mullen, C., Jones, T., Tight, M., Jopson, A., & Chisholm, A. (2013). Policies for Promoting Walking and Cycling in England: A View from the Street. Transportation Policy, 27, 66–72.

[43] Rantasila, K. (2015). The impact of mobility as a service concept to land use in Finnish context. In IEEE (Ed.), 2015 International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART) (1–7).

[44] Smile mobility (2015). Results of the smile pilot. Retrieved from https://smile-einfachmobil.at/pilotbetrieb_en.html#dieergebnisse

[45] Smith, G., & Hensher, D. A. (2020). Towards a Framework for Mobility-as-a-Service Policies. Transport Policy, 89, 54–65.

[46] Sochor, J., Arby, H., Karlsson, M., & Sarasini, S. (2018). A Topological Approach to Mobility as a Service: A Proposed Tool for Understanding Requirements and Effects, and for Aiding the Integration of Societal Goals. Research in Transportation Business & Management, 27, 3-14.

[47] Sochor, J., Strömberg, H., & Karlsson, I. C. M. (2015). Challenges in integrating user, commercial and societal perspectives in an innovative mobility service. Washington DC, USA: Proceedings 94th Annual Meeting of the Transportation Research Board.

[48] Sochor, J., Strömberg, H., & Karlsson, M. (2015). Implementing Mobility as a Service: Challenges in Integrating User, Commercial, and Societal Perspectives. Transportation Research Record, 2536(1), 1–9.

[49] Stopka, U., Pessier, R., & Gunther, C. (2018). Mobility as a Service (MaaS) based on intermodal electronic platforms in public transport. (419–439). Las Vegas, Nevada, USA: International Conference on Human-Computer Interaction, Springer.

[50] Tønnesen, A., Knapskog, M., Uteng, T. P., & Øksenholt, K. V. (in press). The Integration of Active Travel and Public Transport in Norwegian Policy Packages: A Study on 'Access, Egress and Transfer' and Their Positioning in Two Multilevel Contractual Agreements. Research in Transportation Business & Management.

[51] Wangsness, P. B., Proost, S., & Rodseth, K. L. (2020). Vehicle Choices and Urban Transport Externalities: Are Norwegian Policy Makers Getting It Right? Transportation Research Part D: Transport and Environment, 86, 102384.

[52] Yang, S., Ahmad, A., Park, P. Y., Sohn, G., & Krygsman, J. (2020). Public Transit Service Reliability Assessment Using Two-Fluid Model. Transportation Research Record, 2674(4), 89-100.

[53] Yang, H., Ma, Q., Wang, Z., Cai, Q., Xie, K., & Yang, D. (2020). Safety of Micro-Mobility, Analysis of E-Scooter Crashes by Mining News Reports. Accident Analysis and Prevention, 143, 105608.

[54] Zhang, M., Zhao, P., & Qiao, S. (2020). Smartness-Induced Transport Inequality, Privacy Concern, Lacking Knowledge of Smartphone Use and Unequal Access to Transport Information. Transport Policy, 99, 175–185.

DO SEAFARERS NEED TRAINING IN MEDICAL FIRST AID AND MEDICINE FOR SEAFARERS?

Rosanda Mulić M.D., Ph.D.
University of Split, Faculty of Maritime studies, Croatia
University of Split, School of Medicine, Croatia

Karlo Kos
Andrea Russo, PhD, Associated professor
University of Split, Faculty of Maritime studies, Croatia

Iris Jerončić Tomić, Ph.D.
University of Split, School of Medicine, Croatia

ABSTRACT

Introduction: Seafaring has always been considered as a hard and dangerous occupation. As a rule, merchant ships do not carry qualified medical doctors. In case of need, medical care is provided by the second mate, the master or a person in charge appointed by the master. In this regard, seafarers complete adequate training through maritime secondary schools, faculties or courses.
Aim: This study aimed to examine the opinions of the maritime students and active seafarers on the need of training in this area.
Materials and Methods: A questionnaire was designed to find out the views on the contents of the courses in Medical care among the regular maritime students and active seafarers attending the Special Education Program for Seafarers, whose program does not comprise medical care topics. The latter was completed by a total of 70 respondents.
Results: There is no significant difference in views of the surveyed students and seafarers regarding the importance of acquiring knowledge in medicine for seafarers. They all agree that this knowledge is necessary on board.
Conclusion: It is neither feasible nor cost-efficient to carry medical doctors on merchant ships, although the seafarers covet to have one on board. Training programs in medical matters are required and defined by international conventions and it is considered that the seafarers / designated persons, having satisfactorily completed training in medical care, are able to deliver medical care on board in case of need.

Keywords: Medical first aid, Medical care, courses, seafarers

1. INTRODUCTION

Seafaring has always been considered as a hard and dangerous occupation and the issue has been recognized by a number of international organizations engaged in seafarers' safety, Including the International Maritime Organization (IMO) and the International Labor Organization (ILO) [1-3] to reduce the risk and improve the quality of medical care in case of emergencies at sea, the IMO creates and proposes model courses with developed programs based on current medical problems and needs of seafarers. In case of sudden illness or an accident and injury during the ship's voyage, the chances of receiving proper and effective treatment are not as good for seafarers as for workers on shore, because of lack of direct and prompt access to competent medical assistance. As a rule, merchant ships do not carry qualified medical doctors. In case of need, medical care is provided by the second mate, the master or a person in charge appointed by the master [4, 5]. As maritime shipping developed as a globally important economic sector, the IMO introduced mandatory education and acquisition of medical certificates of competence, i.e. elementary first aid, medical first aid and medical care, through the STCW (The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) [2, 3]. In accordance with the international maritime regulations, the captain is primarily responsible for this and should therefore be able to provide medical support to the casualty at any time [6]. Due to above mentioned, seafarer's health education and training of seafarers to provide basic medical services on board are mandatory [2, 6, 7]. In this regard, seafarers complete adequate training through maritime secondary schools, faculties or courses.

At the Faculty of Maritime Studies in Split, Croatia, the curriculum developed for the students attending the undergraduate program of nautical studies includes the mandatory courses in First Aid (containing elementary first aid and medical first aid programs) as well as Medicine for seafarers. The total workload amounts to 33 hours for the first aid course (elementary first aid + medical first aid) and 45 hours for the medicine for Seafarers' course [8].

The syllabus of the medicine for seafarers' course is entirely in line with the syllabus developed for the medical care course. This course has been designed for future employees in charge of providing medical care on board ship, enabling them to become competent to participate effectively in coordinated schemes for medical assistance on ships at sea and to provide the sick or injured with a satisfactory standard of medical care while they remain on board.

Until recently, the Elementary First Aid and Medical First aid Programs were mandatory in all other undergraduate studies at the Faculty of Maritime Studies in Split: Marine engineering, Yacht and Marina Management Technologies, Marine Electrical Engineering and information technologies, and Maritime Management. According to the last amendments to the detailed proposals of the study programs, the Elementary First Aid is no longer a compulsory course. Instead, students who lack education in this area have an opportunity to obtain necessary knowledge and skills through the so-called Introductory Supplemental Program during the first two semesters, in order to be entitled to the necessary certificates of competence [8].

In addition to the students of the undergraduate program of nautical studies, the course in Medicine for seafarers can be taken, as an elective course, by the students attending the undergraduate programs in marine engineering and marine electrical engineering and information technologies [8].

With regard to the above facts and the importance of the above medical programs, the authors of this research have been interested to find out the standpoints of maritime students and seafarers regarding the need and importance of these programs and seafarers' competence for providing first aid and medical care on board ships. Our research has been additionally motivated as it has been detected, over the years of the interaction with students and active seafarers, that some of the students show poor interest in the medical programs, while the active seafarers' stance is quite opposite: they demonstrate a higher interest and desire to master these medical programs.

Their viewpoints and opinions on the above matter have been examined through an anonymous survey.

2. MATERIALS AND METHODS

A questionnaire was designed to find out the views on the contents of the courses in Medicine for Seafarers / Medical Care among the regular maritime students and active seafarers attending the Special Education Program for Seafarers, whose program does not contain medical care topics. Comprising 28 questions, the questionnaire was available at Google platform and the participation in the survey was voluntary and anonymous. It was deemed that a participant's consent was granted by the very act of filling in the questionnaire. The latter was completed by a total of 70 respondents, of which 49 attendants of the special education program for seafarers and 21 full-time students of nautical studies at the Faculty of Maritime Studies in Split. The first part of the questionnaire referred to the socio-demographic features of the respondents, while the second part involved the statements by which the respondents expressed their level of agreement.

The Likert scale was used to allow the individual to express how much they agree or disagree with a particular statement. Their positive-to-negative strength of agreement was defined on a scale from 5 to 1, where 5 indicated the most positive stance and 1 the most negative stance.

The Mann-Whitney U test was used for testing the statistical significance. The level of significance was defined by value $p<0.05$.

Hypothesis: students of the Faculty of Maritime Studies are less aware of the need of acquiring knowledge and skills in rendering first aid and medical care on board than the actively sailing seafarers.

3. RESULTS

The survey involved 70 respondents, of which 49 active seafarers and 21 regular full-time students at the Faculty of Maritime Studies in Split. The respondents aged between 19 and 58, the average age being 30.75. The surveyed population was predominantly male (66 or 94.29%), and included only 4 women (5.71%). The research was conducted from the 1st January to 30th September 2021. Regarding their residence, most of the respondents live in places with the population ranging between 1,000 and 10,000 inhabitants (n=26; 37.14%), whereas the few come from the places with less than 1,000 inhabitants (n=9; 12.86%). As for the secondary education, most of the respondents completed nautical high schools (40 respondents; 56.34%) and grammar schools (19 respondents; 26.76%).

The responses / agreements with the statements are presented in Table 1. The difference in standpoints between active seafarers and students is notable in Statements 2, 3, 4, 7, 8 and 12.

The highest level of similarity in opinions can be detected in the Statement "Competence in First Aid and Medicine for Seafarers is essential on-board ship", where the close correspondence amounts to 4.53 out of maximum 5, with an average deviation from the arithmetic mean of 0.73. 64 of all respondents (94.29%) agree that the competence in First Aid and Medicine for Seafarers is essential on-board ship. There is no statistically significant difference ($p>0.05$).

Active seafarers more often than students believe that competence in first aid and medicine for seafarers can be applied in everyday life, not only on board. The difference is statistically significant ($p<0.05$).

Unlike active seafarers, students think that they need more practical classes in first aid and medicine for seafarers ($p<0.005$). Maritime students say that their curriculum should include more content related to maritime medicine ($p<0.05$). Most respondents (41, i.e.

58.57%) agree that the responsibility of providing medical care is too stressful for officers on board (agreement levels 4 and 5). However, students agree stronger than seafarers with this statement, and the statistical difference is significant ($p<0.05$).

Active seafarers / officers, more than maritime students, believe that it would be better if a physician or medical doctor provided medical care on board ship, instead of a trained officer – the level of agreement among the officers is 3.49 and the statistical difference is significant ($p<0.005$). The seafarers have right to receive timely and adequate medical aid on board.

The ship's personnel is responsible for medical care on board. According to the international maritime rules, the ships traveling more than 3 days and carrying 100 or more seafarers on board, must have a ship physician on board. Ships with more than 800 persons on board need to have a second physician. Ships that carry a physician, need to carry a nurse, too [6]. With only a few exceptions, e.g. cruise ships, merchant ships have no physician on board [4, 6, 7].

For a long time now, the importance of education and life-long learning in the life and work of seafarers has been recognized globally. The training of the seafarers on merchant ships is regulated by the International Convention on Standards of Training, Certification and Watchkeeping, known as STCW, which was established in 1978 [9].

Under international guidance, there are three levels of first aid training for seafarers. Before starting working at sea, all seafarers are required to master elementary first aid, which is a short course designed to provide a basic knowledge of what to do in case of an accident or medical emergency. Ship officers are required to complete proficiency in medical first aid training, covering the provision of immediate first aid in the event of an accident or illness on board. The provision of medical care on board a ship shall be carried out by the master or designated crew member who has completed medical training [2, 3, 6].

When comparing the length of education and training of maritime students in matters related to medicine, it has been found out that, at higher education maritime institutions in Germany [7], the initial medical education at university consists of over 120 hours of classes. The future officers learn about anatomy, frequently occurring diseases, tropical diseases, general patient care, pharmacological basics, reanimation, hypothermia and the ability to take a complete medical history for telemedical advice. The medical training also includes a practical section of 2 weeks in a hospital's emergency room and bedside teaching. At the Faculty of Maritime Studies in Split, the workload related to medicine amounts to 78 hours of classes that comprise all matters in compliance with the relevant IMO Model Course. The students have practical training but the exercises in a hospital's emergency room are not included. As the overall workload is considerably lower, this probably affects the students' feeling of readiness to provide first aid and medical care, as well as their self-confidence.

This pilot research has been launched in order to find out the standpoints of maritime students and seafarers on the Medical First Aid and Medical Care courses that are mandatory within the curriculum of the undergraduate program in Nautical Studies. It was assumed that the active seafarers with real-life experience were more aware of the importance of medical knowledge and skills than maritime students. However, it turned out that the hypothesis was not correct – both categories expressed a high level of agreement on the importance and need of this type of competence on board.

The survey results confirm that seafarers, more than students, feel that a vessel should carry a physician instead of a trained officer, to deal with the healthcare of the crew members, although they are aware of the fact that it is not in the shipping company's interest to increase the crew. Owing to the developments in telecommunication and telemedicine, a trained seafarer / officer will probably do everything that can be done, given the circumstances. Unless they are forced to, the shipping companies will not agree to employ a physician on board merchant ships.

The surveyed seafarers say that their current learning literature and sources are obsolete, while both categories agree that the learning materials for the first aid and medical care courses are complicated and hard to understand. From the teacher's empirical perspective, it appears that students tend to use various crib sheets and abridged versions of learning material, instead of the recommended literature and sources (available in 2020), probably thinking that this approach would save time for other, more attractive, activities. As for international sources, the International Medical Guide for Ships (published by the World Health Organization, 2007) is the manual that all ships must carry on board. It is true that some things have changed over time, but not to such an extent to make the manual useless. The fundamental principles have remained the same and, according to the existing regulations, seafarers must undergo a refreshment in Medical Care every five years [2, 6, 7]. Our research confirms that the seafarers themselves do not think that they should complete that refreshment more often. Some nations, like Great Britain and Germany, have provided their seafarers with the national manuals on rendering medical care on board ships.

A similar research was performed among the Turkish maritime students. The results show that the general perception of risk for most of the health problems, particularly of infectious diseases, is very low for all of them. The results show that most of the students get information about health and illness issues from the Internet sources [10].

As for the incidence of the need of medical aid according to the type of vessels, the vessels carrying more passengers, more often than other vessels, require medical aid, as expected. According to international studies on emergency medicine on cruise ships, however, an almost 70% chance of having a medical emergency, resulting in a cruise ship's deviation, represents a reality [7].

The incidence of requests for medical care on merchant ships depends, to a large extent, on the type of vessel [10]. As their crew decrease in number, so do their requests [6, 7].

The study of Oldenburg et al. about the occurrence of serious medical emergencies in respect of the vessel type indicate that, on merchant ships, traumas are the most frequent issues, followed by various cardiovascular conditions, gastrointestinal diseases and serious skin or pulmonary infections [7].

All these conditions and diseases are included in the syllabi of the mandatory Medical Care courses [9]. According to this study, serious emergencies on board (leading to a deviation to an emergency port of call) are most frequently related to trauma or cardiovascular diseases [7].

Both categories agree that the ship officers in charge of providing medical care do not have sufficient knowledge or skills for performing the task.

Both categories agree that the learning materials for the first aid and medical care courses are complicated and hard to understand.

The research has not confirmed the hypothesis that the active seafarers, more than maritime students, consider the competence in rendering first aid and medical care at sea as essential for living and working on board (p=0.220) – see Table 1. Both categories of the respondents are fully aware of the importance of rendering first aid and medical care on board ships.

Table1: Maritime students and seafarers views on first aid and medical care on board

No.	Statement	Student		Seafarer		Z	P*
		Average	SD	Average	SD		
1	Competence in first aid and medicine for seafarers is essential on board ship.	4.67	0.58	4.51	0.73	0.77	0.220
2	I can apply competence in first aid and medicine for seafarers in everyday life, not only on board.	2.90	1.14	3.38	0.96	1.65	**0.049**
3	More practical classes in first aid and medicine for seafarers are needed.	3.62	1.12	2.69	1.38	2.59	**0.005**
4	The university curriculum / Special Education Program for Seafarers should include more content related to maritime medicine.	4.05	0.86	3.47	1.04	2.02	**0.022**
5	Medical care encompasses all areas relevant to human life protection.	3.05	0.74	2.82	0.83	1.13	0.128
6	More human lives would have been saved if this type of education was controlled better and stricter.	3.71	1.38	3.87	1.25	0.27	0.392
7	The responsibility of providing medical care is too stressful for officers on board.	3.81	1.03	3.07	0.91	3.08	**0.001**
8	Instead of an officer in charge of health issues, a vessel should carry a trained physician / medical doctor.	2.62	0.86	3.49	1.36	2.80	**0.003**
9	Officer in charge of medical care on board does not take his/her responsibility seriously.	4.43	0.68	4.51	0.73	0.66	0.254
10	I am sufficiently educated to render immediate aid to a person on board.	3.48	1.08	3.36	1.53	0.15	0.440
11	My learning literature and sources are adequate for seafarers and students.	3.57	1.16	3.64	1.13	0.26	0.396
12	My current learning literature and sources are obsolete.	2.95	1.05	3.53	1.14	1.94	**0.026**
13	Education and knowledge of first aid and medicine for seafarers should be refreshed every year.	3.74	0.99	3.56	1.25	0.37	0.355
14	Officers in charge of providing medical care are sufficiently competent.	2.53	1.22	2.64	0.91	0.90	0.183
15	Learning materials for the first aid and medical care courses are complicated and hard to understand.	4.42	1.02	4.47	0.84	0.03	0.486

4. DISCUSSION

The seafarers have right to receive timely and adequate medical aid on board. The ship's personnel are responsible for medical care on board. According to the international maritime rules, the ships traveling more than 3 days and carrying 100 or more seafarers on board, must have a ship physician on board.

Ships with more than 800 persons on board need to have a second physician. Ships that carry a physician, need to carry a nurse, too [6].

With only a few exceptions, e.g. cruise ships, merchant ships have no physician on board [4, 6, 7].

For a long time now, the importance of education and life-long learning in the life and work of seafarers has been recognized globally.

The training of the seafarers on merchant ships is regulated by the International Convention on Standards of Training, Certification and Watchkeeping, known as STCW, which was established in 1978 [9].

Under international guidance, there are three levels of first aid training for seafarers. Before starting working at sea, all seafarers are required to master elementary first aid, which is a short course designed to provide a basic knowledge of what to do in case of an accident or medical emergency. Ship officers are required to complete proficiency in medical first aid training, covering the provision of immediate first aid in the event of an accident or illness on board. The provision of medical care on board a ship shall be carried out by the master or designated crew member who has completed medical training [2, 3, 6].

When comparing the length of education and training of maritime students in matters related to medicine, it has been found out that, at higher education maritime institutions in Germany [7], the initial medical education at university consists of over 120 hours of classes. The future officers learn about anatomy, frequently occurring diseases, tropical diseases, general patient care, pharmacological basics, reanimation, hypothermia and the ability to take a complete medical history for telemedical advice. The medical training also includes a practical section of 2 weeks in a hospital's emergency room and bedside teaching. At the Faculty of Maritime Studies in Split, the workload related to medicine amounts to 78 hours of classes that comprise all matters in compliance with the relevant IMO Model Course. The students have practical training but the exercises in a hospital's emergency room are not included. As the overall workload is considerably lower, this probably affects the students' feeling of readiness to provide first aid and medical care, as well as their self-confidence.

This pilot research has been launched in order to find out the standpoints of maritime students and seafarers on the Medical First Aid and Medical Care courses that are mandatory within the curriculum of the undergraduate program in Nautical Studies. It was assumed that the active seafarers with real-life experience were more aware of the importance of medical knowledge and skills than maritime students. However, it turned out that the hypothesis was not correct – both categories expressed a high level of agreement on the importance and need of this type of competence on board.

The survey results confirm that seafarers, more than students, feel that a vessel should carry a physician instead of a trained officer, to deal with the healthcare of the crew members, although they are aware of the fact that it is not in the shipping company's interest to increase the crew. Owing to the developments in telecommunication and telemedicine, a trained seafarer / officer will probably do everything that can be done, given the circumstances. Unless they are forced to, the shipping companies will not agree to employ a physician on board merchant ships.

The surveyed seafarers say that their current learning literature and sources are obsolete, while both categories agree that the learning materials for the first aid and medical care courses are complicated and hard to understand. From the teacher's empirical perspective, it appears that students tend to use various crib sheets and abridged versions of learning material, instead of the recommended literature and sources (available in 2020), probably thinking that this approach would save time for other, more attractive, activities. As for international sources, the International Medical Guide for Ships (published by the World Health Organization, 2007) is the manual that all ships must carry on board. It is true that some things have changed over time, but not to such an extent to make the manual useless. The fundamental principles have remained the same and, according to the existing regulations, seafarers must undergo a refreshment in Medical Care every five years [2, 6, 7]. Our research confirms that the seafarers themselves do not think that they should complete that refreshment more often. Some nations, like Great Britain and Germany, have provided their seafarers with the national manuals on rendering medical care on board ships.

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The study of Oldenburg et al. about the occurrence of serious medical emergencies in respect of the vessel type indicate that, on merchant ships, traumas are the most frequent issues, followed by various cardiovascular conditions, gastrointestinal diseases and serious skin or pulmonary infections [7]. All these conditions and diseases are included in the syllabi of the mandatory Medical Care courses [9]. According to this study, serious emergencies on board (leading to a deviation to an emergency port of call) are most frequently related to trauma or cardiovascular diseases [7].

5. CONCLUSION

The research proves that maritime students and active seafarers are fully aware of the importance of competence in providing first aid and medical care at sea. Compared to seafaring officers, students would like to have more education and practical training as they perceive that part of work as very stressful.

It is possible that this standpoint is partly affected by the lack of experience and fear of future responsibilities. Both students and seafarers agree that the ship officers in charge of providing medical care do not have sufficient knowledge or skills for performing the task, which implies the need for supplementary education, i.e. changes in the curricula.

Although the ship officers would gladly give the responsibility of rendering medical support over to the professionally educated and trained physicians, this is not likely to happen as it is neither feasible nor cost-efficient to carry medical doctors on merchant ships. Training programs in Elementary First Aid, Medical First Aid and Medical Care are compulsory and defined by international conventions. It is considered that the seafarers / designated persons, having satisfactorily completed training in medical care, are able to deliver medical care on board in case of need. Complemented by continuously available telecommunication advice support, it is considered that the acquired knowledge and skills are sufficient for the needs of crew members on merchant vessels.

REFERENCES

[1] International Labour Organization. Maritime Labour Convention, 2006. URL: https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:91:0::::P91SECTION:M_LCA_AMEND_A4 (accessed: 13/07/2021)

[2] Edumarine. Medical First Aid and Medical Care. URL: https://www.edumaritime.net/stcw-code/stcw-vi-4-medical-first-aid-and-medical-care (accessed: 14/07/2021)

[3] International Medical Guide for Ships, 3rd edition. (2007) World Health Organization, Geneva.

[4] Mulić R., Vidan, P. Educating/teaching students of maritime studies about medicine for seafarers, 16. Proceedings - 16th Annual General Assembly and Conference of the International Association of Maritime Universities, IAMU AGA, University of Rijeka, Faculty of Maritime Studies in Rijeka, Croatia, 2015.

[5] Jerončić, I., Mulić R., Nikolić J. (2014) Maritime medicine and medicine for seafarers. Proceedings of the 6th IMSC, Solin, Croatia.

[6] Hristova, I. (2019) Need for training of seafarers in first aid and medical matters. Scientific Bulletin "Mircea cel Batran" Naval Academy; Constanta, 22(2):133-137,133A. Doi:10.21279/1454-864X-19-I2-016.

[7] Oldenburg, M., Rieger, J., Sevenich, C. et al. (2014). Nautical officers at sea: emergency experience and need for medical training. J Occup Med Toxicol., 9(19). doi.org/10.1186/1745-6673-9-19. PubMed PMID: 24817903.

[8] Syllabus and detailed proposal of the undergraduate university study programme in Nautical Studies, Faculty of Maritime Studies in Split, 2021.

[9] IMO. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. (1978). Available at: https://www.imo.org/en/OurWork/HumanElement/Pages/STCWConvention.aspx. Accessed: December 5, 2021.

[10] Türkistanli, T. T., Sevgili, C. (2018). Awareness of health risks and communicable diseases among undergraduate maritime students. Int Marit Health. 69(2):142-148. Doi:10.5603/IMH.2018.0021. PubMed PMID:29939392.

[11] Mulić, R., Radošević, J., Vidan, P., Poljak, N. K. (2021). Infectious Risks on Different Types of Ships with Reference to the Covid-19 Pandemic. ToMS. Published online 13/12/2021. doi: 10.7225/toms.v11.n01.w04.

EMERGING TOPICS IN MARITIME TRANSPORTATION CONCERNING HUMAN ELEMENT

Pınar Ozdemir, Dr.
Taner Albayrak, Dr.
Alaettin Sevim
Piri Reis University, Deniz Kampüsü, Tuzla; Istanbul, Turkey
pozdemir@pirireis.edu.tr, talbayrak@pirireis.edu.tr, alaettin.sevim@pru.edu.tr

ABSTRACT

People are the most important components of any system. Although developments in the digital and physical world have changed their roles in the work-life and the expectations of others from them, they continue to remain a key factor in all sectors. One of the sectors where these changes and developments bring new duties and responsibilities to people is the maritime sector. This study aims to focus on the stakeholders' viewpoints concerning the human element in light of the emerging topics in maritime transportation. The data used in the study was obtained from a survey that was responded to by the stakeholders in 5 different countries in the frame of the MINE-EMI Project*. The results showed that the welfare and safety of the people on board are important issues for the stakeholders who are also concerned with attracting new generations to the maritime jobs as well as managing them in the most appropriate way to ensure resilience. Another important point that the survey revealed is the need to revise master's degree programs on Maritime Business Management to prepare the graduates for the future business environment and to update the programs continuously so that they will be proficient enough to provide the students with up-to-date knowledge. No matter how advanced the technology is, the human factor will maintain its importance under all circumstances and at all times, which requires the human element-related issues to be studied continuously.

Keywords: Human element, maritime, future needs, training and education, welfare, safety

1. INTRODUCTION

Making the most efficient use of the human factor, which is the backbone of any business, is important for the success and sustainability. All people who play a role in the business in one way or another contribute to the business. Increasing this contribution and making the business more successful and efficient require investing in people, in other words, enriching the human capital of the business. People are able to accomplish goals in organizations that they would be unable to accomplish alone, and they spend large portions of their lives interacting in organizational contexts [1]. This increases the importance of a harmoniously working human element in an organization. Because organizations that have a well-educated and effective human element can make use of opportunities to nurture innovative ideas, become more effective at solving problems, often focus on critical organizational goals [2]. That makes the human element one of the most important assets in a company.

In maritime, the human element focuses on the human side of shipping, the people involved in every aspect of ship safety and prevention of marine pollution from seafarers to ship operators to port state control officers. According to IMO (International Maritime Organization), the human element involves the entire spectrum of human activities performed by ships' crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to cooperate to address human element issues effectively [3]. Although human element in maritime is studied a lot from the safety point of view [4], [5], there are other aspects which have crucial importance concerning the human element.

In this study, the data gained from the literature review will be compared with the data obtained from a survey applied by the authors in the frame of an Erasmus+ project, and the issues that will gain importance in the future will be discussed.

2. LITERATURE REVIEW

The human element has always been a focus of attention in the maritime and the subject of many pieces of research. Although the research on the subject generally concentrated on its safety aspect, especially in recent years, the research has been multi-faceted due to the unpredictable changes that have taken place at an unexpected speed. It is seen that research is carried out within the framework of issues that have gained importance recently and has been the subject of many studies from various points of view.

Among these studies, those that investigated the role of the human element in autonomous shipping are predominant. One of them is conducted by Mallam et al. [6], which established a framework of the issues humans are likely to face in emerging autonomous systems and operations. They concluded that traditional seafaring skills might be obsolete and unnecessary while skills necessary to operate automated and autonomous maritime systems gain importance successfully and in a sustainable way.

In another study, Ahvenjärvi [7] pointed out that the need for the human element will go on even if fully unmanned ships are being used because they will be controlled and used by ashore-based people. His work also emphasized the safety issues that could arise from controlling ships from the shore.

Another important issue in human element-related studies is safety. It is found that an increasing number of accidents with casualties have been caused by human errors in maritime [8]. Because of the increasing number of accidents, IMO (International Maritime Organization) developed regulations related to the human element and stated the human element as a key element of the safety of life on board ships and a contributing factor to most of the casualties in the shipping sector. It was also emphasized by IMO that maritime safety and the safety of navigation can be enhanced by strengthening the focus on the human element [3].

Some studies researched the safety issue with autonomous ships. One of these studies is carried out by Streng and Kuipers [9], who pointed out the positive effect autonomous shipping could have on sailing safety while emphasizing the fact that it could cause a decrease in employment in shipping, an increase in onshore employment. Teperi et al. [10] pointed out the importance of creating a positive safety culture and emphasized that safety should be improved in the whole system, operative personnel should participate in safety operations/processes and safety data should be shared openly. That is how the maritime safety culture can be improved concretely.

Dijk et al. [11] underlined the importance of education and training for occupational safety and health. Safety is one of the most important concerns on board and it can be improved by efficient education systems [12]. That has been emphasized by some studies. For example, Vederhus et al. [13] approached the human element issue in maritime from a different perspective and focused on its role in the prevention of maritime casualties. They tried to find the connotations of the word demanding for seafarers since they thought that if the perception of demanding work is understood well, then the safety-oriented pieces of training can be designed better to suit the needs of the people. In this sense, they studied both safety and MET (Maritime Training and Education).

Another research studying the role of seafarers in autonomous shipping is the research conducted by Shahbakhsh et al. [14]. After a systematic literature review, they concluded that the importance of the role and intelligence of the human element is largely neglected. They said the skills, competencies, and characteristics of the future seafarers should be determined first, and then the content, resources, and facilities of the MET (Maritime Education and Training) institutions should be decided upon. The same requirement has been emphasized by Sharma and Kim [15] who pointed out the fact that the emergence of autonomous ship technologies required seafarers to be trained to have the necessary skills and competencies to use them efficiently. They identified key technical and non-technical competence requirements for the navigators, which can be used in the revision of STCW competence requirements to train seafarers for autonomous shipping

3. METHODOLOGY

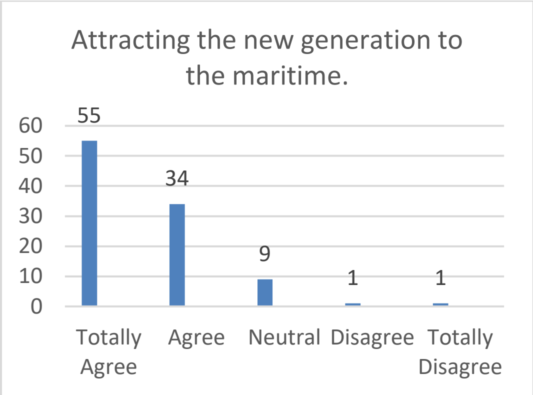
Two-stage research was conducted in order to determine the topics that are expected to gain importance in terms of the human factor in maritime. First of all, a literature review covering the last 3 years was made and prominent issues were noted. Secondly, the data we obtained from the survey that we applied in the frame of the MINE-EMI Project was used.

MINE-EMI Project is an ***ERASMUS + Strategic Partnership Project***, aiming to determine emerging issues in maritime so that a master's program can be shaped accordingly. The project is carried out by 7 partners in 5 countries, which are Piri Reis University (Turkey), Constanta Maritime University (Romania), Nikola Vaptsarov Naval Academy (Bulgaria), The University of the Aegean (Greece), Marine Cluster Bulgaria, (Bulgaria), Municipality of Piraeus, (Greece) and Conference of Peripheral Maritime Regions, CPMR (France). The survey in the Project contained some questions related to the human element in the maritime along with other topics.

A pilot test of the questionnaire was carried out within the scope of reliability and validity tests. By determining the key components measured by the survey questions, factor loads were identified, and the internal consistency of the questions was checked. The final stage of the validity process was putting the finishing touches on the survey based on the information gathered from key components analysis. After that, the survey was activated online. There were 50 questions in the survey to be responded to in 5-point Likert Scale. The survey was sent to maritime stakeholders, which are chambers of commerce, educational institutions, shipyards, tourism, port authorities, companies, student organizations, etc., and was answered by 224 of them. Approximately 56% of respondents were academicians and students in higher education institutes. The remaining 44% were stakeholders from other areas of shipping (ship owners, seafarers, firm employees, etc.).

4. FINDINGS

Two of the human-element-related items in the survey are about attracting new generations to the sector and managing them efficiently. The first item related to this subject is: “The Human Element: How to attract a new generation to the World of shipping to meet the need for qualified seafarers”. Employing qualified personnel has always been the number 1 concern in the sector since working onboard requires the seafarers not only to be competent regarding the skills they need to do their job but also requires them to have a strong stamina to bear the hardships they are likely to meet onboard. As Figure 1 shows, 89% of the respondents appreciated the importance of attracting new generations to the sector, which may be translated as the sector should be made attractive to them.



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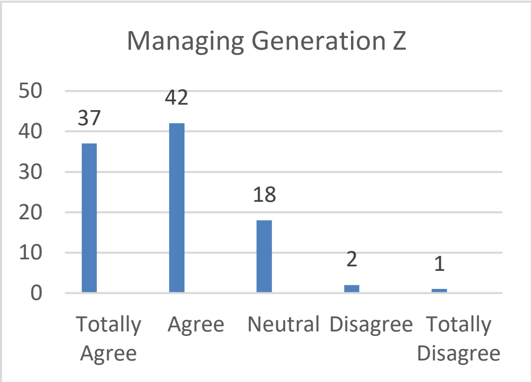
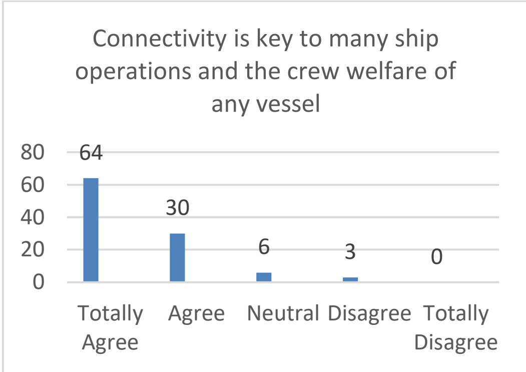


(b)

Figure 1: Attracting the new generations to the maritime (a) and Managing Generation Z (b)

Another important issue is keeping the new generation in the sector to provide resilience. As Generation Z enters the work-life, employers should be prepared for their arrival. Like every generation, they have their own characteristics, distinct needs and behaviours that should be understood well so that they can work productively and contribute to the success of the company [16]. Employers should also take extra precautions to make the maritime sector attractive to the new generation since seafaring is a demanding job that requires a lot of sacrifices. Maritime needs qualified staff and to keep the staff in the sector, it needs to adapt to the changes that the traits of the new generation require such as the organization of the work, communication among employees and business partners [17]. Figure 1 (b) shows 79% of the respondents point out the importance of managing Generation Z both as maritime employees and customers.



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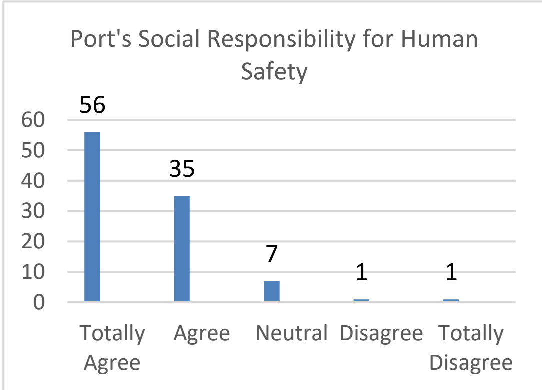
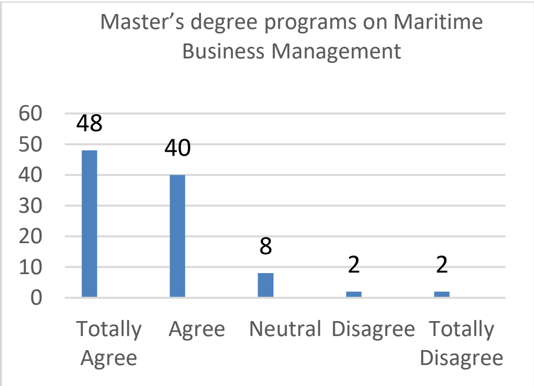


(b)

Figure 2: Connectivity (a) and Port's Social Responsibility (b)

As the Maritime Labour Convention 2006 states, seafarers should have reasonable access to ship-to-shore telephone communications, email and internet facilities. By means of this connectivity, the welfare of the seafarers can be influenced positively. They can easily communicate with their family members or friends, Access various apps that can provide them with different opportunities such as education and training about various subjects, video consultations with doctors or any kind of support to help those in need. Connectivity can increase profitable and efficient working conditions for seafarers [18]. The pleasure that connectivity brings got the highest mark on the Seafarers' Happiness Index for Q1 2018 [19]. It is also critical for safe and reliable maritime operations Innovations such as IoT (Internet of Things), robotic shipping and AI(Artificial Intelligence) will all play a critical role in the near future, emphasizing stable, fast connectivity at sea. Besides, future maritime technologies for smart shipping, IoT, advanced communications, artificial intelligence, robotics and big data will contribute to the connectivity ([20]. As Figure 2 (a) shows, its importance has been appreciated by the stakeholders, too, %94 of whom said it was important for the welfare of the seafarers.

Safety is another issue stressed by the stakeholders. There are a number of human-related factors that affect the safety in ports such as fatigue, carelessness, stress, health, situation awareness, inadequate training, and safety culture [21]. Every port and country is required to be in full conformity with IMO standards to maintain port safety. In 2016, the ILO (International Labour Organization) Code of Practice on safety and health in ports was adopted. It is not legally binding and was designed to provide practical guidance to all stakeholders concerned. It aims to raise the profile of safety and health issues in ports in all parts of the world, and contribute to the health, morale, and well-being of port workers. Another issue that increased the importance of safety at ports is the adoption of LNG (Liquefied Petroleum Gas) which is widely accepted because of its low impact on the environment, easy availability, high energy efficiency. Because of the risks posed by the use of LNG, some risk assessment methods were conducted [22]. Zhang [23], who conducted one of them, found a method that designers could use to ensure port safety management. An increase in the number of such studies proves the importance given to people in maritime.



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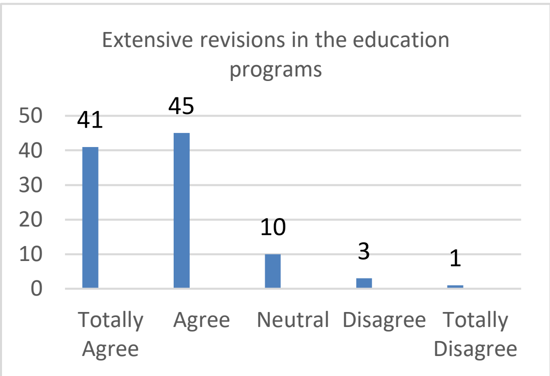
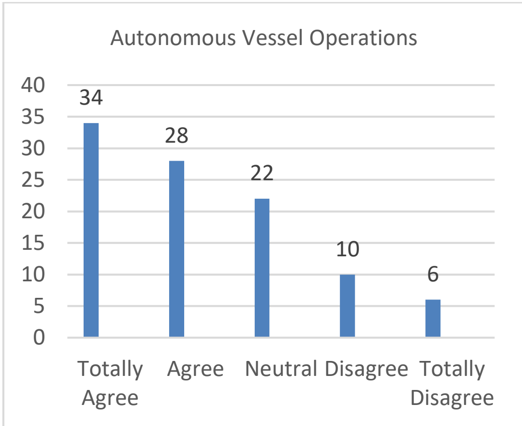


(b)

Figure 3: Responses for the revision of Master degree programs (a) and education programs in general (b)

Another striking idea supported by the stakeholders is the need to modify the MET (Maritime Education and Training) in line with the requirements to keep pace with the developments so that it will be possible to educate the seafarers of the future. The survey had two items concerning MET. According to the responses, as Figure 3 (a) shows, 88% of the respondents think that master's degree programs in Maritime Business Management have to be revised to prepare graduates to the future business environment and, as Figure 3 (b) shows, 86 % think that port facilities and equipment will be subject to profound technological changes that will require extensive revisions in the respective education programs.

Autonomous ship operations are one of the most emphasized issues. In the survey, there was quite a detailed item about autonomous ships which included autonomous vessel operations, regulations for autonomous vessel operations, inshore requirements for autonomous vessel operations, training the operators, unmanned aerial, surface, and underwater vehicles. It is surprising that 62 % of the respondents agree on the importance of autonomous vessel operations while 22 % are neutral, which means they don't have any positive or negative idea on the issue and 16 % don't think this is an important issue. Figure 4 (a) shows the responses of the participants to each choice on autonomous ship operations.



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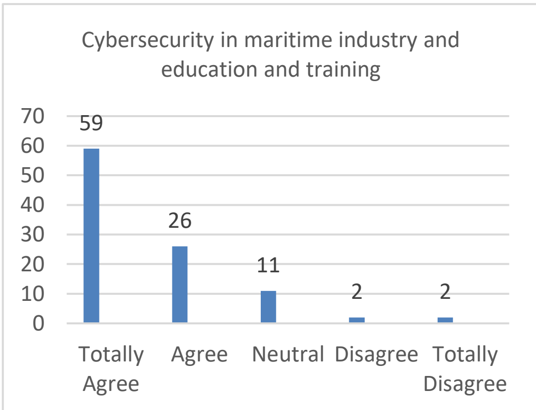

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Figure 4: Responses for the revision of master's degree programs (a) and education programs in general (b)

Next popular issue in the maritime, like in all other sectors, is cybersecurity. As Figure 4 (b) shows 85% of the respondents agreed that cybersecurity is an important issue in industry and it should be handled with care in education and training.

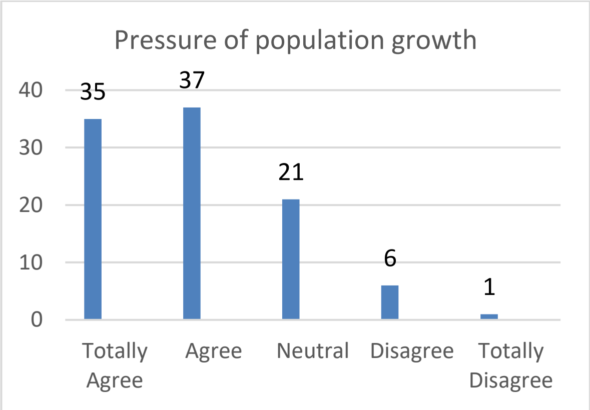

Figure 5: Pressure of population growth on management of marine areas

Coastal regions house about half of the world's population. They make use of the advantages provided by marine ecosystems; however, they harm many coastal areas [24]. Among the problems caused by the rapid and uncontrolled increase in population in marine areas are the increasing amount of human litter, habitat loss, and contamination of coastal and land areas caused by urban and agricultural land use and scarcity of housing and food [25]. As indicated by the responses to the survey, it is vital to implement strategies to mitigate the effects of a rapidly growing population in the coastal areas. Figure 5 shows that 72% of the respondents to the survey agree that population growth has negative impacts on maritime.

5. CONCLUSION

An effective and efficient human capital is an indispensable prerequisite for creating a successful workplace that can achieve its goals more easily. In order to create a successful and peaceful atmosphere in the workplace, thus increasing the efficiency and enabling the business to reach its goals more easily, the relations among people and the attitudes of people towards the conditions of the workplace should be positive and constructive. Although there is no change in some basic factors in today's conditions, there are also differences in the expectations and needs of the human factor in parallel with the changes and developments. These factors may also vary from sector to sector.

From the perspective of the maritime sector, it is noteworthy that studies focused on the human element have recently intensified around a few issues. In the literature review made on the basis of the last three years, it is seen that the issues that are most emphasized are the studies that deal with the human element in relation to the situation in autonomous ships. Researchers have frequently studied the place of humans and the skills they are expected to possess in an industry dominated by autonomous ships. The next issue that has been widely studied is safety. It has been studied alone or in the context of autonomous shipping. Emerging topics in MET and how to transfer them to the curricula to make the future seafarers keep pace with the developments have been studied a lot. In addition to these, the literature review showed that the competencies, skills, and characteristics of the future seafarers have been questioned and efforts were made to align with expectations. Additionally, the issues that deal with cybersecurity and security from different perspectives occupy a prominent place among all studies.

The second source of information that we consulted while determining emerging topics in maritime concerning the human element was the survey applied within the frame of the MINE-EMI Project. Based on the information we obtained from the survey, we see that in addition to the issues covered by the literature review, the topics of attracting young people, that is Z generation, to the sector and managing them are expected to occupy the agenda of maritime stakeholders widely.

As can be seen, the results obtained from the literature review and the survey overlap to a large extent. Like all industries, the maritime industry is in a constant state of development and change. In order to respond to expectations effectively and to ensure sustainability in the sector, all stakeholders must follow the latest innovations and take the necessary measures to keep up with them. In addition, ensuring the professional development of the employees of the sector and understanding them despite the generational differences, and managing them in a way that will achieve the highest efficiency should be priorities.

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REFERENCES

[1] Funtowicz, S., 1997. People in Organizations. Stampa A E III 1997 Advances in peer review research. Science and Engineering Ethics 3(1): 1–104.http://faculty.haas.berkeley.edu/chatman/papers/24_peopleinorgs.pdf

[2] The Human Element, 2022. https://thehumanelement.bconglobal.com/organizational-solutions/why-the-human-element-matters-in-business#

[3] www.imo.org/en/OurWork/HumanElement/Pages/VisionPrinciplesGoals-Default.aspx

[4] Havold, J. I. 2000. Culture in maritime safety, Maritime Policy & Management, 27:1, 79-88, DOI: 10.1080/030888300286716

[5] Schröder-Hinrichs Jens-Uwe, Erik Hollnagel, Michael Baldauf, Sarah Hofmann & Aditi Kataria (2013) Maritime human factors and IMO policy, Maritime Policy & Management, 40:3, 243-260, DOI: 10.1080/03088839.2013.782974

[6] Mallam, S.C., Salman Nazir & Amit Sharma (2020) The human element in future Maritime Operations – perceived impact of autonomous shipping, Ergonomics, 63:3, 334-345, DOI: 10.1080/00140139.2019.1659995

[7] Ahvenjärvi, S. 2016. The Human Element and Autonomous Ships. Transnav. the International Journal on Marine Navigation and Safety of Sea Transportation. Volume 10 Number 3 September 2016 DOI: 10.12716/1001.10.03.18

[8] Rajapakse, A and Emad, GR. (2020). 'Maritime logistics disruptions caused by human element', paper presented at the *10th Asian Logistics Round Table Conference (ALRT)*, 19-20 November 2020, Launceston, Tasmania.

[9] Streng, M. and Kuipers, B. 2020. Economic, social, and environmental impacts of autonomous shipping strategies. Chapter 7 -, Editor(s): Thierry Vanelslander, Christa Sys, Maritime Supply Chains, Elsevier, pp. 135-145. ISBN 9780128184219. https://doi.org/10.1016/B978-0-12-818421-9.00008-2.

[10] Teperi, AM., Lappalainen, J., Puro, V. et al. (2019) Assessing artefacts of maritime safety culture—current state and prerequisites for improvement. WMU J Marit Affairs 18, 79–102. https://doi.org/10.1007/s13437-018-0160-5

[11] Dijk, F. J. van, Bubas,M. and Smits. P. B. 2015. Evaluation Studies on Education in Occupational Safety and Health: Inspiration for Developing Economies, Annals of Global Health. Volume 81, Issue 4. pp. 548-560. ISSN 2214-9996. https://doi.org/10.1016/j.aogh.2015.08.023.

[12] Demirel, E. and Bayer. D. 2015. Improvement of Safety Education and Training for Seafaring Officers. Elektronic Journal of Social Sciences. Autumn-2015 Volume:14 Issue:55

[13] Vederhus,L., Ødegård, A., Nistad, S., and Håvold, J. I. (2018). Perceptions of demanding work in maritime operations, Safety Science, Volume 110, Part A, pp. 72-82, ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2018.07.008.

[14] Shahbakhsh, M., Emad, G. R., Cahoon, S. (2022) Industrial revolutions and transition of the maritime industry: The case of Seafarer's role in autonomous shipping. The Asian Journal of Shipping and Logistics, Volume 38, Issue 1, pp. 10-18. ISSN 2092-5212. doi.org/10.1016/j.ajsl.2021.11.004.

[15] Amit Sharma & Tae-eun Kim (2021) Exploring technical and non-technical competencies of navigators for autonomous shipping, Maritime Policy
&Management, DOI: 10.1080/03088839.2021.1914874

[16] Schroth H. 2019. Are You Ready for Gen Z in the Workplace? California Management Review. 61(3):5-18. doi:10.1177/0008125619841006

[17] Pichler, S., Kohli, C., Granitz, N. 2021. DITTO for Gen Z: A framework for leveraging the uniqueness of the new generation, Business Horizons, Volume 64, Issue 5, pp. 599-610, ISSN 0007-6813. https://doi.org/10.1016/j.bushor.2021.02.021

[18] https://www.ses.com/blog/how-connectivity-supporting-many-factors-influence-seafarer-well-being .Société Européenne des Satellites

[19] www.safety4sea.com/wp-content/uploads/2018/06/The-Mission-to-Seafarers-Seafarers%E2%80%99-Happiness-Index-Q1-2018-2018_06.pdf

[20] Eutelsat.com. 2022. 5 Future Maritime Technologies Powered by Connectivity

[21] Tseng, PH., Pilcher, N. Maintaining and researching port safety: a case study of the port of Kaohsiung. Eur. Transp. Res. Rev. 9, 34 (2017). https://doi.org/10.1007/s12544-017-0250-z

[22] Aneziris,O., Koromila, I., Nivolianitou, Z. 2020. A systematic literature review on LNG safety at ports. Safety Science.Volume 124, ,104595,ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2019.104595.

[23] Zhang, Q.S. 2009. Quantitative risk assessment approach in LNG tank shipping container in port water area.Nat. Gas. Ind., 29 (1) pp. 114-116

[24] Creel, L. 2003. Ripple Effects: Population and Coastal Regions. https://www.prb.org/resources/ripple-effects-population-and-coastal-regions/

[25] Clark GF, Johnston EL (2016). Coasts: Coasts. In: Australia state of the environment 2016, Australian Government Department of the Environment and Energy, Canberra, https://soe.environment.gov.au/theme/coasts, DOI 10.4226/94/58b659bdc758b

THE REVIEW OF USE OF THE MAGNETIC COMPASS IN NAVIGATION

Ivica Pavić, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 38, 21000 Split, Croatia
ipavic71@pfst.hr

Andrej Androjna, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, 6320 Portorož, Slovenia
andrej.androjna@fpp.uni-lj.si

Blagovest Belev, Ph.D.
Black Sea University, Nikola Vaptsarov Naval Academy
9002 Varna, Bulgaria
bl.belev@naval-acad.bg

Jakša Mišković, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 38, 21000 Split
jmiskov2@pfst.hr

ABSTRACT

The development and application of contemporary ship compasses, satellite-based navigation systems, and the Electronic Chart Display and Information System (ECDIS) have had a significant impact on facilitating, speeding up, and increasing the reliability of maritime navigation, as well as enabling the permanent display of the ship's course and position. This technological development reduces the need to use the magnetic compass for navigation, steering and determining the ship's course. Nevertheless, due to its simple design and independence from any source of power, the magnetic compass remains a mandatory navigational device under the provisions of the Safety of Life at Sea (SOLAS) Convention. The magnetic compass is a valuable device for navigation in cases where it is not possible to use other types of compasses and other electronic navigation devices and systems. In this paper, the use of the magnetic compass in navigation is analyzed. For this purpose, a survey was conducted among navigation officers and captains. The results indicate an insufficient level of knowledge, improper use, and error determination of magnetic compass.

Keywords: magnetic compass, maritime navigation, position determination

1. INTRODUCTION

Safety of maritime navigation is of particular importance within the system of maritime safety. The development of electronic navigation devices as well as satellite-based positioning systems has increased the safety of navigation. Of particular importance for safe navigation is the use of global navigation satellite systems (GNSS) and ECDIS. Contemporary maritime navigation has been greatly accelerated by the use of ECDIS, which uses information from mandatory and optional sensors to provide a permanent display of a ship's position, heading and other relevant navigational information [1]. This development has led to a significant decrease in the use and importance of the magnetic compass in navigation. The magnetic compass has become the secondary means of application for navigation for steering ships and keeping them on course. Today, the gyro compass is the most used type of compass because it is more accurate than the magnetic compass. Since both types of compasses have some advantages and disadvantages, magnetic and gyro compasses are usually used in combination on board. Because of its high precision, the gyro compass is used in normal (regular) situations, while the magnetic compass is used because of its high reliability and autonomy in case of gyro compass failure [2]. The advantages of a magnetic compass are its simplicity of construction, reliability, and autonomy [3], while the disadvantages are its lower accuracy compared to other types of compasses, the need for regular compensation, and the possibility of deviation of the magnetic course in case of instabilities of the ship's magnetism [2, 4]. Regardless of the disadvantages, the main advantage of a magnetic compass over all other compass types is its independence from any source of power, and this is the reason why it is (still) a part of the necessary navigation equipment on board [5]. The magnetic compass must be adjusted every year [2] by compensation to ensure its proper use and accuracy. The classical method of compensation is by sailing in cardinal and intercardinal courses and then calculating the coefficients of deviation

[1] and adjusting the magnetic compass correctors. As a result, a table or curve of residual deviation is produced [6]. The consequences of non-implementation or poor implementation of compass compensation are shown in inertia, oscillation of the magnetic rose at major course changes, uneven representation of course changes, the unsteady compass rose in rough seas, stronger influence of a change in latitude on the deviation, large and unreliable deviations. [7]. Ignorance of all these errors by the officer of the watch can endanger the ship and crew when using the magnetic compass in navigation. It is important to note that compensation is a relatively time-consuming job, requiring several hours of work by a certified or qualified compass adjuster [1, 4].

To speed up and simplify the compensation process, some methods different from the classical method of compensation (required by the regulations) have been proposed. The authors in [4] proposed a method that eliminates all types of deviations simultaneously by increasing the coefficient of the guiding force. To apply this method, it is necessary to make some changes in the design of magnetic compasses by using a standard suspension device. Also, it is important to mention the methods developed to compensate the latitude error, since this error can cause the actual deviation of the magnetic compass not corresponding with the data of the deviation table [1].

These methods include the use of the least-square method to calculate the deviation coefficients by observing the compass deviation in any course [8], the use of an automatic system to acquire and algorithm to evaluate the magnetic compass deviation [9], and an algorithm to calculate the latitude error in any geographical position [10]. All these methods are based on least square calculations and for their application it is necessary to use a deviation table and they must be thoroughly tested and evaluated in practice. For a correct application it is necessary to adjust the magnetic compass with the deviation table or curve. In navigation, it is necessary to check the deviation regularly according to the relevant international regulations. Periodic checking of the compass deviation in navigation may indicate the need for repair, testing or adjustment of the magnetic compass [4].

This paper presents updated results from our article entitled: "Determining Residual Deviation and Analysis of the Current Use of the Magnetic Compass" published in the Journal of Marine Sciences and Engineering on February 16, 2021 [1] in the part related to a survey of navigation officers and captains on the basic requirements for the proper use of the magnetic compass. The paper consists of five sections. Section 2 discusses the legal requirements under the relevant international regulations. Section 3 describes the methodology. Section 4 presents the results and Section 5 provides conclusions.

2. LEGAL REQUIREMENTS

Legal requirements for magnetic compasses are set by the International Maritime Organization (IMO). IMO regulations require ships to carry and use a magnetic compass. According to SOLAS regulation V/19.2.1.1, all ships, irrespective of size, shall have a properly adjusted standard magnetic compass or other means, independent of any power supply to determine the ship's heading and display the reading at the main steering position [11]. The regulation does not apply to ships below 150 GT, ships below 500 GT not engaged on international voyages, and fishing vessels, unless otherwise determined by the Administration [11]. According to IMO Magnetic Compass Carriage and Performance Standards Annex I Regulation 1.3, each magnetic compass (standard and spare) shall be properly compensated, and its table or curve of residual deviation shall be available on board in the vicinity of the compass at all times [6]. IMO also requires that masters and officers in charge of navigational watch know, understand, and master the operation and error determination of the magnetic compass [12]. Carrying this compass on SOLAS ships and knowing its proper use is mandatory. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) requires in Section A- VIII /2, Part 4-1 that the officer in charge of the navigational watch (OiC) shall make regular checks to ensure that the standard compass error is determined at least once a watch and, when possible, after any mayor alteration of course, and that the standard compass and gyro compass are frequently compared and repeaters are synchronized with their master compasses [12]. These checks must be recorded in the compass observation (deviation) book.

3. METHODOLOGY

The research methodology is based on a survey of deck officers and captains with the aim of determining the level of knowledge and current use of magnetic compasses on board. For this purpose, a questionnaire with three parts was developed. These are an introductory part, a general part and a part with specific questions. The introductory part of the questionnaire contains general remarks (i.e., research objectives, instructions for respondents, importance of the survey, and a statement regarding voluntary and anonymous participation in the survey) [1]. The questionnaire consists of closed-ended questions with a series of predefined single-choice and multiple-choice responses. The general questions related to the holding of certificates of competency (CoC), experience at sea, and current (or last) assignment with the aim to categorize respondents [1]. The group of specific questions was divided into two categories. The first category related to questions about the appropriate use of the magnetic compass in navigation with the goal of collecting specific data about the respondents' knowledge. The second category referred to questions about the intensity of the importance and frequency of the use of the magnetic compass in navigation with the aim of establishing a connection with the answers to the previous category of questions. The answers to the questions are formulated in the form of a scale ranging from one (lowest level) to five (highest level) [1]. After development, experts review and making some corrections, the questionnaire was published in Google Forms and distributed online via a link. The initial target group consisted of 320 respondents and was later expanded. The survey was launched in December 2020 and is still open to participants. As of February 28, 2022, we have received exactly 150 responses from the target group of deck officers and captains. To avoid possible ambiguities and to increase the trustworthiness of the responses, interviews were conducted with selected 10% of the respondents according to their CoC criteria and their assignment on board. Inconsistencies in some of the responses were also verified in later interviews. In this paper, the same methodology (in terms of survey) was used as in [1], but with updated results as the survey is still open for respondents.

4. RESULTS

Once the responses to the questionnaire were received, the data were processed using descriptive statistics and comparative methods. In the first part of the survey, general questions were asked to determine the structure of the respondents. The answers to the question about the respondents' certificate of competence are shown in Table 1.

Table 1: Certificates of Competency of respondents

Certificates of Competency	Nr.	%
OiC on ships of 500 GT or more	55	36.7
Chief mate on ships of 3,000 GT or more	21	14.0
Master on ships of 3,000 GT or more	61	40.7
Other (national) certificates	13	8.6

Source: Authors

The distribution of responses to the question about the respondents' seagoing experience is shown in Table 2.

Table 2: Seagoing experience of the respondents

Seagoing experience (in years)	Nr.	%
One to four	32	21.3
Four to ten	47	31.4
Ten to fifteen	29	19.3
More than fifteen	42	28.0

Source: Authors

The answers to the question about the current (or last) assignment onboard of the respondents are shown in Table 3.

Table 3: The current (or last) assignment of the respondents

Assignment	Nr.	%
3rd Officer	23	15.3
2nd Officer	54	36.0
Chief mate	29	19.3
Master	44	29.4

Source: Authors

From the data presented in the tables 1 to 3, it can be concluded that the sample is suitable to draw conclusions about the knowledge of the requirements and the appropriate use of the magnetic compass on board. The specific questions were related to regular deviation check, use of a deviation curve (table), steering, opinion about reliability, and use of a magnetic compass in coastal navigation. When asked about the regular deviation check (error determination) of the magnetic compass, 123 (82%) of the respondents answered positively, while 27 (18%) answered negatively. For proper use, it is necessary to have knowledge about the regular deviation check according to the regulations. To determine the level of knowledge regarding STCW requirements, respondents were asked about the intervals of regular deviation check of the magnetic compass. The responses to this question are shown in Table 4.

Table 4: Intervals of regular checking of the deviation of the magnetic compass

Intervals of regular deviation check of the magnetic compass	Nr.	%
At least once a month	15	10.0
At least once a week	15	10.0
At least once a day	26	17.3
At least once a watch	24	16.0
At least once a watch and, when possible, after any mayor alteration of course	49	32.7
Other	21	14.0

Source: Authors

Responses to this question indicate that only 48.7% (16.0% + 32.7%) of respondents are aware of or applies the STCW Convention provision on magnetic compass deviation control intervals. In a survey conducted in 2017 on the same question, Pleskacz presented in [13] the result of 53%. Comparing the results of these two surveys indicates a trend that the implementation of deviation control has slightly decreased in the last five years. It should be noted that more than 50% of the respondents are not aware of or do not apply the relevant provisions of the STCW Convention in navigation. Another important factor affecting the appropriate use of a magnetic compass in navigation is the use of the deviation curve (or table). When asked about this issue, 88 (58.7%) of the respondents answered positively, while 62 (41.3%) answered negatively.

This distribution of responses also indicates an inadequate level of knowledge and/or improper use of the magnetic compass by more than 40% of the respondents. The respondents were asked about their opinion on the reliability of compasses. The responses are shown in Table 5.

Table 5: The respondents' opinion on the reliability of ship compasses

Type of compass	Nr.	%
Magnetic compass	37	24.6
Gyro compass	97	64.7
Optical compass	11	7.3
Satellite compass	4	2.7
Astronomical compass	1	0.7

Source: Authors

The distribution of answers to this question shows that the majority of respondents consider the gyrocompass to be the most reliable. This is because most of the respondents have practical experience only with a gyro compass and a magnetic compass, while only 10% of the respondents have used other types of compasses with a high level of reliability. The next question asked of respondents was about the use of a compass type for steering. The responses are shown in Table 6.

Table 6: The use of a type of compass for steering

Type of compass	Nr.	%
Magnetic compass	14	8.4
Gyro compass	141	84.4
Optical compass	7	4.2
Satellite compass	5	3.0
Astronomical compass	0	0.0

Source: Authors

The answers to this multiple-choice question confirm the importance of using the gyrocompass in steering compared to the magnetic compass. The results should be interpreted because a relatively small number of respondents use other modern types of compasses in practice. Determination of position in coastal navigation is of great importance for the safety of navigation. Position in coastal navigation can also be determined using a magnetic compass.

To obtain data on the frequency and reliability of using a magnetic compass in determining position in coastal navigation, respondents were asked two questions on this topic. The first question asked respondents how often they use a magnetic compass to determine a ship's position in coastal navigation. The responses are shown in Table 7.

Table 7: The use of a magnetic compass to determine a ship's position in coastal navigation

The intervals of use of a magnetic compass	Nr.	%
To determine every position	6	4.0
To determine position every hour	3	2.0
To determine a position during the watch	20	13.3
Don’t use the magnetic compass at all	98	65.4
Other	23	15.3

Source: Authors

The fact that more than 60% of respondents do not use a magnetic compass at all to determine their position can be interpreted in the context of widespread use of contemporary electronic devices and satellite-based systems to determine and display position on ships. In the second question on determining position in coastal navigation, respondents were asked about the most reliable methods for determining position in coastal navigation. The responses are shown in Table 8.

Table 8: The most reliable methods of determining a ship's position in coastal navigation

Method to determine ships position	Nr.	%
Terrestrial navigation method using a magnetic compass to determine directions	2	1.3
Terrestrial navigation method using a gyro compass to determine directions	6	4.0
Terrestrial and electronic navigation method (determination of direction by magnetic compass and distance by radar)	10	6.7
Terrestrial and electronic navigation method (determination of direction by gyro compass and distance by radar)	65	43.3
Terrestrial and electronic navigation method (determination of direction by other types of compasses and distance by radar)	4	2.7
Electronic navigation method (determination of direction(s) and distance(s) by radar)	12	8.0
Satellite-based positioning system (GNSS/GPS)	3	2.0
Satellite-based positioning system (GNSS/GPS) together with position check by using radar	45	30.0
Others	3	2.0

Source: Authors

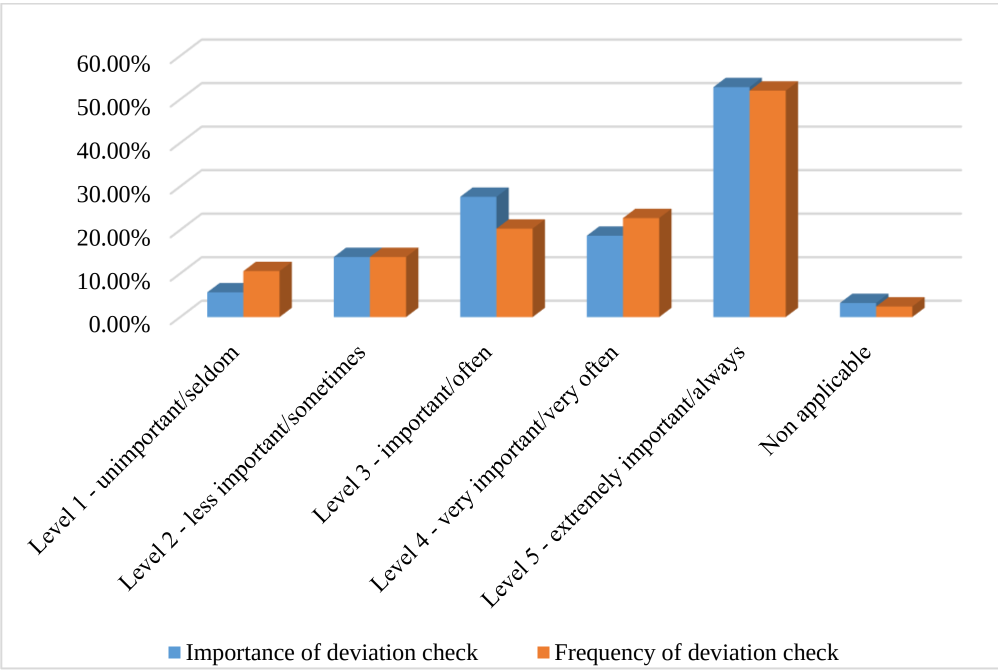
The responses in Table 8 confirm the low use of coastal navigation position determination methods based on the use of the magnetic compass compared to other methods that use electronic navigation devices and systems. This is understandable, because methods based on the use of electronic navigation devices and systems provide faster and more accurate position determination.

In the second category from the group of specific questions, respondents were asked to estimate the importance and frequency of checking the magnetic compass deviation. The responses are shown in Figure 1. Comparing the data on regular deviation check (Table 4) with the data on its importance and frequency (Figure 1), we see that a very similar percentage of respondents perform regular deviation checking of the magnetic compass and at the same time give it the highest importance (52.9%) and frequency (52.7%). This suggests that respondents disagree with or are unaware of the prescribed procedures [1]. Respondents were also asked to estimate the importance and frequency of determining position using a magnetic compass. The responses are shown in Figure 2. Comparing the data on the use of the magnetic compass to determine ship's position in coastal navigation (Table 7) with the data on its importance and frequency (Figure 2) reveals a situation almost identical to the response to the previous question. A very small percentage of respondents use the magnetic compass to determine ship position in coastal navigation, while giving it the highest importance

(8.0%) and frequency (10.0%), further confirming the decline in its use.

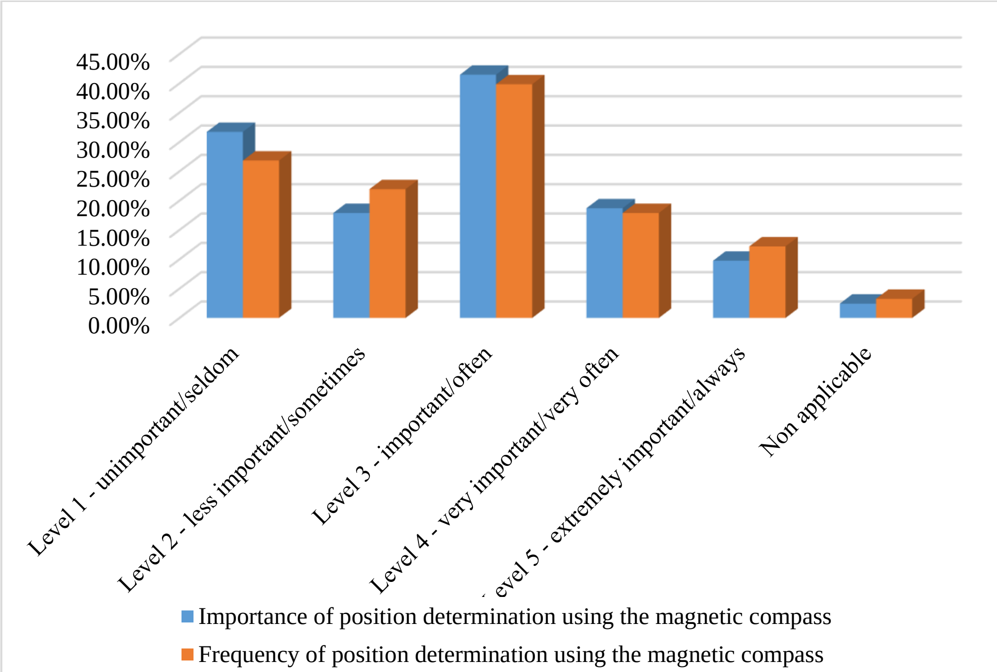
5. CONCLUSION

The magnetic compass has not been considered the most important marine compass for a relatively long time, as the gyro compass is very widely used. The gyro compass is more accurate, precise, and easier to use than the magnetic compass. However, the use of the magnetic compass is still mandatory on SOLAS ships because it is reliable, especially in case of emergencies and possible cyber-attacks on ships. This paper presents the results of a survey. The analysis of the survey results, conducted among officers in charge of a navigational watch and masters, showed that 51.3% of the respondents do not perform regular deviation checks, while 41.3% do not use the deviation table. Comparing the results of this survey to a similar survey conducted by Pleskacz in 2017 shows a slight decrease in the implementation of deviation checks. The survey results also show that less than 10% of respondents use a magnetic compass for steering, while more than 65% of respondents do not use a magnetic compass at all to determine ship's position in coastal navigation. Although the results of the survey are as expected, it should be emphasized that these results show a decline in the level of use and associated knowledge of the proper use of magnetic compasses. The widespread use of gyro compasses and other types of electronic compasses along with contemporary electronic navigation devices and satellite-based systems will further reduce the use of magnetic compasses. Regardless of these facts, as long as the magnetic compass is in use, it is a valuable and reliable tool for safe navigation, especially during emergencies and cyber-attacks.



Source: Authors

Figure 1: The observed importance and frequency of deviation check of the magnetic compass



Source: Authors

Figure 2: The observed importance and frequency of position determination using the magnetic compass

REFERENCES

[1] Androjna, A., Belev, B., Pavic, I., & Perkovič, M. (2021). Determining Residual Deviation and Analysis of the Current Use of the Magnetic Compass. J. Mar. Sci. Eng., 9(204).

[2] Lushnikov, E. (2015). Magnetic compass in modern maritime navigation. TransNav., 9(4), 539–543.

[3] Lushnikov, E. (2012). The reliability of compass information at navigational safety. Sci. J. Marit. Un. Szczecin., 29(101), 117–121.

[4] Lushnikov, E. & Pleskacz, K. (2018). The ultimate solution to the deviation problem of magnetic compasses. Sci. J. Marit. Un. Szczecin., 53(125), 74–80.

[5] Basterretxea-Iribar, I., Muñoz, J., & Labajos, C. (2014). Latitude error in compass deviation. Mathematical method to determine the latitude error in magnetic compass deviation. PMR 3(83), 25–31.

[6] IMO. Resolution A.382(X). 1977. Available online: https://www.register-iri.com/wp-content/uploads /A_X_Resolution_382.pdf, accessed Feb 23, 2022.

[7] Benković, F., Piškorec, M., Lako, Lj., Čepelak, K., & Stajić, D. (1986). Terestrička i elektronska navigacija. Split: Hidrografski Institut Ratne mornarice.

[8] Nguyen, V. S. (2019). Calculation of the deviation coefficients for marine magnetic compass. J. Int. Marit. Saf. Environ. Affairs Shipp., 2(2), 112–115.

[9] Felski, A. (1999). Application of the Least Squares Method for Determining Magnetic Compass Deviation. J. Navig., 52(3), 388–393.

[10] Basterretxea-Iribar, I., Sotés, I., & Uriarte, J. (2016). Towards an improvement of magnetic compass accuracy and adjustment. J. Navig., 69(6), 1325–1340.

[11] IMO. (2020). The International Convention for Safety of Life at Sea. 2020 Consolidated Edition. London: IMO Publishing.

[12] IMO. (2017). The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers-78. London: IMO Publishing.

[13] Pleskacz, K. (2017). Necessity for a change to the control procedures for merchant vessel course indicators. Sci. J. Marit. Un. Szczecin., 49(121), 69–74.

SELECTION OF PROPER THEORETICAL NUMERICAL MODEL TO DESCRIBE THE BEHAVIOR IN LUBRICANT LAYER OF RADIAL PLAIN BEARINGS

Igor Pavlović, M.Eng.
Liane Roldo, Ph.D.
Đorđe Dobrota, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
ipavlovic@pfst.hr, lroldo@pfst.hr, ddobrota@pfst.hr

ABSTRACT

The research and determination of the most suitable theoretical and numerical models available to model the behavior of the lubricant layer in marine radial plain bearings on the newly installed test rig of the University of Split, Faculty of Maritime Studies – PFST is a matter to be resolved. The numerical simulation modeling determines the pressure distribution in the lubricant layer of a radial plain bearing, from which the bearing reaction force and its longitudinal position is obtained by integration. Hence, the goal of this paper is to select a numerical model, which in terms of verification and validation gives the best results by using the MS Excel program “S11BearingsR.xls”, and improve it based on the research results provided by the PFST instrumented test rig. With the experimental verification of the calculated results produced with the program, the values of the bearing reactions and their positions obtained by the calculation can be compared with those that will be produced by the test rig. The numerical model will be obtained by finite differences method, from analytical solution of Reynolds equation and from analytical solution presented in DIN/ISO standards. The obtained results will indicate the selection of the most suitable model.

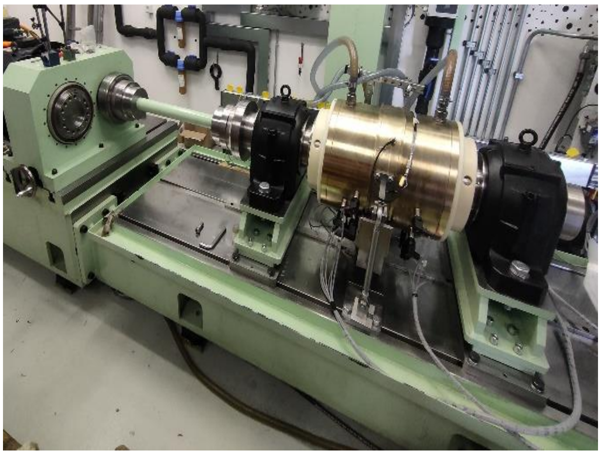
Keywords: Radial plain bearings, instrumented test rig, DIN 31652 standard, Reynolds equation, method of finite differences

1. INTRODUCTION

The numerical analysis is used for computing, using an approximate way, a solution of differential equations which describe the behavior of a dynamic system. Selecting the numerical model required, in solving a numerical analysis problem with the best results, has always been a challenge without the experimental verification of the results. A new instrumented test rig, used to validate the lubricant pressure distribution in the numerical model of radial plain bearings installed in the TEMPO lab - Testing of Engineering Materials and Products Lab at the University of Split, Faculty of Maritime Studies will provide the experimental validation. The instrumented test rig has been assembled, installed and is currently at the testing stage of its pressure modules and different lubricants. Once completed it will allow for evaluation of radial plain bearings of different materials and sizes which will operate in hydrodynamic or mixed lubrication conditions, considering the mechanical properties of the bearing itself (elastohydrodynamic properties) [1]. In this paper, the following three methods were used to obtain a numerical model to describe the behavior in lubricant layer of radial plain bearings:

- Finite differences method (FDM) [2]
- Analytical solution of Reynolds equation [3]
- Analytical solution presented in DIN/ISO standard 31652-2:1983 [4]

Reason behind the selection of the methods is the MS Excel program “S11BearingsR.xls”. The program uses FDM and DIN standard 31652 method through which the numerical model has been obtained and its results are compared with the results provided by the test rig. For the calculation with FDM the program uses a Matlab program “Partial” which is the core of the numerical calculation whereas for the analytical solution it uses the analytical calculation procedure based upon the standard DIN 31652-2:1983 [5][6]. The obtained results of the used methods have been compared with one another and based on their analysis, the most appropriate numerical model is selected. The program requires specific bearing parameters in order to calculate the dimensionless and dimensional values which were taken from the bearing which is currently installed on the test rig (Figure 1).



Source: Picture taken by Igor Pavlović

Figure 1: Instrumented test rig for testing of radial plain bearings.

Among the 3 methods presented, the aim of this study is, based on the results from MS Excel program "S11BearingsR.xls" and the applicable parameters, to select the model which will be used during the trial of the instrumented test rig. Thus, after verification and validation, provided by the test rig, select the most appropriate method.

2. OBTAINING THE NUMERICAL MODELS OF RADIAL PLAIN BEARING

The behavior of lubricant layer in marine radial plain bearings can be described by the Reynolds partial differential equation [3][7]:

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6*\eta*(u_S+u_B)*\frac{\partial h}{\partial x} \tag{1}$$

where:

- x is the coordinate in direction of motion (circumferential direction) [m];
- h is the local lubricant film thickness [m];
- p is the local lubricant film pressure [Pa];
- z is the coordinate perpendicular to direction of motion (axial) [m];
- η is the dynamic viscosity of lubricant [Pa*s];
- u_S is the sliding velocity of shaft [m/s];
- u_B is the sliding velocity of bearing [m/s].

The solution to the above equation can be obtained by the finite differences method and with the analytical (theoretical) form. Finite difference method is often used to convert partial differential or ordinary differential equations, that can be nonlinear, into a system of linear equations which can be solved by matrix algebra techniques [2]. Modern computer programs can solve these linear algebra computations very efficiently which has led to the disseminated use of FDM in modern numerical analysis and makes it as one of the most common approaches in numerically solving partial differential equations [2].

The analytical solutions of Reynolds equation are limited to very narrow bearings (λ<0.25) and for very wide bearings (λ>4), while in reality the bearings have a design feature λ between 0.25 and 4 [8]. Considering that the length to diameter ratio of the bearing that will be tested is λ=1 the analytical solution of the Reynolds equation is not applicable for this research.

The input data of bearing dimensions, lubricant properties, loading and arc bearing angle were calculated by utilizing the numerical solution of Reynold's equation resulting in nondimensional values, namely: Sommerfeld number, eccentricity to radial clearance ratio, attitude angle, frictional coefficient, etc., as well as dimensional values: minimal lubricant film thickness, maximal pressure, radial load, etc. [6]. An analytical solution, with several important values, such as: eccentricity to radial clearance ratio, attitude angle, Sommerfeld number, frictional coefficient, presented in DIN standard 31652 can also be calculated. If the program "S11BearingsR.xls" cannot calculate the required value, it will convey a warning sign that the DIN standard is not applicable. The algorithm used to calculate, as an outcome, generates 3D graphs of pressure force field which is displayed in absolute units and friction force field which is displayed in percentages [6].

3. TEST RIG SPECIFICATIONS

The device is able to test bearings of nominal diameters in range from 60 mm to 300 mm, as well as relative lengths up to λ=4. The maximum length of the shaft can be 3500 mm. The bearing or shaft is able to be loaded with a radial load in the range from 1 kN to 100 kN, while the maximal axial load of axial bearings is 400 kN [1].

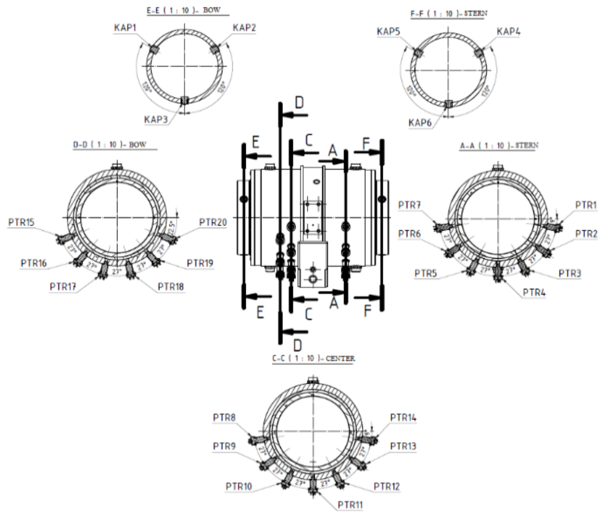
The nominal speeds of rotation of bearing sleeves are from 80 rpm to 3600 rpm. In continuous operation at stable speed the maximum rated load is Tn=400 Nm. The sleeve is able to rotate in both directions as well as oscillate [1].

Operation of test bearings can be done under different lubrication conditions such as: lubrication with oil, sea or fresh water, as well as condition of insufficient lubrication – dry operation [1].

The device is designed modularly as an assembly consisting of the following parts:

- drive module;
- test module;
- radial module;
- thrust module;
- load module;
- lubrication module;
- cooling module;
- control module.

The drive module consists of a drive electric motor and a transmission, and are centered on the thrust module within the location of radial and axial bearings. The second bearing point is the shaft on the radial module within which the radial bearing is installed with same load capability and lifespan as the bearing in the thrust module [1]. The bearing that is to be tested can be installed in the test module which can be located either outside of the thrust and radial module i.e. cantilever or between the thrust and radial module [1]. The test module allows for a controlled eccentric mounting of the bearing bush in relation to the thrust and radial module axis within ±1 mm. This module is affected by the friction moment of the bearing, which must be measured directly during the test, which means that this moment must be precisely determined in relation to the friction moments in other bearings [1]. This module also includes connections for lubricant supply and drainage, temperature sensors, pressure sensors, as well as sensors that measure the thickness of the lubricant layer (Figure 2) [1].



Source: TEMPO lab

Figure 2: Radial module sensor position

The load of the bearing or bearing sleeve being tested is achieved by the load module. The load module is attained with hydraulic cylinders, hydro accumulators, pressure regulators, servo distribution valves, measuring cells etc. The load module is able to take any position within the operating range of the device. With respect to the magnitude of the axial force the load module is attached in an appropriate way in order to test axially loaded bearings [1].

4. SELECTION OF THE NUMERICAL MODEL

The input data required for the program "S11BearingsR.xls" to calculate the dimensional and dimensionless values are shown in Table 1.

Table 1: Input data

Bearing nominal diameter	302.36	mm
Bearing length	302.36	mm
Bearing to journal diameter clearance	2.36	mm
Lubricant density	1000	kg/m3
Lubricant kinematic viscosity	1.1843	mm2/s
Bearing radial load	6	kN
Maximal continuous engine power	0	kW
Engine speed at MCR	300	rpm
Arc bearing angle	360	°
Misalignment parameter	0	
Number of nodes in the i, x or y direction	61	

Source: MS Excel program "S11BearingsR.xls"

By observing the input data, it is clear from the lubricant density and viscosity that the bearing in question is being lubricated by fresh water instead of the more commonly used lubricating oil. Furthermore, the bearing clearance recorded is having a deviation from the preferable clearance value calculated from [9]. The bearing clearance is a value that greatly affects the operational performance of the plain bearing and sometimes deviations occur between the practical case and calculated mean value [9]. The elastic modulus and Poisson's coefficient of the bearing material were not considered for this test [10]. Upon entering the required input data in the program and pressing calculate, the program produces results both for DIN standard 31652 and for FDM which are shown in Table 2.

Table 2: Calculated results of DIN 31652 and FDM

DIMENSIONLESS	DIN 31652	FDM	
ε	0.9902	0.9903	
W*	N/A	35.7607	
β	9.6097	9.9967	°
So_{calc}	107.4566	107.2822	
p^*_{max}	N/A	199.4168	
F*	N/A	53.5856	
μ*	N/A	1.4984	
μ	0.00226	0.00195	
Re	N/A	4695.28	
Re_{max}	N/A	467.5	
DIMENSIONAL			
h_{min}	N/A	0.029	mm
F_t	N/A	0.01	kN
F_r	N/A	5.94	kN
p_{mean}	N/A	0.07	MPa
p_{max}	N/A	0.73	MPa
P_{loss}	N/A	0.055	kW

Source: MS Excel program "S11BearingsR.xls"

The meaning of the symbols shown in Table 2 are as follows:

- ε - eccentricity to radial clearance ratio;
- W^* - Dimensionless journal bearing load in radial direction;
- β - attitude angle;
- So_{calc} - Calculated Sommerfeld number;
- p^*_{max} - Dimensionless pressure;
- F^* - Petroff multiplier;
- μ^* - Dimensionless friction coefficient;
- μ - Frictional coefficient;
- Re - Reynolds number;
- Re_{max} - Maximal Reynolds number;
- h_{min} - Minimal lubricant film thickness;
- F_t - Frictional force;
- F_r - Radial load (from pressure);
- p_{mean} - Mean pressure;
- p_{max} - Maximal pressure;
- P_{loss} - Power loss in the bearing.

5. RESULTS AND DISCUSSION

By evaluating the gained results shown in Table 2, it was observed that the FDM gives substantially more information and results compared with the analytical solution from the DIN standard 31652. Furthermore, it was observed that the DIN 31652 method is not applicable for dimensional calculated results. Therefore, by comparing the results obtained by both methods, very small deviations can be observed between the values (Table 3).

Table 3: Comparison between DIN 31652 and FDM results

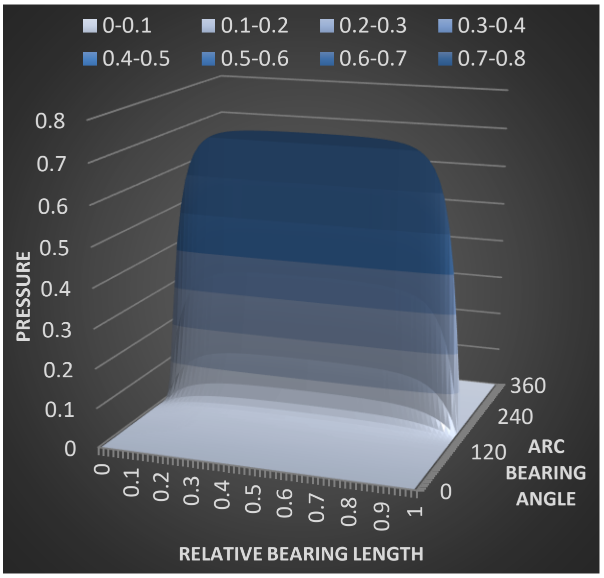
	DIN 31652	FDM	Deviation
ε	0.9902	0.9903	0.01%
β	9.6097°	9.9967°	3.87%
So_{calc}	107.4566	107.2822	0.16%
μ	0.00226	0.00195	13.72%

Source: MS Excel program "S11BearingsR.xls"

Even though the frictional coefficient result deviation is showing a high percentage value (13.72%), its numerical value is in 0.0003 decimal difference which makes the result acceptable. The eccentricity to radial clearance ratio and attitude angle, which describe the magnitude and position of the minimum thickness of lubricant film, show acceptable result deviations as their percentage values are minimal (0.01% and 3.87%). The Calculated Sommerfeld number is a parameter for the load-carrying capacity which depends on the relative eccentricity, the relative bearing length and the angular span of bearing segment [7]. Its result from the test is showing 0.16% deviation which is an excellent result.

Another outcome is a program generated 3D graph of pressure force field and friction force field along with their table of corresponding numerical values. The number of nodes displays the density of the mesh in the 3D graphs are also a part of the input data that can be entered. For this article 61 nodes were used to display the results for a more dense and accurate mesh.

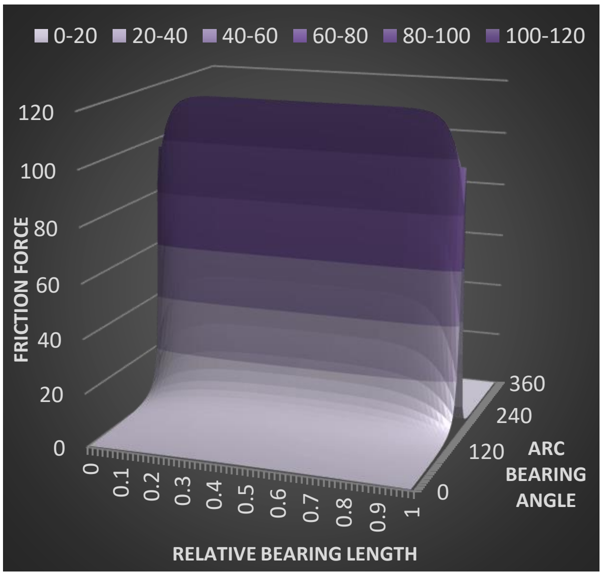
The pressure force field graph (Figure 3) displays the pressure [MPa] for partial bearing at certain bearing angle. The maximal pressure recorded is 0.73 MPa at 186° arc bearing angle at position 0.5 ratio of relative bearing length. The mean pressure value recorded is 0.07 MPa.



Source: MS Excel program "S11BearingsR.xls"

Figure 3: Pressure force field

The friction force field graph (Figure 4) displays the friction force [kN] for partial bearing at certain bearing angle. The lowest force recorded is 0.0026 kN at 360° arc bearing angle throughout the relative bearing length from one end to another, while the highest force recorded is 117.1 kN at 186° arc bearing angle at position of 0.25 - 0.3 and 0.7 - 0.75 ratio of relative bearing length.



Source: MS Excel program "S11BearingsR.xls

Figure 4: Friction force field

Out of the calculated results provided by the program "S11BearingsR.xls" and FMD method, presented in Table 2, preliminary results that can be currently produced on the instrumented test rig are the following dimensional values:

- h_{min} - Minimal lubricant film thickness;
- p_{mean} - Mean pressure.

The results produced on the instrumented test rig are shown in Table 4 in comparison with the results from Table 2.

Table 4: Comparison between FDM and test rig results

	FDM	Test rig	Deviation
h_{min}	0.029 mm	0.032 mm	9.375%
p_{mean}	0.07 MPa	0.05 MPa	28.57%

Source: MS Excel program "S11BearingsR.xls" and TEMPO lab

From the Table 4 it is visible that both results deviations are showing large percentage value (9.375% and 28.57%) while their decimal difference is only 0.003 for the minimal lubricant film thickness and 0.02 for mean pressure. Such preliminary results are acceptable and look promising for future research and experiments.

6. CONCLUSION

Out the three methods selected to obtain the numerical model for the testing purposes of describing the behavior in lubricant layer of radial plain bearing one method stood out. The FDM gave the most and best results which is why it is one of the widely used method in modern numerical analysis. The analytical solution of Reynolds equation was not applicable for this scenario due to length to diameter ratio being out of range to calculate. The analytical solution presented in the DIN 31652 standard displayed good results in comparison with the FDM, but produced only 4 results out of the 16 required values, while it was completely not applicable for dimensional values. Without the program which used the analytical solution presented in DIN 31652 standard and the finite differences method it would be very difficult and time consuming to manually calculate all the required values.

The calculated dimensional values provided by the FDM were compared with the preliminary values produced by the PFST instrumented test rig and the results were surprisingly good. Once the testing stage of the test rig is fully completed, more research will be carried out and the output parameters will be directly compared with the results obtained by the FDM which should help in improving the model and correcting possible wrong hypothesis. If the numbers continue to match within an acceptable deviation as they did in this article, then it will mean that indeed the finite difference method was the best method used to obtain and select the most suitable numerical model to describe the behavior in lubricant layer of radial plain bearings.

REFERENCES

[1] …, *Technical specification of test device for sliding bearings* (in Croatian), Faculty of Maritime Studies, Split (2018.)

[2] Christian Grossmann; Hans-G. Roos; Martin Stynes (2007). *Numerical Treatment of Partial Differential Equations. Springer Science & Business Media*. p. 23. ISBN 978-3-540-71584-9.

[3] Osborne Reynolds (1886). *IV. On the theory of lubrication and its application to Mr. Beauchamp tower's experiments, including an experimental determination of the viscosity of olive oil,* Phil. Trans. R.Soc., 177:157–234

[4] Standard DIN Deutsches Institut für Normung, Berlin. (1983). *Plain bearings – Hydrodynamic plain journal bearings designed for operation under steady-state conditions – Part 2: Functions necessary when designing circular cylindrical bearings*, DIN 31652-2:1983

[5] Stachowiak, G., & Batchelor, A. W. (2014). *Engineering Tribology* (4th ed.), Butterworth-Heinemann.

[6] Nenad Vulić (2011). *Hydrodynamic lubrication properties of radial journal bearings*, Croatian Register of Shipping

[7] Standard DIN Deutsches Institut für Normung, Berlin. (1983). *Plain bearings – Hydrodynamic plain journal bearings designed for operation under steady-state conditions – Part 1: Design of circular cylindrical bearings*, DIN 31652-1:1983

[8] Ivan Komar (2012). *Contribution to the selection methodology of the most convenient marine propulsion stern tube bearings* (in Croatian) [Doctoral dissertation, Faculty of Maritime Studies, University of Rijeka].

[9] Standard DIN Deutsches Institut für Normung, Berlin. (1983). *Plain bearings – Hydrodynamic plain journal bearings designed for operation under steady-state conditions – Part 3: Operational parameters necessary when designing circular cylindrical bearings*, DIN 31652-3:1983

[10] Junsong Lei, Ruiping Zhou, Hao Chen, Yakun Gao, Guojun Lai (2021). *Experimental investigation of effects of ship propulsion shafting alignment on shafting whirling and bearing vibrations*, Journal of Marine Science and Technology.

EFFICIENCY OF MONITORING WORKING CONDITIONS OF SEAFARERS ON FOREIGN SHIPS IN THE PORTS OF THE REPUBLIC OF CROATIA

Ranka Petrinović, Ph.D.
Nikola Mandić, Ph.D.
Faculty of Maritime Studies, University of Split
Ruđera Boškovića 37, Split, Croatia
ranka@pfst.hr, nmandic@pfst.hr

Trpimir Perkušić, Ph.D.
University of Split, Faculty of Law
Ulica Domovinskog rata 8, Split, Croatia
trpimir.perkusic@pravst.hr

Tony Vuković, mag. iur.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
tvukovic@pfst.hr

ABSTRACT

The inspection of foreign ships in EU state ports is managed under *The Paris Memorandum of Understanding on Port State Control (Paris MOU),* adopted in 1982, and amended many times since then. All states signatories of *the Paris MOU* have pledged to maintain an inspection system of ships calling at their ports, to enable all ships, without discrimination as to flag, to comply with the standards of numerous international conventions on navigation safety, protection of the marine environment, as well as the standards of seafarers' working and living conditions. In Croatia, *the Ordinance on the inspection of navigation safety regulates* the inspection of foreign ships. The paper analyzes the inspection system of ships in ports of the States signatories of *the Paris Memorandum* to reduce the deficiencies in working conditions of seafarers. Labor relations of seafarers are regulated by the *Maritime Labour Convention* - MLC 2006, which covers almost all aspects of seafarers' life and work. According to its provisions, all Member State ships shall have a maritime labor certificate as prima facie evidence that the requirements of this *Convention* have been met. In particular, the paper presents and compares statistical data on the types and number of deficiencies on foreign ships related to non-compliance with the *MLC* in Croatian ports and the number of deficiencies identified in ports of other Paris Memorandum countries over a period of six years (2016-2021). Based on statistical data, an assessment of the effectiveness of monitoring the working conditions of seafarers in the ports of the Republic of Croatia is given.

Keywords: Paris Memorandum of Understanding on port State control (Paris MOU), Ordinance on the inspection of navigation safety, working conditions of seafarers, Maritime Labour Convention, 2006

1. INTRODUCTION

The Republic of Croatia has the right and obligation to carry out inspections of the working and social conditions of seafarers on foreign ships entering Croatian ports which are open to international traffic. Inspection activities are the activities of performing inspection supervision over the implementation of the provisions of the Maritime Code related to the safety of navigation, protection of marine environment and living and working conditions of crew members on ships, the provisions of by-laws adopted under the Maritime Code and the provisions of relevant international agreements ratified by Croatia. In Croatia, these tasks are performed by navigational safety inspectors of the Ministry of the Sea, Transport and Infrastructure and port authorities. [8]

Inspection of foreign ships in EU state ports is carried out in accordance with the provisions of the Paris Memorandum of Understanding on Port State Control which was adopted in 1982 (hereinafter: the Paris Memorandum) and has been amended several times. All States Signatories to the Paris Memorandum, including Croatia, have committed themselves to maintain an effective control system for the control of ships entering their ports in order to ensure that ships meet the standards of numerous international conventions on the safety of navigation, marine environment, and seafarers' working and living conditions. [11]

The international character of maritime navigation, the social position of seafarers, and their working conditions on ships require uniform and high international standards in their field of work. These requirements are fulfilled by the adoption of international conventions under the umbrella of the International Labour

Organization (hereinafter: ILO). [20] Within the ILO, a large number of conventions and recommendations on the regulation of seafarers' labor conditions have been adopted since 1920. The greatest success in this regard was made in 2006, with the adoption of the Maritime Labour Convention (hereinafter: MLC Convention). The Convention entered into force in August 2013 (twelve months after it was ratified by 30 countries with at least 33% of the world's gross tonnage). [14]

Without introducing new, significantly different requirements, but in compliance with the prescribed obligations of flag states and port state inspections, the Convention enables a more effective application of the prescribed standards in relation to the previous ILO conventions. The novelty was that Member State authorities can inspect working conditions in their ports and on ships of the states that have not ratified the Convention, which has accelerated the Convention's entry into force. [14]

Under the provisions of the MLC, each Member must ensure that a ship flying its flag has a Maritime Labor Certificate and a Declaration of Maritime Labor Compliance. The flag State is obliged to exercise supervision over ships flying its flag and to issue certificates, while the port State has the right and obligation to inspect by verifying that the ship has the appropriate certificate and that the conditions on board comply with the provisions of the MLC. [6]

The system of ship surveillance in the ports of the states of the Paris Memorandum aims, among other things, to reduce the number of deficiencies on ships related to the working conditions of seafarers prescribed by the MLC Convention. [11] The paper presents and analyzes statistics on the types and number of deficiencies on foreign ships caused by violations of the MLC Convention in Croatian ports and compares them with deficiencies identified in the ports of other Paris Memorandum member states over a period of six years (from 2016 to 2021).

2. MARITIME LABOUR CONVENTION, 2006

2.1. Characteristics of MLC Convention

For seafarers, as a special category of employees, the place of work is also the place of living, and their living and working conditions vary greatly from the conditions of employees in other economic activities performed on land. [1] Many international conventions have been adopted within the ILO, and the adoption of the MLC convention in Geneva in 2006, which entered into force in 2013 (ILO 186). Its provisions ensure the full protection of the fundamental rights of all seafarers, regardless of their nationality or the flag State. So far, 97 countries have ratified the Convention with over 90% of the total world gross tonnage, including most European Union countries. [21] The Republic of Croatia ratified the MLC Convention in February 2010 and harmonized its national legislation with its provisions.

The MLC Convention has a similar structure to the practice used by the International Maritime Organization (hereinafter: IMO) for its international treaties, which is the consolidation of binding norms and recommendations into one act. The MLC Convention consists, in addition to the preamble, of the Articles, Rules and Code. The Articles and Rules contain the fundamental rights and principles as well as the fundamental obligations of the members of the Convention, while the Code contains details regarding the application of the Rules. Part A of the Code (Standards) is binding, and Part B (Guidelines) contains recommendations that the Member States should take into account in the process of adopting national regulations while implementing the Convention. The Rules and the Code are divided into five chapters: Minimum requirements for seafarers to work on a ship, Conditions of employment, Accommodation, recreational facilities, food and catering, Health protection, medical care, welfare and social security protection, and Compliance and enforcement. [6]

The MLC convention was amended in 2014, 2016, and 2018. Thus, in 2014, for the first time in the history of maritime affairs, the position of abandoned seafarers and their financial claims (within the provisions on repatriation) were regulated through binding international legislation. [15] Further Amendments followed in 2016 (elimination of harassment and bullying on board) and in 2018, which regulate the right to pay and repatriation during seafarers' abduction (by pirates, etc.). [21] The new amendments were partially adopted in 2021 at the first part of the ILO tripartite meeting, while the second part of the meeting will take place in May 2022. The latest amendments focus on the covid crisis, which has had an extremely negative impact on the position of seafarers in international navigation.

2.2. Application of the MLC Convention in the Republic of Croatia

The MLC Convention let national legislatures to regulate the working and social position of seafarers in the spirit of their legal and political system, while meeting the highest standards set by The Convention. [14] The Republic of Croatia ratified the MLC Convention in February 2010 and aligned its national legislation with its provisions. [6] The provisions of the Convention were implemented by the Croatian legislator in the amendments to the Maritime Code of 2011 and 2013 [17] and the Ordinance on the Application of the Maritime Labor Convention of 2006 (hereinafter: the Ordinance on the Application of the MLC Convention or the Ordinance). [19]

The Ordinance regulates in detail the financial guarantee in accordance with the 2014 Amendments to the MLC Convention in the case of abandoned seafarers [7] and contractual claims. According to this Ordinance, the shipowner is obliged to maintain in force insurance or other financial guarantee to assist seafarers in the event of their abandonment and to cover the costs of the contractual claims of seafarers. The contractual claim is a claim relating to the death or long-term disability of a seafarer resulting from an injury at work, illness or in relation to some dangerous goods or dangerous activity, as defined by national law, seafarer's employment contract, or standard collective agreement. [13]

In addition to the Maritime labour certificate and Declaration of maritime labour compliance, the shipowner shall ensure that the ship has a document issued by an insurance provider or other financial guarantee, which confirms that there is a sustained financial guarantee. [13] Such a document must be placed in a visible and accessible place on board the ship and contain the necessary information about the ship and the shipowner and the provider of the financial guarantee as well as the period of validity of the financial guarantee. This includes confirmation from the insurance provider or other financial guarantee that the financial guarantee meets the requirements of Standard A 2.5.2. and Standard A 4.2.2. of the MLC Convention. [19]

3. INSPECTION OF SEAFARERS' WORKING AND LIVING CONDITIONS

In Croatia, the inspection of foreign ships is prescribed in detail in the Regulation on conducting the navigation safety inspection (hereinafter: the Regulation on inspection or the Regulation). [18]

It is important to note that the authorities of the Member States may also inspect working conditions on board ships which have not ratified the MLC. [14] When inspecting a ship flying the flag of a State other than a signatory to the MLC, navigational safety inspectors will ensure that the treatment of that ship and its crew is not more favorable than that of a ship flying the flag of a State signatory to the Convention. Such a ship is subject to a more detailed inspection in accordance with the principle of no more favorable treatment in accordance with the procedures laid down in the Paris Memorandum. [16]

3.1. Paris Memorandum

Inspections of foreign ships of EU state ports are carried out in accordance with the provisions of the Paris Memorandum of Understanding on Port State Control adopted on 26 January 1982, which has been amended several times (significant changes were adopted in 2011 with the introduction of the New Inspection Regime - NIR).

The purpose of adopting this Memorandum is to unify and coordinate the procedures which control, in individual ports, whether the ships entering them respect and to what extent the existing international standards, without discrimination on the basis of their flag. The goal of these controls is to completely eliminate ships, which do not meet the standards, from the ports of the countries where such control is carried out. The Paris Memorandum itself does not set any new standards that merchant ships arriving in the ports of the Member States should meet – moreover, the standards whose application is controlled by the port states and are contained in international conventions adopted within the IMO (LL 66, SOLAS 74, MARPOL 73/78, STCW 1978/1995, COLREG 72, TONNAGE 69, CLC 92, AFS 2001) and the ILO (MLC 2006). An inspection of a foreign ship primarily checks whether the ship has valid documentation in accordance with the provisions of these international conventions. [10] The Republic of Croatia has been a full member of the Paris Memorandum since 1st January 1997. In accordance with its requirements, it conducts inspections of foreign ships in its ports in line with the European standards.

During the inspection, an inspector aims to determine whether the ship has the necessary certificates, whether it presents a risk to safety, human health, and the marine environment, whether it has safety protection, whether the crew has a satisfactory level of knowledge for safe ship management and whether the working conditions are in accordance with international standards. If it is found that the ship does not meet the prescribed standards, it will be detained from sailing until the deficiencies are eliminated. After the inspection, the results are entered into the Paris Memorandum Thetis information system (an online database) and are in that way available to the other Member States. The publication of data eases future inspections and avoids unnecessary duplication. [16]

Navigational safety inspectors inspect foreign ships based on their risk profile. The ship's risk profile is determined by a combination of general and historical parameters. The category of the ship affects the technical methods of ship maintenance, so the type of the ship is the basic general parameter on which the choice of the ship for inspection depends. The next important general parameter is the age of the ship. The age limit of the ship is 12 years. Historical parameters are based on the number of deficiencies and detentions within a given period. In addition to the general and historical parameters that determine the degree of risk of ships, there are other determining and unforeseen factors that, in exceptional circumstances, increase ship risk. [12]

Based on the risk profile of the ship, the priority of the inspection, the time intervals between inspections, and the scope of the inspection are determined. Inspections can be periodic, additional, basic, detailed, and extended inspections. [18] The selection of ships for inspection is made according to the degree of risk. Ships are categorized into three groups: High Risk Ships which are inspected at 6-month intervals; Standard Risk Ships which are inspected at 12-month intervals and Low Risk Ships that are inspected at intervals of 24 to 36 months. [16]

Based on the inspection of foreign ships in the port countries, three lists are formed: a white, gray, and black list. The flag states on the black list are significantly worse than the Paris Memorandum average, the countries on the gray list are the average ones, and the countries on the white list are, according to the number of detentions of their flagships in relation to the number of inspections, significantly better than the Paris Memorandum average. In addition, flag States are divided into those of very high risk, high risk, medium to high risk, and medium risk, depending on the number of detentions. In order to classify the flag State on the black, grey, or white list, it is necessary that at least thirty ship inspections are conducted in the Member States of the Memorandum. [16] The Croatian flag is on the white list.

The member States are ranked on one of these three flag lists based on the results of ship inspections performed over a three-year period. The data on a shipping company are obtained by comparing the number of detentions, deficiencies, and inspections for all ships in the fleet, compared to other companies. Two indices have been formed: the detention index and the deficiency index. The detention index is the ratio of the number of detentions of all ships in a company's fleet and the number of inspections of all ships within the fleet in the previous 36 months, in relation to the average detention ratio for all inspected ships. The deficiency index is the ratio of all deficiencies of all ships in the company's fleet and the number of inspections within the fleet in the past 36 months, relative to the average deficiency ratio for all ships inspected in the system. [16]

3.2. Procedures and guidelines for ship inspection in Croatia

The procedures and guidelines for the inspection of foreign ships in Croatia, as a member of the Paris Memorandum, are contained in Annex VI to the Ordinance on the inspection of navigation safety. [18] In the event that deficiencies are found on a foreign ship, which obviously endanger safety, health or the environment, the inspector will impose a measure of detention or stoppage of operation of the ship. [16] Detention is a formal prohibition of a ship to continue sailing due to identified deficiencies which, individually or together, make the ship incapable of navigation. Stoppage of an operation is a formal prohibition of a ship to continue her operations due to identified deficiencies which, individually or together, would render the continued operations hazardous. [18]

Ordinance on the inspection of navigation safety also prescribes measures for refusal of access for certain ships. Detention order is a decision issued to the master of the ship, the company responsible for the ship and the flag state of the ship, informing that the ship will be denied access to all ports and anchorages in the Paris Memorandum. [18]

Thus, access will be refused to any ship flying the flag of a State included on the black list due to the number of detentions and to any ship to which a detention of operations was issued more than twice in the previous 36 months in the State of the Paris Memorandum or to any ship flying the flag of a State which was listed, due to the number of detentions, on the gray list and which has been issued a stoppage of operations more than twice in the previous 24 months in the Member State of the Memorandum. Detention is applied as soon as the ship departs from the port or anchorage where it was stopped for the third time. [18] The inspector is obliged to enter the data related to inspections of foreign ships in the Thetis inspection database as soon as an inspection report is completed or the measure of detention of the ship is lifted.

3.3. Inspection of MLC provisions within the Paris Memorandum

If it is determined that the working and living conditions on board clearly endanger safety, health, or protection of seafarers or that the deficiencies present a serious or repeated violation of the MLC Convention, the Navigational Safety Inspection will impose a detention or stop operations. The measure of detention or stoppage of operations is not revoked until the stated deficiencies are eliminated or until the safety inspector accepts the so-called Rectification Act Plan (RAP) contained in the Ordinance on inspection (Appendix XXX) and until it is assured that the plan will be implemented promptly. When deciding whether to accept an RAP, the inspector takes into account the following elements: the length and nature of the planned trip; the nature and dangers to seafarers' safety and health; the seriousness of violation of the MLC Convention requirements (including the rights of seafarers); the history of deficiencies and their recurrence; whether the deficiencies are related to working hours or rest periods; the minimum number of crew members in accordance with the MSMD as well as the number and nature of deficiencies identified during the inspection. [16]

If the navigation of a ship is prevented due to a serious or repeated violation of the MLC Convention requirements (including seafarers' rights), or due to living and working conditions on board which clearly endanger safety, health, or security of seafarers, a competent navigation safety authority informs the flag State and invites a representative of the flag State to be present, if possible, during the inspection, requesting a response from the flag State within the prescribed time limit. The competent safety management authority will also report without delay to the relevant seafarers' and shipowner' organizations in the port where the inspection was carried out. [18]

If it is established, after a more detailed inspection, that the working and living conditions on board do not comply with the requirements of the MLC Convention, the inspector will immediately notify the master of the ship of the deficiencies, stating the time limits by which they have to be rectified. In case the inspector considers that these are significant deficiencies or if the deficiencies are related to the complaint from Annex V, Part A of the Ordinance (if the ship has extremely poor hygiene conditions; if there is a report or reasonable doubt that working conditions relating to the working hours of the crew members are not complied with, if there is no timetable of work schedule or records of seafarers' hours of work and rest, if a complaint is made alleging that certain working and living conditions on board do not comply with the requirements of the MLC, if the documents required by the Convention are not available or are not kept properly or are invalid on some other grounds, if working and living conditions on board are not in accordance with the requirements of the Convention the inspector will inform the relevant seafarers' and shipowner's organizations in the Republic of Croatia, and may inform the representative of the flag State and provide relevant information to competent authorities of the next port of call. [16]

3.4. Complaint procedures according to the MLC convention

In order to expedite the resolution of all labor disputes related to the ship, the MLC Convention contains framework regulations on the procedure for settlement of complaints on board and on land. The procedure for resolving complaints on board is prescribed by the flag State of the ship, but the Convention specifies that it must be fair, efficient, and prompt, and that the claimant must not be harassed. The term harassment refers to any harmful act taken by a person against a seafarer because of filing a complaint which was not made for the purpose of harassment or malice. The procedure for resolving complaints in the port is quite simple, but to some extent involves the cooperation of the flag state and the port state and the possibility for the participating authorities to internationalize the complaint by delivering the report to the Director-General of the International Labor Office. [6]

Under the MLC Convention, seafarers have at their disposal the procedure for filing a complaint on board on any matter which allegedly constitutes a violation of the requirements of the MLC Convention (including seafarers' rights). The conduct of the procedure should seek to resolve the complaints at the lowest possible level. According to Standard A5.1.5. of the MLC Convention, seafarers are in all cases entitled to file complaints directly to the master of the ship and, if they find it necessary, to the appropriate authorities outside the ship. [6]

A seafarer's complaint of an alleged violation of the requirements of the MLC Convention may be reported to the Navigational Safety Inspectorate. In cases when such a ship enters a port in the Republic of Croatia, the navigational safety inspection conducts an initial investigation, and in cases when the ship does not enter a port in the Republic of Croatia, he reports to the port state control service in which the ship is expected to enter. [16]

Depending on the nature of the complaint, the initial investigation will include, if necessary, an assessment of whether the procedures carried out per complaint on board the ship are provided in Regulation 5.1.5. of the MLC Convention. In this regard, the safety inspection may conduct a more detailed inspection. The navigational safety inspector will advocate the handling of the complaint at the ship level. If a seafarer's complaint relating to matters covered by the MLC Convention is not resolved at the ship level, the safety inspection will promptly report to the flag State seeking advice and the submission of a Correction Plan. The report on all performed inspections is submitted in electronic form to the Thetis database. [16]

If the complaint is not resolved even after the taken measures, the safety inspection will submit a copy of the inspection report to the Director General of the ILO, together with all responses received from the competent authorities of the flag State within the required time limit. The Navigational Safety Inspectorate will also inform the relevant seafarers' and shipowners' organizations in the Republic of Croatia. Furthermore, the Ministry of the Sea, Transport and Infrastructure will regularly provide the Director-General of the International Labor Office with statistics and information relating to the handling of such complaints. [6]

4. NUMBER OF DEFICIENCIES AND DETENTIONS OF SHIPS BASED ON VIOLATIONS OF THE PROVISIONS OF THE MLC CONVENTION IN CROATIAN PORTS AND PORTS OF THE PARIS MEMORANDUM FROM 2016 TO 2021

The aim of the Paris Memorandum is to prevent the navigation of substandard ships in the region of Europe. The flag status in the world is monitored on the basis of the results of ship inspections in foreign ports, i.e., on the basis of proportion of ships detention of each flag in relation to the total number of inspections in a period of three years.

As a basic tool for measuring the performance of the flag state, the Paris Memorandum has been applying a statistical method for many years based on the percentage of stops of a certain flag and taking into account the total number of inspections on ships of a certain flag. This method classifies flag states to black, gray, or white lists. The ships on the black list are more often subject to inspection, and repeatedly stopped ships are detained from entering the ports of Paris Memorandum with the possibility of permanent expulsion of such sub-standard ships. As a member state of the Memorandum, the Republic of Croatia conducts inspections of foreign ships in its ports based on the Maritime Code and the Ordinance on inspections, which are harmonized with the Paris Memorandum.

According to the annual Paris Memorandum reports, in the past six years the deficiencies resulting from violations of the provisions of the MLC Convention (hereinafter: MLC deficiencies) account for between 15% and 20% of all deficiencies on ships in Paris Memorandum ports, which is a relatively high percentage, but also an indicator of frequent inspections which verify the correctness of the implementation of the provisions of the MLC Convention since the working conditions on board are equally important on all ships, regardless of their size or type. [16]

Based on the available annual reports of the Paris Memorandum [11], i.e. the inspections carried out under the jurisdiction of the signatory states of the Memorandum in the period from 2016 to 2021, the data on identified MLC deficiencies on inspected ships are analyzed, as shown in Table 1 and the common MLC deficiencies on foreign ships and the number of their stops in Croatian ports are analyzed, as shown in Table 2.

Table 1: Top 5 MLC deficiencies

MLC deficiencies top 5	2016.	2017.	2018.	2019.	2020.	2021.
Deficiencies	deficiencies	deficiencies	deficiencies	deficiencies	deficiencies	deficiencies
Access/ structural features (ship)		322.00	306.00	298,00	259.00	
Ropes and wires		337.00	303.00	283.00	249.00	278.00
Seafarers employment agreement (SEA)	624.00	553.00	466.00	484.00	530.00	540.00
Records of seafarers' daily hours of work or rest	416.00	420.00	351.00	337.00		
Sanitary Facilities	273.00					
Cleanliness of engine room	317.00				400.00	365.00
Electrical	361.00	435.00	365.00	370.00	330.00	443.00

The data on the most frequently reported deficiencies related to the provisions of the MLC Convention for the period from 2016 to 2020 were extracted from the annual reports of the Paris Memorandum, and for 2021 the statistics available on the official website of the Memorandum were used. The data presented and analyzed in Table 1 show that the most identified MLC deficiencies relate to MLC deficiencies in Seafarers employment agreement (SEA), Records of seafarers daily hours of work or rest and Electrical.

Throughout the observed period, the Seafarers employment agreement (SEA) and Electrical occur within the 5 most common deficiencies at the level of all Paris Memorandum ports. As can be seen from Table 1, Records of seafarers' daily hours of work or rest in the last two years do not appear in the top 5 deficiencies under the MLC convention, while on the other hand Cleanliness of engine room in the last two years reappeared as one of the major deficiencies under the MLC convention. The deficiency related to crew salaries, which in some earlier periods often caused ships to stop, does not fall within the top 5 MLC deficiencies in the observed period. The table above shows that in 2020 the number of deficiencies on ships in the ports of the Paris Memorandum decreased significantly due to the fact that the COVID-19 pandemic has made it difficult to sail internationally, and this has resulted in the reduced number of ship inspections, and thus deficiencies and stops.

The number of MLC deficiencies and the number of ship detentions in Croatian ports show only the deficiencies that were reported nine or more times in the observed period. Analyzing the data from Table 2 on the conducted inspections on ships in the ports of the Republic of Croatia in the period 2016 to 2021, it can be seen that most MLC deficiencies are related to Cleanliness of engine room, Ropes and wires, Seafarers' employment agreement (SEA), Protection machines/parts and Lighting (Working spaces). It can be seen that a larger number of identified MLC deficiencies per category did not cause a larger number of ship detentions. The best example of this is the salaries of the crew, where in the six-year period only 12 deficiencies related to the salaries of seafarers were identified, and they caused 3 detentions. A similar thing is with the deficiencies related to Certificate or documentary evidence of financial security for repatriation and Heating, air conditioning and ventilation in which 25 deficiencies were identified and caused 5 detentions.

The largest number of deficiencies in all observed categories was identified in 2016 (93), which did not result in the largest number of detentions. Also, it is interesting to compare 2018 in which 76 deficiencies were identified caused by 10 ship detentions and 2019 in which a similar number of deficiencies were identified (81), which caused only 2 detentions. In 2020, the impact of the COVID-19 pandemic on the number of inspected foreign ships was also recorded in Croatia, which resulted in a reduced number of deficiencies (only 55 deficiencies) that did not cause any stoppages. Comparing ports in the Republic of Croatia with other ports of the Paris Memorandum, a number of deficiencies have been identified in the Seafarers Employment Agreement (SEA), so the reasons for violating the provisions of the Seafarers Employment Agreement (SEA), which is the basis of seafarers' labor and social rights, should be investigated.

Table 2: Overview of identified deficiencies and number of detentions in accordance with the MLC Convention in the Republic of Croatia from 2016 to 2021

RH MLC recorded deficiencies	2016.		2017.		2018.		2019.		2020.		2021.		TOTAL	
Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies	deficiencies	Detainable Deficiencies
Non-payment of wages	4.00	1.00	2.00		2.00				1.00		3.00	2.00	12.00	3.00
Provisions quantity	1.00				3.00		3.00		1.00		2.00		10.00	0.00
Food segregation	1.00		4.00		3.00		9.00				2.00		19.00	0.00
Heating, air conditioning and ventilation	4.00				2.00	1.00	2.00		2.00		1.00	1.00	11.00	2.00
Cold room, cold room cleanliness, cold room temperature	1.00		3.00		3.00		2.00		1.00		4.00		14.00	0.00
Medical Equipment, medical chest, medical guide	3.00		1.00		4.00	1.00	1.00		4.00		5.00		18.00	1.00
Lighting (Working spaces)			8.00		5.00		6.00		2.00		9.00		30.00	0.00
Electrical	2.00		2.00		5.00		4.00		4.00		4.00		21.00	0.00
Protection machines/parts	7.00		4.00		3.00		6.00		5.00		5.00		30.00	0.00
Ropes and wires			5.00		11.00		8.00		13.00		13.00		50.00	0.00
Anchoring devices	12.00		1.00		1.00		1.00		2.00		3.00		20.00	0.00
Winches & capstans	1.00		1.00				2.00				6.00		10.00	0.00
Cleanliness of engine room	19.00	1.00	19.00		17.00	2.00	12.00		9.00		7.00	1.00	83.00	4.00
Access / structural features (ship)	3.00				2.00		2.00		1.00		5.00		13.00	0.00
Medical certificate	10.00		1.00	1.00	4.00	1.00	6.00		1.00		3.00		25.00	2.00
Seafarer' employment agreement SEA	11.00		10.00	1.00	3.00	1.00	2.00	1.00	1.00		3.00		30.00	3.00
Shipboard working arrangements	2.00		3.00		1.00	1.00	4.00	1.00	2.00				12.00	2.00
Records of seafarers' daily hours of work or rest	4.00	1.00	4.00	1.00	1.00		8.00		5.00		4.00		26.00	2.00
Procedure for complaining under MLC 2006	4.00		1.00		2.00		1.00				1.00		9.00	0.00
Certificate or documentary evidence of financial security for repatriation	4.00		1.00		4.00	3.00	4.00		1.00				14.00	3.00
TOTAL	93.00	3.00	70.00	3.00	76.00	10.00	83.00	2.00	55.00	0.00	80.00	4.00	457.00	22.00

In the ports of the Republic of Croatia, as well as in the ports of the Paris Memorandum signatory states, many deficiencies were identified in the Seafarers' employment agreement (SEA), so the reasons for violating the provisions of the Seafarers' employment agreement (SEA) should be investigated, which is the basis of the employment rights and social rights of seafarers.

5. CONCLUSION

The Maritime Labor Convention, 2006 entered into force in 2013. The flag State is required to inspect ships of its nationality and to issue certificates to ships accordingly, as proof that the working and living conditions on board are in accordance with the provisions of the MLC Convention, while the port State has the right and obligation to inspect that the ship has the appropriate certificates and that the conditions on board comply with the provisions of the MLC Convention. If the ship does not meet the mentioned conditions, the port state has the right to detain the ship. Port State control is applied to all ships over 500 gross tonnage regardless of whether their State has ratified the Convention.

The inspection of foreign ships of EU state ports is carried out in accordance with the provisions of the Paris Memorandum of Understanding on Port State Control, which was adopted in 1982, and which has been amended several times. All signatories to the Paris Memorandum, including Croatia, have committed themselves to maintaining an effective control system for ships entering their ports to ensure that all ships meet the standards of numerous international conventions on safety of navigation, the marine environment and working and living conditions of seafarers. In the Republic of Croatia, the inspection of foreign ships is regulated by the Ordinance on inspection.

If the working and living conditions on board clearly endanger safety, health, or security of seafarers or if the deficiencies present serious or repeated violations of the MLC Convention (including seafarers' rights), the safety inspection will impose a detention or stoppage of operations. The measure of detention or stoppage of operations will not be revoked until the stated deficiencies have been eliminated or until the safety inspector accepts Rectification Act Plan.

Several conclusions can be drawn based on the analysis of the presented statistical data of the Paris Memorandum and especially the data of the Croatian inspection on the types and number of deficiencies on foreign ships caused by violations of the MLC Convention, which were identified during inspections of foreign ships in ports of the Paris Memorandum and especially Croatian ports in the six-year period from 2015 to 2020,

The most common deficiencies that appeared at the beginning of the monitoring of MLC deficiencies (since 2014) and were the reason for stopping ships in the Paris Memorandum are: crew salaries, prescribed number and crew structure, seafarers' employment contracts, working hours records and hours of rest periods of seafarers during the day, sanitary facilities, cleanliness of the engine room, calculation and payment of wages and procedures for filing complaints under the MLC Convention. [16]

Analyzing the two tables, we can conclude that the lack of Records on the number of working hours and rest hours of seafarers during the day that was common at the beginning of MLC deficiency statistics no longer appears among the most common MLC deficiencies which resulted in ships detention in Croatia or other Paris Memorandum states.

Also, the lack of procedures for submitting complaints at the beginning of keeping statistics held a high place as an identified MLC deficiency, i.e., as the reason for detaining a ship and now there seems to be a negligible number of such complaints both in Croatia and in other members of the Paris Memorandum.

However, the MLC deficiencies of the seafarers employment contract is a deficiency with a tendency to increase both in the total number of deficiencies and as a reason for ship detention. It is perceived as the most frequent deficiency, although in Croatia it holds the third place, but it is a deficiency that most frequently detains ships. The reasons for frequent violations of the provisions of seafarers employment contracts should certainly be investigated which is the basis for the implementation of their working and social rights and the guarantee of fair and humane working conditions on board ships.

Finally, it should be added that the crisis caused by the COVID-19 pandemic can also be seen in the number of deficiencies and ship stops in all ports of the Paris Memorandum, including the ports of the Republic of Croatia.

REFERENCES

[1] Bilić, Andrijana – Buklijaš, Boris, Međunarodno radno pravo (with special reference to the International Labor Organization), University of Split, Faculty of Law, Split, 2006.

[2] Directive 2013/38/EU of the European Parliament and of the Council on the Amendments of the Directive 2009/16/EZ on port State control (SL L 218, 14th August 2013). - DIRECTIVE 2013/38/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12th August 2013 amending Directive 2009/16/EC on port State control

[3] Directive 2009/16/EZ of the European Parliament and of the Council on port State control (SL L 131, 28th May 2009)

[4] Directive of the Council 2009/13/EZ of 16th February 2009 on the implementation of the Agreement on the Seafarer' Labor Convention from 2006, concluded between European Community Shipowners' Association (ECSA) and the European Transport Workers' Federation (ETF) of 2006, and amending the Directive 1999/63/EC (SL L 124, 20th May 2009), as last amended by the Directive of the Council (EU) 2018/131 of 23rd January 2018 implementing the Agreement concluded between European Community Shipowners' Association (ECSA) and the European Transport Workers' Federation (ETF) amending the Directive 2009/13/EC in accordance with the 2014 amendments to the Maritime Labour Convention 2006 approved by the International Labor Conference on 11th June 2014 (SL L 22, 26th January 2018).

[5] Grabovac, Ivo – Petrinović, Ranka: Pomorsko pravo (Pomorsko javno, upravno i radno pravo), Split, 2006.

[6] Seafarers' Labor Convention, Official Gazette, International Treaties, no. 11/09.

[7] Luttenberger, Axel Pomorsko upravno pravo, University of Rijeka, Faculty of Maritime Studies in Rijeka, Rijeka, 2005.

[8] Luttenberger, Axel Pomorsko upravno pravo, University of Rijeka, Faculty of Maritime Studies in Rijeka, Rijeka, 2005.

[9] Ljubičić, Ivana: Inspekcijski nadzor stranih brodova u lukama Republike Hrvatske, Zbornik radova Pravnog fakulteta u Splitu, year 46, 4/2009., p. 829–843.

[10] Ozcayir, Z. Oya, Port State Control, London, 2004.

[11] Paris Memorandum of Understanding on Port State Control, www.parismou.org –

[12] Petrinović, Ranka; Baumgartner, Dario; Perkušić, Marko: Inspekcijski nadzor sigurnosti plovidbe i zaštite morskog okoliša u RH - usklađivanje s najnovijim zahtijevima Pariškog memoranduma, Zbornik radova II. savjetovanje s međunarodnim učešćem, Ekologija i saobraćaj, Travnik, 2011, p. 422-435.

[13] Petrinović, Ranka; Lovrić, Ivana, Novo pravo o pravu pomoraca za slučaj napuštanja i repatrijacije, Zbornik radova 1. Međunarodne znanstvene konferencije pomorskog prava - ISCML 2016, p. 276.-308.

[14] Petrinović, Ranka; Lovrić, Ivana, Osiguranje pomoraca prema novoj konvenciji o radu pomoraca, PPP, year 54 (2015), 169, p. 145-170.

[15] Petrinović, Ranka; Lovrić, Ivana; Perkušić, Trpimir, The Role of P&I Insurance in Implementing the Amendments to the MLC 2014, Transactions on Maritime Science, 6 (2017), 1; 39-47.

[16] Petrinović, Ranka; Perkušić, Trpimir, Vuković, Tony, Inspekcijski nadzor radnih uvjeta pomoraca prema MLC konvenciji u lukama država Pariškog memoranduma, Zbornik radova 3. Međunarodne konferencije iz pomorskog prava „Suvremeni izazovi pomorske plovidbe", Split, Hrvatska, 8th – 9th April 2021 (MZKPP Split, 2021), p. 177. – 205.

[17] Maritime Code, Official Gazette no.181/04,76/07, 146/08, 61/11, 56/13, 26/15 and 17/19

[18] Ordinance on the inspection of navigation safety, Official Gazette, no. 39/11, 112/14, 33/15, 86/15, 29/16 and 32/20.

[19] Ordinance on the Application of the Maritime Labor Convention of 2006, Official Gazette, no. 122/16 and 42/19.

[20] Učur, Marinko Đ., Radnopravni status pomoraca, Faculty of Law, University of Rijeka, Rijeka, 2003.

[21] www.ilo.org (retrieved on 22nd January 2022)

OPTIMIZING THE OPERATION OF THE SHIP'S POWER PLANT USING RENEWABLE ENERGY SOURCES

Tomislav Peša, M.Sc.
Ministry of Defence of the Republic of Croatia
Trg kralja Petra Krešimira IV br. 1, 10 000 Zagreb, Croatia
tomopesa@yahoo.com

Maja Krčum, Ph.D.
University of Split, Faculty of Maritime Studies
Ulica Ruđera Boškovića 37, 21000 Split, Croatia
mkrcum@pfst.hr

Ivan Karin, M.Sc.
Plovput d.o.o.
Obala Lazareta 1, 21000 Split, Croatia
ivan.karin@plovput.hr

Bruna Bacalja, M.Sc.
Maritimus Consultant d.o.o.
Split, Croatia
bruna@maritimus-consultant.hr

ABSTRACT

Shipbuilding is a compromise that tries to achieve the full functionality of a vessel trough optimal usage of all ship systems. The aim of shipbuilding is to reduce the size of a vessel and the costs of its implementation and exploitation while keeping initial technical requirements fullfiled. As a result of size reduction, one can minimize the costs of purchase and maintenance throughout their exploitation period. Because of that, it is necessary to conduct optimization from different points of view for each device installed on the ship. The goal is to choose a system that acomplishes all of the above-mentioned requirements without losing necessary safety and reliability level.
This article shows different approaches in optimizing ship power plant. It brings out the advantages of using hybrid systems and shows the configuration of ship's electric propulsion system. Furthermore, this paper presents renewable energy sources (RES) that are appropriate for maritime environment and are in accordance with the recent trends in applying RES in shipbuilding industry. It describes the basics of simulation model usage and highlights its validation and verification process.

Keywords: Ship power plant, renewable energy sources, optimization, model, verification and validation

1. INTRODUCTION

The ship's power system can be observed as an isolated island network [1]. Typical ship's electrical network consists of systems for the production, distribution and consumption of electricity. Exceptions are electric vessels that sail shorter distances and do not have devices for generating electricity. Due to the large oscillations in the network load, especially in the case of electrical propulsion, the ship's power plant should ensure the required quality of power supply for all devices. Production of electricity on vessels is carried out through primary movers (diesel engine, turbine, engine shaft, gas turbine). The most common source of electric power on board is an easily controlled diesel generator that adapts to the power network.

The ship's electrical network is specific because it simultaneously conducts production and consumption of electrical energy. The essential difference between a ship's network and an isolated island network is the type of the load. The changes of the load of the vessel's network are more significant, consequently requirements for the resilience of the network are more demanding. It is necessary to provide a sufficient amount of energy in a relatively short time thus energy storage system (ESS) is an excellent supplement to the ship's energy system in total. According to [2] ESS provides primary frequency support and also improves the transient stability of the network. Rechargeable batteries, super capacitors and flywheels are mainly used for the ship's ESS.

Electronic power devices that control the flow of energy on the ship play a crucial role in the optimal use of energy resources. The aim is to achieve energy and economic efficiency in the design and operation of vessels. Optimal energy management contributes to the stability of the network in different operating conditions while reducing fuel consumption.

The ship's generator must adapt to the requirements of electrical energy consumers. In the event of a short-term overload, the ESS supplies energy to the grid. On the contrary, in the case of a long-term overload, ship's power grid needs for more energy, hence the system automatically switches on the "standby" generator. If the consumption of electricity exceeds the possibilities of its production, it is possible to disconnect less important consumers from the network. Less important consumers are those who do not significantly affect the safe management of the ship and cargo.

The characteristics of electrical power consumers largely depend on the type of the ship and the cargo being transported. The ship's power plant manages the entire flow of electrical energy onboard, thus its efficiency is fundamental to the overall efficiency of the vessel.

There are different approaches in the design of the ship's electrical network due to the features of each individual vessel. However, the most common approach is to use a low-voltage three-phase alternating current system with a voltage level of 400 V or 440 V. The advantage of this approach is the use of standard industrial equipment and worldwide available devices. This approach is not cost-effective for large ships powered by electric propulsion, hence on these ships high voltage and low voltage levels are usually combined to supply the devices as Figure 1. shows.

This figure serves as a basis for understanding the ship's power system topology and the role of its individual elements. Picture depicts sources of electrical energy: diesel generators, fuel cells, and batteries. Fuel cells are a renewable source of energy. However, the batteries and the shore connection can also be observed as RES if they are supplied from renewables.

Electric propulsion motors are supplied by high voltage, while auxiliary ship's devices such as pumps, compressors, fans, etc. are supplied by low voltage.

Alternating machines, regularly synchronous generators are used to produce electrical energy of certain frequency and voltage. Those are the basic parameters that should be maintained within defined values. Ship's generators are to the greatest extent powered by a diesel engine or gas turbine. The speed governor maintains the referent frequency, while the automatic voltage regulator (AVR) regulates the generator voltage. The speed governor design can be hydraulic-mechanical or electrical. AVR is an electronic device used to regulate the excitation current and consequently, it regulates the generator voltage.

It is simple to regulate one generator, however, when two or more generators work in parallel operation, the situation becomes more complex. Instability in operation or failure of the entire system may occurre because one generator takes most of the load. Due to that, it is necessary to harmonize the operation of the generators in order to the even load distribution.

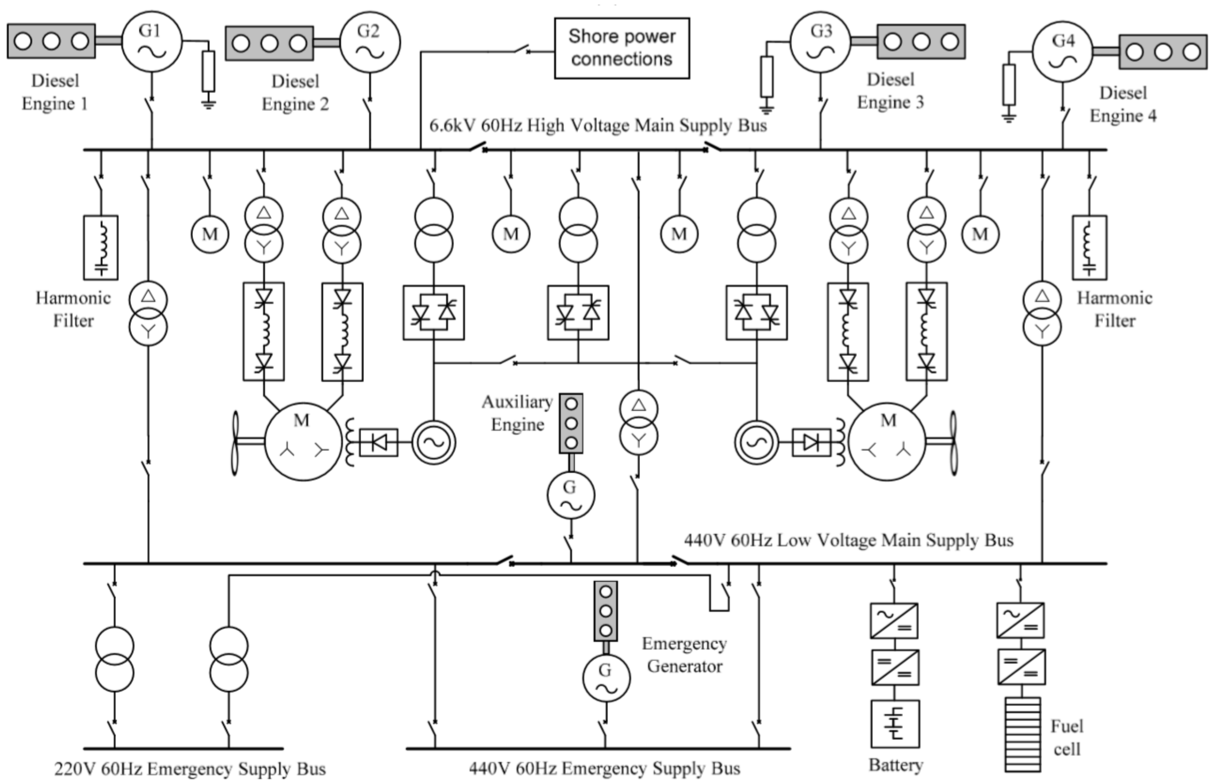


Figure 1: Cruising ship Queen Elizabeth II power plant example [1]

2. SHIP'S POWER PLANT

The goal of optimization is saving in fuel comsumtion, which positively affects the economical and ecological aspects of exploatation of the vessel. However, the priority is to obtain high level of reliability of the vessel power network. According to [3], reliability is achieved by installing high quality system components and redundancy of structural system components. All components installed in the energy system should be tested through various methods of verification before installation and additionally in everyday use. At the end of the testing period, components of lower quality and reliability are replaced. Unfortunately, this is an expensive way to increase the level of availability of a particular technical system. The redundancy of key systems also accomplishes the required level of reliability even though the installed equipment is of poorer quality. Therefore, when using this method, it is necessary to have a well-trained and equipped crew which is able to quickly return the defective device to operational condition.

According to [4] the redundancy of generators alone does not provide a sufficient level of reliability. Usage of energy storage units is increasing in recent times. That improves the security in terms of the quality of produced electrical energy supplied to ship's consumers. Due to the different modes of operation of energy storage systems, they have certain advantages over the addition of diesel-electric generators. The essential advantage is the energy availability in a short time. In case of the power network oscillations the response time in the electrical energy storage system is much shorter and can be measured in a few milliseconds, for example, flywheels [5].

Electrical energy storage units are frequently used in the car manufacturing industry, buses, and train production. On the other hand, maritime transport occupies a small percentage of the research and application of new technologies. Therefore, it is necessary to strive for the application of existing technologies from advanced energy developed industries. Energy storage facilities are generally used as a supplement to the existing energy system. However, there are functional examples in which only rechargeable batteries electricity is used as the only source of energy on board. The leading representatives of exclusively electric propulsion vessels are ferries operating on shorter distances [6].

The reliability of the ship's power system is achieved not only by doubling the number of the devices but also by placing the equipment in separate rooms. Because of the fire or water flooding possibility in the engine room, there is a danger of failure of the entire power supply system onboard. Therefore, key devices for the production and distribution of electrical energy must be placed in different rooms. Furthermore, diesel power units often malfunction because of fuel supply problems, so it is necessary to design a system in which the diesel engines have an independent supply of fuel from different tanks.

In the case of vessels with the required high reliability, cable routes are installed over both sides of the ship in order to avoid power outages of key devices. Automatic switches which turn the available line on are most commonly installed. Due to the growing number of installed consumers of electrical energy on newer ships, the switchboard is becoming more complex. The switchboard's investment costs, the required installation space and its mass are increasing. Therefore, the optimization of the ship's power plant is even more important in the efficiency of the ship [7]. The type of vessel, the route on which it is sailing, the available type of propulsion energy and legal restrictions for the area of navigation should be taken into account while searching the most suitable solution.

In the past period the advanced power management systems of the ship's power plant have been aimed to improve efficiency. One of the methods is that power flow control is formulated as an optimization problem where the optimal load distribution on power sources is determined through numerical methods. Each variable needs to be assigned a corresponding cost that has a direct impact on the selection of the most favorable method. However, the cost of a particular energy source is not the only parameter in decision-making [8]. For example, taking into account the price of electricity obtained from batteries, their price is higher due to multiple conversions and losses. Despite the above, energy from rechargeable batteries is in certain conditions most favorable when there is an excess of energy produced in the power system of the ship. Paper [9] presents a model of electric propulsion optimization of a merchant ship based on the exploitation profile and the energy price, which is the main optimization criterion. Economic and energy modules represent an appropriate transmission function. Output data is energy price and other factors of influence.

The cruise ship industry is at the forefront of introducing innovations in the improvement of the ship's power plant [10]. As these are large ships with a large number of passengers and crew members, the need for electricity production is extremely high, especially given the fact that electric motors are most often used to propel the ship [11]. Because of the interest of maritime companies, and even more due to the pressure of legal framework related to the emission of harmful gases, the goal is to reduce fuel consumption for supplying diesel-electric generators. According to [12], savings are possible by using alternative fuels to power ship generators. This paper demonstrates that the presented approach can support decisions for identifying the cruise ships power plants optimal solutions. That simultaneously results by reduction of the lifecycle costs and emissions whilst enhancing the system safety. In the best scenario the NOx emissions reduction can be by 71- 72% less in comparison to the baseline. Ship's draft and displacement, weather force and direction, hull and propeller roughness also affect fuel consumption [13].

2.1. Hybrid system application

According to [14] by applying advanced hybrid systems, and depending on the type of vessel and the type of route, it is possible to reduce fuel consumption by 10% to 35%. Naval ships, towing vessels, and offshore vessels are suitable for hybrid energy application because of their operational profile. In these types of ships the engine power is 20% or less at 90% of its operational time. The application of hybrid propulsion systems on overseas ships is currently questionable from an economic point of view [15]. The efficiency of the ship's power network depends on choosing the most suitable sources of electrical energy at a given time in accordance with the needs of power consumers [16, 17, 18].

In marine power plants with multiple generators, as primary energy sources, it is necessary to use the generator in the optimal mode of operation. This is done by reducing the number of generators connected to the network and increasing the load on those connected to the network. Due to the above, fuel consumption is reduced and thus there is a reduction in emissions of harmful gases. It is commonly known that the efficiency of the generator is higher at higher loads, as shown in Figure 2. Under light load conditions of diesel engine specific fuel oil consumption can go up to 400 g/kWh while at a load of 87% is 200 g/kWh. According to [19] optimal operating range of a diesel-electric generator is between 70% and 89% of its rated power. Also, the maximum load should be avoided because of diesel engine life span reduction and absence of avaible energy.

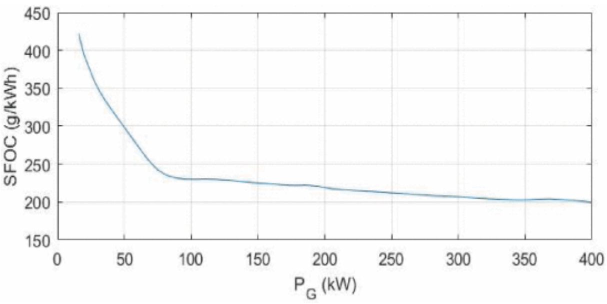


Figure 2: Specific diesel oil consuption for engine Perkins 2506C-E15TAG1 [20]

Hybrid systems are particularly suitable for certain types of vessels that require a large amount of electricity in a short period of time. Ferries and passenger ships are suitable for this type of propulsion due to restrictions on the emission of harmful gases and noise into the environment. Furthermore, tugs operate in navigation regimes that vary significantly in intensity.

Due to the different load profiles, the ship's power plant must be adaptable and able to select the most suitable energy source from several different aspects. In general, the economic aspect of the operation of the vessel is the most dominant, but when the ship is located near urban areas, the impact on the environment becomes most important. In order to achieve optimal use of the energy system, the control mechanism should take into account the parameters of the energy storage system, the state of charge of the batteries, and daily energy needs [21].

2.2. Electric propulsion vessels

In recent times, more research and development on the application of DC network technology is conducted. The disadvantages of alternating current when compared to direct current are asymmetrically loaded phases, the appearance of harmonics, and reactive power [8]. There are many advantages of direct current application, especially in hybrid systems. On the contrary, the major weaknesses of DC systems are: limited control and switching actions, insuficient system capacity and unavailability of equipment on the worlwide market. Also, DC voltage cannot be step up or step down easily. Electrical storage systems, as most RES, are DC so no additional energy conversion is required. Furthermore, it is not necessary to synchronize the generator units, which allows the exploitation of diesel machines in the most suitable mode of operation [22, 23, 24]. Figure 3 shows the elements of the electric propulsion system.

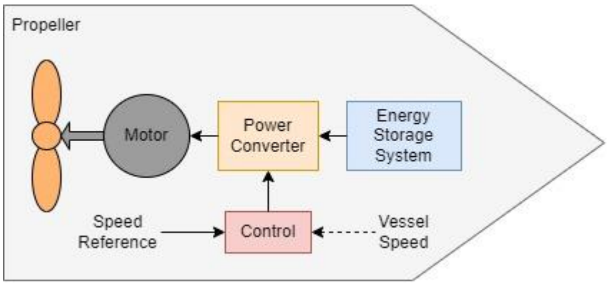


Figure 3: Electric propulsion system elements

Advances in power electronics that are becoming more accessible and energy-effective enable the efficient transmission of electricity to consumers while reducing the weight and volume of equipment required. According to [25] the remarkable advancement in semiconductor electronics is improved capacity and switching speed that leads to improved power control and efficiency. On those grounds, DC networks will soon take lead in certain areas of application. Energy storage or onshore power can be used when the ship is at berth and therefore there are no emissions of harmful gases into the environment (if they are produced from renewable sources) or noise production.

When designing a new vessel power system, various ideas and technologies can be applied in order to achieve the most efficient solution. However, there are a number of limitations to the modernization of existing ships [26]. The designer should consider the possibility of accommodating equipment, the possibility of installing an energy storage system, installation of lower-power generators, considering the investment costs and the time of return on investment.

With standard diesel-mechanical propulsion, the drive machine often operates in an unfavorable mode, especially with certain types of vessels, such as tug boats [14]. By replacing one main engine that directly drives the shaft with several generators, it is possible to operate the diesel engine in more favorable operating modes. That results with an increase in the reliability of the energy system.

2.3. New maritime technologies applications review

This paragraph presents new trends and technologies aiming to optimize the operation of ship power plant. All these concepts are introducing renewables in order to reduce harmful emissions from ships into the atmosphere. Large global companies involved in the design and construction of ships have presented concepts that predict new ways of building ships. The introduced concepts suggest the way in which modern shipbuilding should be developed with the long-term goal of independence from fossil fuels.

NYK Super Eco Ship 2030

The concept ship has been crafted as a pure car and truck carrier (PCTC) in cooperation with MTI and Elomatic, an engineering and consulting company based in Finland. NYK said the power needed to operate the ship has been cut by 70 percent by remodeling the hull to decrease water friction, reducing the weight of the hull, introducing fuel cells for electric propulsion, and relying on other highly efficient propulsion devices. Instead of fossil fuels, the ship would be powered by solar energy and hydrogen produced from RES, all of which would lead to a reduction of CO2 by 100 percent and thus result in a zero-emission vessel [27].

B-9 cargo ship

B9 Shipping, part of the B9 Energy group of companies, are developing the ships and have started work on a full-scale demonstration vessel validating the engineering and economic assumptions of the initial vessel design. The initial design featured a 100 metre, 3000 ton cargo carrier with three masts each rising 55 metres. Powered by soft sails and biogas from anaerobic digestion, the ships will optimize naturally available resources to provide efficient and affordable low-carbon shipping [28].

Zero-Emission Ferry Concept

Scandlines has ordered a new zero-emission freight ferry for the Puttgarden-Rødby route. The ferry will be inserted in 2024 and will launch the next generation of ferries on the route. With a crossing time of one hour, the ferry is emission free. It can also be operated as a hybrid ferry and then the crossing time is 45 minutes [29].

Viking Energy, Eidesvik Offshore

In recent years, ammonia has been frequently experimented with as an energy carrier, which is considered by many to be the marine fuel of the future. The Finnish marine technology group Wärtsilä has launched ammonia combustion tests to help the company prepare for the use of ammonia as an environment-friendly marine fuel. The company is developing ammonia storage and supply systems as part of an ammonia fuel cell installation project on the Eidesvik Offshore supply ship, Viking Energy. The plan is to install a large 2 MW ammonia propulsion cell on the ship by 2023, which will allow it to sail on clean fuel for up to 3,000 hours a year [30].

Propulsion with ammonia as a fuel or energy carrier is easier to use than hydrogen. Ammonia has a higher energy density (energy per unit volume), so it can be more easily stored in a liquid state at a temperature closer to ambiental temperature. Also, ammonia contains more hydrogen molecules per unit volume than hydrogen itself, which makes it an excellent carrier of energy [31].

Ammonia as a fuel is toxic and corrosive, so special measures are required for its handling and storage [32]. In order to enable the use of ammonia, it is necessary to build infrastructure that will ensure its storage and delivery to vessels. All safety, environmental and legal requirements (that have not yet been fully defined and should be in line with national and international standards) should be fulfilled. Although the use of ammonia as a marine fuel is a new technology, the Republic of Croatia has over 100 years of experience in the synthesis of ammonia through the company Petrokemija.

Even though decarbonization is a trend pursued by global shipping, there are technological and economical constraints that will affect the application of new technologies in shipping. Although most of the world's trade is conducted by sea, it produces only about 3% of total pollution. However, due to the use of cheaper, lower-quality fuel containing a higher proportion of sulfur, shiping industry makes 13% of total global SO2 emissions [33].

3. MODEL APPLICATION

Simulation models have become a basic tool in various research areas when designing a particular system. Modeling of the entire system is necessary when a large group of experts is working on the project, each of whom is making a model of a smaller part of the system or subsystem. The energy system is complex and its planning is a demanding process that is constantly evolving and upgrading.

The models use different mathematical algorithms and databases, which allows them to solve the most complex problems in a relatively short time. This enabled the emergence of the so-called E^3 models (energy-ecology-economy) which take into account the energy, environmental and economic aspects of the application of a particular solution [34].

The most commonly used mathematical techniques in energy models are linear, integer, and dynamic programming. Linear programming is a mathematical technique based on the principle of maximizing or minimizing a given criterion with given constraints.

Integer programming has developed as an extension of linear programming and is applied to analyzes whose results are integer. Dynamic programming is a method that divides the initial problem into several smaller problems and finds the optimal solution for each of them [35]. Models with stochastic and Fuzzy-linear programming techniques have been used more often in recent times to solve the problem of uncertainty in the values of parameters, data and decision variables (linear program solutions).

3.1. Validation and verification

Simulation models are commonly used to solve certain problems. Researchers and other users of computer models use the results obtained in the decision-making process, so it is crucial that the models and data are accurate. The model is adapted to a specific purpose or area of application and its reliability is determined for a specific area [36]. The applicability of the model should be examined for all possible conditions in which the actual system can be found in order to determine that the model credibly represents a given system. The level of model reliability is a parameter that is determined before or at the very beginning of the modeling process.

There are multiple advantages in the application of computer models in the optimization of marine power plants. However, it is crucial to determine the reliability of the model through validation and verification. Although these two concepts seem to be very similar, in practice they are quite different.

Verification provides an answer to the question of whether the applied algorithms solve the set equations in the correct way, regardless of how accurately they represent the modeled system.

Validation is a process in which the accuracy and reliability of simulation results is determined by comparison with experimental results [37]. Although validation and verification are conceptually different, they are most often performed simultaneously.

It would take too many resources to determine that the model is absolutely reliable in the entire domain of possible applications. Instead, the model is evaluated until the required level of reliability is reached, so it can be said that the model is valid for a given application. Figure 4 shows the relationship between reliability, resources required, and model value for end-user. When a high level of reliability is required, the costs of validation can be significant [35].

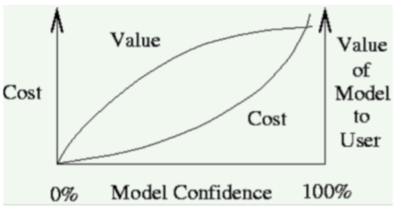


Figure 4: Model reliability

The verification and validation process needs to be carried out throughout the model development process. The simplest approach is for the development team to make a subjective assessment of reliability based on the output data. A more advanced option would be for the model users themselves to conduct a simulation model evaluation. When it comes to larger models in the development in which a larger number of people participate, it is desirable to include impartial experts who evaluate the model. In this way, the computer model gains credibility. Regardless of the type of validation and verification approach, it is important that it is implemented during the design process to keep model costs as low as possible.

Verification and validation of the model of the existing marine power plant can be done by comparing with the actual results in different operating conditions. If the results match, it can be said that the simulation model represents the real system. Such a validated model can be used to test conditions and parameters that would be potentially harmful for installed equipment and devices in real conditions. If it is a matter of verification and validation of a system that is in the design phase, then other available methods of model validation are used. In choosing the method of validation of the simulation model, there is no unique pattern of which techniques and procedures should be used due to the specifics of each model and the area of its application. However, the most commonly used algorithm is the one that shows the process of software development, Figure 5.

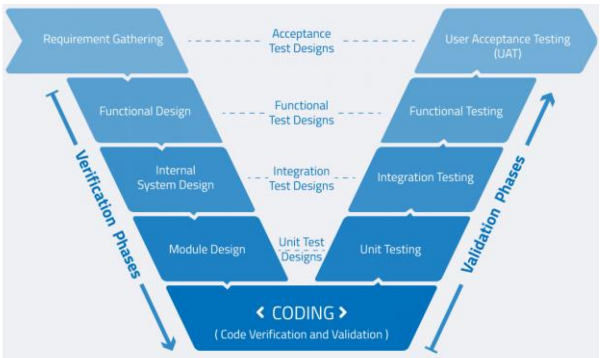


Figure 5: Model validation and verification process [38]

In the process of creating the model, an error occurs due to excessive simplification of the problem, incorrect and unrealistic assumptions, incorrect mathematical formulation, incorrect input data and incorrect commands in the algorithm and because of the selection of inappropriate numerical method. In case the considered model does not meet the conditions of verification and validation, it is necessary to make improvements of the model in order to representatively bring out the actual system. At the end of the verification and validation process, the model should represent the behavior of the real system and as such can be used to conduct tests with a certain level of reliability. If the reliability of the model is high, the model can be used for decision making.

4. CONCLUSION

Because of environmental legislations, the performance of the ship's power plant must be improved. In order to make ship more environmental friendly while conducting optimization, a comprehensive effort needs to be done. The aim of this review article is to present different approaches to shipboard power plant optimization. It points out the benefits of using hybrid systems and describes the configuration of the power system of an electric vessel. The latest trends in the maritime industry regarding the use of RES were also presented as well as the application of the model and their validation and verification.

The conclusion of this paper is that with introducing new technologies from renewables, battery, propulsion and control system industries can improve ship electrical system and make it more efficient.

REFERENCES:

[1] Al-Falahi, M.D.A.; Tarasiuk, T.; Jayasinghe, S.G.; Jin, Z.; Enshaei, H.; Guerrero, J.M. (2018). AC Ship Microgrids: Control and Power Management Optimization. Energies, 11, 1458.

[2] Adrees, A., Milanovic, J.V., (2017). Impact of Energy Storage Systems on the Stability of Low Inertia Power Systems, 7th IEEE International Conference on Innovative Smart Grid Technologies (IEEE PES ISGT Europe 2017), Torino, Italy, 26/09/17. https://doi.org/10.1109/ISGTEurope.2017.8260263

[3] Tarelko, W. (2018). Application of redundancy in ship power plants of offshore vessels, New trends in production engineering (Vol. 1, Issue 1, pp. 443-470).

[4] Anvari-Moghaddam, A., Dragicevic, T. ,Meng, L., Bo, S., Guerrero, J. (2016). Optimal Planning and Operation Management of a Ship Electrical Power System with Energy Storage System.

[5] Robyns, B., Francois, B., Delille, G., Saudemont, C., (2015). Energy Storage in Electric Power Grids, ISTE Ltd i John Wiley & Sons Inc., London i Hoboken.

[6] Gagatsi, E., Estrup, T., Halatsi, A. (2016). Exploring the potentials of electrical waterborne transport in Europe: the E-ferry concept, Proceedings of 6th Transport Research Arena, April 18-21, Warsaw, Poland.

[7] Bordin, C., Mo, O., (2019). Including power management strategies and load profiles in the mathematical optimization of energy storage sizing for fuel consumption reduction in maritime vessels, Journal of Energy Storage, (Vol. 23, pp 425-441).

[8] Miyazaki, M. R., Sørensen, A. J., Lefebvre, N.,. Yum, K. K., Pedersen, E. (2016). Hybrid Modeling of Strategic Loading of a Marine Hybrid Power Plant With Experimental Validation, in IEEE Access (Vol. 4, pp. 8793-8804).

[9] Al-Falahi, Monaaf D.A., Nimma, Kutaiba S., Jayasinghe, Shantha D.G., Enshaei, H., Guerrero, Josep M. (2018). Power management optimization of hybrid power systems in electric ferries, Energy Conversion and Management.

[10] Cruise Lines International Association. Cruise industry outlook. 2020.

[11] Giuffrida. M., (2013). Electrical Plants and Electric Propulsion on Ships, Switzerland.

[12] Bolbot, V., Trivyza, N. L., Theotokatos, G., Boulougouris, E., Rentizelas, A., & Vassalos, D. (2020). Cruise ships power plant optimisation and comparative analysis. Energy, 196, [117061].

[13] Bialystocki, N., Konovessis, D. (2016). On the estimation of ship's fuel consumption and speed curve: A statistical approach, Journal of Ocean Engineering and Science, Volume 1, Issue 2, Pages 157-166, https://doi.org/10.1016/j.joes.2016.02.001.

[14] Geertsma, R. D., Negenborn, R. R., Visser, K. and Hopman, J. J. (2017). Design and control of hybrid power and propulsion systems for smart ships: A review of developments, Appl. Energy (Vol. 194, pp. 30–54).

[15] Vu, T. L., Ayu, A. A., Dhupia, J. S.,. Kennedy, L. and Adnanes, A. K. (2015). Power management for electric tugboats through operating load estimation. IEEE Trans. Control Syst. Technol. (Vol. 23, no. 6, pp. 2375–2382).

[16] Miyazaki, M. R., Sørensen, A. J. and Vartdal, B. J. (2016). Reduction of fuel consumption on hybrid marine power plants by strategic loading with energy storage devices, IEEE Power Energy Technol. Syst. (Vol. 3, no. 4, pp. 207–217).

[17] Kalikatzarakis, M., Geertsma, R. D., Boonen, E. J., Visser, K. and Negenborn, R. R. (2018). Ship energy management for hybrid propulsion and power supply with shore charging, Control Eng. Pract. (Vol. 76, pp. 133–154).

[18] Van Vu, T., Gonsoulin, D., Diaz, F., Edrington, C. S. and El-Mezyani, T. (2017). Predictive control for energy management in ship power systems under high-power ramp rate loads, IEEE Trans. Energy Convers. (Vol. 32, no. 2, pp. 788–797).

[19] Arman Goudarzi, Yanjun Li, Ji Xiang, Chapter 13 - Efficient energy management of renewable resources in microgrids, Renewable Energy Microgeneration Systems, Academic Press, 2021, Pages 285-321, ISBN 9780128217269, https://doi.org/10.1016/B978-0-12-821726-9.00013-8.

[20] Miyazaki, M. R., Sørensen, A. J., Lefebvre, N.. Yum K. K. and Pedersen, E., "Hybrid Modeling of Strategic Loading of a Marine Hybrid Power Plant With Experimental Validation," in IEEE Access, vol. 4, pp. 8793-8804, 2016, doi: 10.1109/ACCESS.2016.2629000.

[21] Chua, L., Tjahjowidodo, T., Seet, G., Chan, R. (2018). Implementation of Optimization-Based Power Management for All-Electric Hybrid Vessels. IEEE.

[22] Bassam, A., Phillips. A., Turnock. S., Wilson, P. (2017). Development of a multi-scheme energy management strategy for a hybrid fuel cell driven passenger ship. Int J Hydrogen Energy (Vol. 42(1), pp. 623–635).

[23] Syverud, T. H. (2016). Modeling and control of a DC-grid hybrid power system with battery and variable speed diesel generators. M.S. thesis, Dept. Electr. Power Eng., Norwegian Univ. Sci. Technol., Trondheim, Norway, 2016.

[24] https://electrical-engineering-portal.com/download-center/books-and-guides/electricity-generation-t-d/ac-grid-vs-dc-grid

[25] Kim, S., Jeon, H., (2022). Comparative Analysis on AC and DC Distribution Systems for Electric Propulsion Ship. J. Mar. Sci. Eng. **2022**, 10, 559. https://doi.org/10.3390/jmse10050559.

[26] Jaurola, M., Hedin, A., Tikkanen, S., Huhtala, K. (2019). Optimising design and power management in energy-efficient marine vessel power systems: a literature review, Journal of Marine Engineering & Technology (Vol 18:2, pp. 92-101).

[27] Offshore-energy (2020), available at: https://www.offshore-energy.biz/nyk-steps-into-the-future-with-super-eco-ship-2050/.

[28] https://www.southampton.ac.uk/engineering/about/making-history/2008-b9-fossil-fuel-free-cargo-ships.page.

[29] https://www.scandlines.com/about-us/our-green-agenda/zero-emission-freight-ferry/

[30] https://eidesvik.no/vessels/viking-energy/

[31] Kim, K., Roh, G., Kim, W., Chun, K.,(2020). Preliminary Study on an Alternative Ship Propulsion System Fueled by Ammonia: Environmental and Economic Assessments. J. Mar. Sci. Eng., 8, 183.

[32] Valera-Medina, A., Xiao, H., Owen-Jones, M., David, W.I.F., Bowen, P.J., (2018). Ammonia for power, Progress in Energy and Combustion Science (Vol. 69, pp. 63-102).

[33] Czermański, E., Pawłowska, B., Oniszczuk-Jastrząbek, A., Cirella, G., (2020). Decarbonization of Maritime Transport: Analysis of External Costs, Front. Energy Res., 27.

[34] Omar, E., Haitham, A-R., Frede, B. (2014). Renewable energy resources: Current status, future prospects and their enabling technology, Renewable and Sustainable Energy Reviws 39.

[35] Sargent, R. G. (2008). Verification and validation of simulation models, Proceedings of the 2008 Winter Simulation Conference, Miami FL, USA, 2008.

[36] Božić, H. (2020). The purposes and methods of energy system modeling, Journal of Energy (Vol.55, br. 5, str. 530-549).

[37] Balić, S., Bešlagić, E., Smriko, E. (2015). Verification as s precondition for cuccessful validation of the results of numerical simulations, 9. Naučno-stručni skup sa međunarodnim učešćem ”QUALITY 2015”, Neum, B&H.

[38] https://www.technolush.com/blog/verification-validation-model

SWARM OF AUTONOMOUS UNDERWATER VEHICLES – PRELIMINARIES

Tomasz Praczyk
Polish Naval Academy
Śmidowicza 69, Gdynia, Poland
t.praczyk@amw.gdynia.pl

ABSTRACT

The paper presents preliminaries in European Defense Agency project category B entitled: "Swarm of Autonomous Biomimetic Underwater Vehicles". It defines the swarm, that is, explains how the swarm is understood in the project, and specifies assumptions and objectives regarding operational scenarios, in-swarm communication, equipment of swarm members (hardware), software, and evaluation criteria.

Keywords: Swarm, Autonomous Underwater Vehicles, Underwater Robotics

1. INTRODUCTION

Autonomous underwater vehicles (AUV) have the potential to take over dangerous missions from both naval ships or special forces. They can operate individually, in teams or in swarms. In the case of swarms, we often deal with redundancy of vehicles and distributed decision-making, which in consequence increases reliability of the whole team/swarm and the likelihood of performing a mission. In the case of the teams, the vehicles form a loosely tied "organism", they often operate in a distance from the others, and they often have to perform their sub-tasks individually. In effect, they should be equipped with all or almost all systems, sensors and devices necessary to operate individually which increases their size and cost and in consequence prevents their massive application.

The principle objective of European Defense Agency project category B entitled "Swarm of Autonomous Biomimetic Underwater Vehicles" (SABUVIS II)[1] to which the current paper is devoted is to design and implement a swarm of closely cooperating AUVs, including the leaders (Leader Autonomous Underwater Vehicles – LAUV) that are responsible for global swarm navigation and the swarm members (Member Autonomous Underwater Vehicles or simply followers – MAUV) responsible for a specific swarm task. The advantage of such system is its reliability and efficiency. First, the swarm system can include redundant elements, which increases reliability in performance of a task – loss of one element does not imply impossibility to complete the mission. Secondly, distribution of all sensors and devices necessary to perform a mission, spread over several vehicles makes it possible to reduce their size and complexity of construction. The vehicles can be simpler, more reliable, and easier to maintain.

The Project will:

- Provide knowledge regarding conditions which have to be satisfied as well as technologies to be provided in order to implement underwater swarms of autonomous robots.
- Provide knowledge and evaluation about feasibility, usefulness, and effectiveness of optical GPS-denied coastal navigation, optical underwater communication, silicone-cast continuum robotics[2] (for example [1-3]) and median and paired fins (MPF) based undulating propulsion.
- Contribute to underwater automation and robotics of underwater vehicles.
- Increase experience in swarm intelligence.
- Carry out sea trials to evaluate the project outcome.

In the paper, preliminaries in the SABUVIS II project are given, that is:

- Operational scenarios which are supposed for the swarm – section 2
- In-swarm communication strategy – section 3
- Required equipment of the vehicles – section 4
- High-level software architecture – section 5
- Final evaluation criteria – section 6.

The paper ends with summary.

2. OPERATIONAL SCENARIOS

Specification of operational scenarios includes four elements, i.e. (i) formation specification, (ii) trajectory specification, (iii) obstacles, and (iv) response to events

[1] The project is currently in the initial stage of requirements specification, scope determination and high-level definition of a target system.

[2] Soft Pneumatically Actuated Robotic Manipulators

(internal and external). It is assumed that equipment, i.e. sensors, navigation and communication devices, of all the vehicles included in the swarm, both LAUVs and MAUVs is fixed, invariable and independent of a specific scenario.

In the paper, a number of scenarios are given: one scenario meant for the final presentation under real conditions and a number of scenarios for analysis under simulation conditions. The former scenario presents a potential application of the swarm to Mine CounterMeasure (MCM). In turn, the purpose of the latter scenarios is to test different swarm control algorithms, different techniques for algorithm optimization, different swarm formations, different swarm composition, different sensor and communication settings, and ultimately to determine optimal conditions for the swarm.

2.1. Formation templates

Two main categories of formations are defined in the project, i.e. loosely and rigidly arranged formations. Regardless of the category, the formations assume that all the vehicles contained in the swarm move on the same depth – each formation is only defined in horizontal plane[3]. The LAUV is responsible for determining the depth of movement for the whole swarm.

The loosely arranged formations have a roughly defined shape and the vehicles maintain the shape as a group, collectively meaning that they do not have specific roles or positions in the formation. Each vehicle can be in different positions, what is more, this position can vary in the course of mission. The exception to this rule is LAUV which leads the formation without paying attention to formation shape and possibly some vehicles which are positioned at the edges of the formation. The formations called "Wide", "Narrow", and "Patch" are examples of loosely arranged formations. Their shape is given in Figure 1.

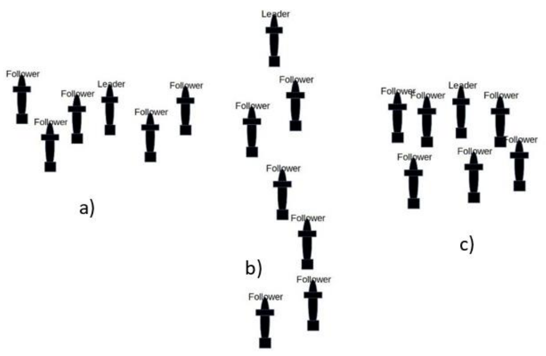


Figure 1: Loosely arranged formations: a) "Wide", b) Narrow, and c) "Patch"

The parameters of all the three formations are: the number of vehicles, the safe minimum distance between the vehicles and the expected density in the formation which specifies its compactness.

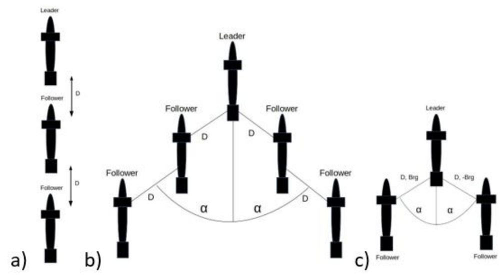


Figure 2: Rigidly arranged formations: a)"I", b) "V", c) "v"

In turn, the rigidly arranged formations are formations whose shape is precisely determined by means of appropriate distances between the vehicles and angles. The formation "I", "V" and "v" depicted in Figure 2 are examples of rigidly arranged formations. The formations "V" and "v" which is "V" reduced to only three vehicles are determined by the distance D between the vehicles and angle α, whereas "I" is determined by only the distance D. In all the rigid formations it is assumed that each vehicle has only one point of reference, i.e. one vehicle (usually the nearest neighbor) which is used to maintain position in the formation by controlling the distance and relative bearing to it.

In order to maintain any rigidly arranged formation, each follower vehicle has to be able to find and identify its point of reference. To this end, it is necessary to enable each follower vehicle to easily differ its point of reference from other vehicles. To do so, it is assumed that for smaller distances between vehicles, only formations "I" and "v" are possible. In formation "I", there is only one frontal neighbor for each follower (except leader) and there is no problem with identifying it. In turn, in formation "v", there are only two followers, at a safe distance from each other, and the leader in the front, so also in this case it should not be any problems with correct identification of the point of reference. In formation "V", and generally, in any "bigger" rigid formation, there are more vehicles and they can mistake their points of reference for other vehicles. In order to avoid such problems, it is assumed that the formations like "V" require larger distances between vehicles and the nearest neighbor is the only point of reference. This way, the followers should not have problems with correct identification of their points of reference, other vehicles should be simply so far away that they cannot be mistaken for true point of reference.

Another problem in each rigid formation is its reconfiguration when one or more swarm members, for some reason, leave the formation. In that case, it must be information that some vehicles leave the swarm. Moreover, each vehicle losing its point of reference has to know where is its next point of reference. What is more, in order for the vehicle losing its point of reference to be able to catch up with a new point, the whole swarm has to slow down.

[3] The swarm can change the depth while avoiding obstacles. However, the change of the depth is the same for all the vehicles in the swarm.

Generally, an algorithm must be defined, different for each formation and position of each vehicle in the formation, which will determine what each vehicle should do in case of necessary reconfiguration. Of course, the problem is that this algorithm will decide what to do but only in situations considered in the algorithm. Other unexpected and difficult to predict cases will not be handled.

The loose and rigid formations differ not only in the shape and rigidness. They also differ in the control strategy used by each follower. In the loos formations, the entire strategy has to be a product of machine learning process. It is simply impossible to "manually" determine how to control each single vehicle, and how to use the information provided by sensors about vehicle surrounding to achieve formation "Narrow", "Wide" or "Patch". There is no single point of reference which narrows down perception and focuses control on it. In this case, the decisions are made based on all available information about the surrounding world and the only known thing is the objective (formation) we want to achieve.

In turn, in the rigid formations, the most important information taken from sensors is relative position to the point of reference and the task of each follower is to maintain the distance and relative bearing to this point. In consequence, the control algorithm for the rigid formations should be simpler than for loose formations. In the case of the former, the task is to find an effective distance and bearing controller, whereas in the case of the latter, we have to determine the entire control strategy. However, this strategy should not change throughout the mission, losing one or more vehicles should not be a problem in this case. Meanwhile, the control algorithm meant for the rigid formations must have an additional logic to cope with reconfiguration problem.

2.2. Trajectory templates

Planned trajectories of the swarm are specified by a sequence of N waypoints and M edges connecting them. Each waypoint W_i ($i \in N$, is a number of a waypoint) is determined by its coordinates (x_i, y_i, z_i) in a local coordinate frame whereas each edge E_j ($j \in M$, is a number of an edge) is specified by a tuple $<V_j, L_j, H_j, Db_j>$ where V is a desired march speed of the swarm, L is the length of the edge (distance between neighboring waypoints starting with lower waypoint number and ending with higher waypoint number), H is the horizontal direction of the edge, i.e. the heading of the swarm when running to the waypoint at the end of the edge and Db is the absolute desired distance to the bottom along the edge.

The difficulty of following the planned trajectory depends on four elements, i.e. (i) the length of edges L, (ii) the absolute depth difference deltaZ = $|z_i - z_{i+1}|$ where i denotes i-th waypoint, (iii) the absolute horizontal direction difference deltaH = $|H_j - H_{j+1}|$ where j denotes j-th edge, (iv) the distance Db, and (v) z which also indicates the distance to the sea surface. The length of the edge L affects the frequency of changes in z (depth), H, and V. The shorter the edges are, the most often changes in swarm depth, speed and heading are. In turn, deltaZ and deltaH affect the magnitude of changes in the depth and heading. Generally, the higher the frequency of changes and the greater the changes are, the more difficult the trajectory is to follow by the swarm. The influence of Db and z on the difficulty of the trajectories results from the influence of the bottom and sea surface on sonar work (harmful reflections, interferences).

2.3. Obstacles

Obstacles which lie on the way between the waypoints and block the passage are a next factor which increases difficulty of the trajectories. However, the obstacle avoidance should be included to the trajectories after positive results with obstacle-free trajectories.

The work on the swarm system should be made incrementally. First, the system should be designed capable of moving the vehicles arranged in a formation along obstacle-free trajectories, then it can be extended with an obstacle avoidance sub-system. The sub-system should be first tested in simulation, and then, in a next step, if a high performance of the system can be achieved under simulation conditions, it can be put to the tests under real conditions.

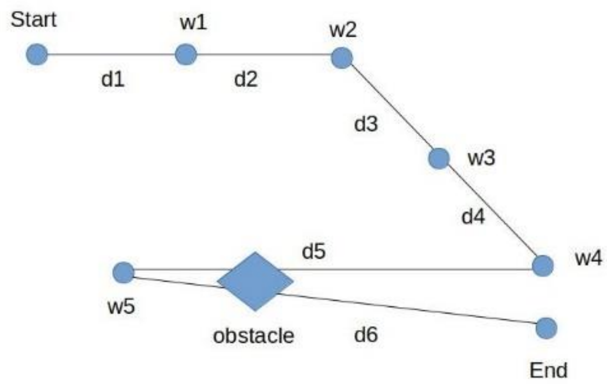


Figure 3: Example generic trajectory

2.4. Events

One element of a real swarm scenario is a response to an event generated by either LAUV or MAUVs, for example, the detection of a mine. The response can be in the form of stopping the swarm, moving a single MAUV a short distance away from the swarm to handle the event, returning to the swarm, and rerunning the mission.

However, this element will not be considered in the project. The objective of the project is to develop the technology of underwater swarm, and all functionalities useful for swarm operation, which, however, do not refer to swarm movement are considered to be outside the main stream of the project.

2.5. Scenario specification

In this section, specification of project operational scenarios is given. The specification includes both the final scenario for demonstration under real conditions and a class of scenarios intended for tests under simulation conditions. All the scenarios differ in: (i) formation specification, (ii) trajectory specification, and possible (iii) obstacles.

Final scenario for demonstration under real conditions

This scenario applies the swarm to MCM or more specifically to detection of mines or generally ferromagnetic objects buried in the sea bottom. In this case, it is assumed that MAUVs are equipped with sensitive magnetometers capable of detecting disturbances in Earth magnetic field[4]. The detection is performed in a differential mode, that is, the object is detected if the difference in indications of different MAUV is observed.

In order for the swarm to be able to fill the above mission, the vehicles have to move close to each other and close to the sea bottom. Therefore, it is assumed that the primary formation of the swarm is formation “v” in which distances between vehicles range from 2 to 6 meters. Moreover, it is also assumed that the swarm moves 2-6 meters from the flat bottom. Flatness of the bottom implies the swarm mission on the horizontal plane without the change of depth (except obstacle avoidance).

Trajectory in the final scenario is a classical lawnmower trajectory and is defined as follows: W1=(0,0,0), E1=<1-1.5m/s,50m,H1,2-6m>, W2=(x2,y2,z), E2=<1-1.5m/s,3-10m,H1+90,2-6m>, W3=(x3,y3,z), E3=<1-1.5m/s,50m,H1+180,2-6m>, W4=(x4,y4,z), E4=<1-1.5m/s,3-10m,H1-90,2-6m>, W5=(x5,y5,z), E1=<1-1.5m/s,50m,H1,2-6m>, W6=(x6,y6,z), W5=(x6,y6,0), where H1 is a heading of the LAUV which will be determined after orienting the trajectory in the space, z is the operational depth corresponding to the distance 2-6m to the bottom (it depends on the area in which the final demonstration will be carried out), and x1..x6, y1-y6 are coordinates of waypoints depending on trajectory orientation.

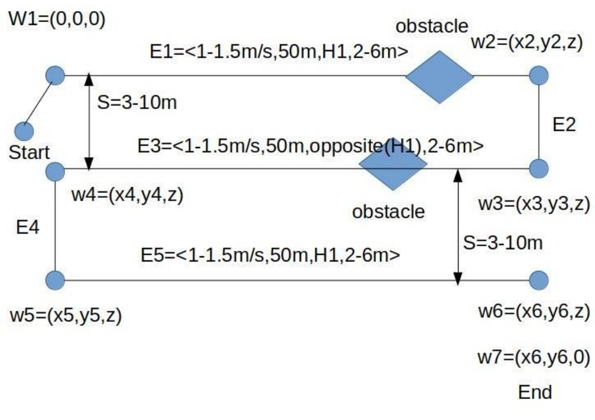


Figure 4: Trajectory during final demonstration

If earlier tests in real conditions prove the ability of the swarm to switch between different formations, this aspect of the swarm operation is also considered in the final scenario. It is assumed that swarm formation can switch between formation “v” to formation “I” or “Narrow”. This maneuver may be useful at each sharp turn of the swarm, that is, at waypoints W2 and W3.

As already mentioned, the obstacles are only considered in the final scenario if earlier tests in the simulation and real conditions show that it is possible to safely avoid obstacles and maintain the swarm formation at the same time. Otherwise, this aspect of the swarm operation will be omitted in the final scenario.

If considered, the real obstacles are implemented as artificial objects, e.g. tires or metal boxes, lying on the sea bottom. The presence of the objects on the way of the swarm will force it to perform a collision free maneuver, for example, by temporarily changing the depth of movement.

The whole scenario can be generally split into three phases, i.e. phase 1 which is formation establishing phase, phase 2 which is trajectory following phase, and phase 3 which is a final evaluation phase.

The phase 1 starts on the surface where WiFi communication channel is used by all the vehicles. Communication takes place through WiFi station on a mother ship, a boat or land. Once LAUV sends message to all MAUVs with the order to follow it in a selected formation, it starts to slowly move in one direction. The MAUVs follow LAUV and once they form a selected formation the whole swarm stars to submerge and the phase 2 begins.

The phase 2 consists in moving the swarm along a desired trajectory and ends when the last waypoint is reached, in which LAUV gives the order to surface – then, the phase 3 begins.

In phase 3, the swarm goes to the surface, stops motors, turns to remote control mode, and records the final GNSS position for evaluation purposes.

Scenarios under simulation conditions

In this case, all the formations specified in Section 2.1 should be examined in terms of their feasibility and difficulty. In addition to the formation shape, different control strategies and formation parameters should be also tested. The goal is to determine favorable conditions for maintaining the swarm, to indicate possible problems and propose solutions to the problems.

In order to specify feasible trajectories for the swarm, intense simulations need to be performed. The goal of the simulations will be to determine parameters of the trajectories which will allow the swarm to safely cover them without loss of any member. During the simulations, a lot of trajectories should be tested differing in their difficulty and external conditions

[4] The magnetometers are only simulated, they are not incorporated into the vehicles.

(environmental disturbances, e.g. sea currents, bottom shape).

The difficulty of the scenarios should increase gradually. After tests with obstacle-free scenarios, the ones including obstacles should be incorporated into the simulations. The goal is to test different swarm obstacle avoidance strategies including the simplest by changing the depth of movement.

In the simulations, the obstacles can be modeled as spheres, ellipsoids, cuboids or cylinders characterized by a position of their centre of gravity (x,y,z) in local coordinate frame and the size (radius or the length of the side).

Like obstacles, the event handling should be also analyzed in the simulations. This can involve such elements as: (i) stopping and rerunning the mission in response to the event generated and sent by either LAUV or MAUV, (ii) waiting for the lost or late MAUV, (iii) change of formation or parameter of formation.

Possible extra tests under real conditions

A useful property of each MAUV is the ability to navigate outside the swarm. This property can be useful if each MAUV becoming a part of the swarm has its own task to perform in a point of interest specified in advance or a point indicated by the swarm in the course of the mission (for example, detection of a mine or other object of interest) and the task of the LAUV is to bring it to this point, leaving it there, or waiting for it nearby.

Other situation in which the above property can be very useful is losing the swarm and attempts to find it again based on the information about current position, speed and heading of LAUV, position of a next waypoint, and estimated position of lost MAUV.

In order to test the above ability of the MAUVs equipped with inertial navigation, the tests in real conditions are planned preceded by designing a data-driven model of the vehicles. In the tests, the accuracy and the range of inertial navigation combined with the data driven model will be examined.

3. COMMUNICATION

Two different communication strategies are assumed, i.e. salient/economical (no. 1), noisy/energy consuming (no. 2). The strategy no. 1 is dedicated for swarms composed of numerous vehicles where loss of a small number of MAUVs is acceptable, whereas, the strategy no. 2 is meant for small swarms where each swarm member is necessary or at least very important to perform a swarm task.

In strategy no. 1, MAUVs are in the possession of the following information broadcasted by LAUV: coordinates of a next waypoint (x,y,z, where $z=OD_L$), the march speed to the waypoint, and a type of current LAUV manoeuvre, e.g. “sharp turn”, “go ahead” (Each manoeuvre has a unique number assigned). The broadcasts are generated only if a next destination waypoint is changed and LAUV changes manoeuvre type. All the broadcasts are generated once without replies from MAUVs (a variant of this strategy with periodical broadcasts from LAUV can be also considered).

Moreover, in strategy no. 1, both types of vehicles broadcast short event-messages, for example: “I am lost”, “mine detected”, “I am returning”, “I am back in the formation”, that inform other vehicles about an environment perceived by the message sender or about its state or actions taken. As above, event messages do not require replies and they are generated only once.

In strategy no. 2, we deal with cyclic messages generated by LAUV. Communication takes place with each vehicle separately, one vehicle after the other. The example complete cycle of message exchange between LAUV and two MAUVs is as follows: M1->RM1->M2->RM2->M1, where M1, M2 are messages to MAUV1, MAUV2, respectively, and RM1, RM2 are replies of MAUV1, MAUV2, respectively. M1 and M2 are messages that include momentary motion parameters of LAUV, i.e. speed, heading, coordinates=(x,y,z), the distance between LAUV and a selected MAUV, i.e. M1 contains the distance between LAUV and MAUV2, whereas, M2 contains the distance between LAUV and MAUV1. Such an approach enables each MAUV to estimate its position in LAUV coordinate frame. Having two successive distances to LAUV, two successive positions of LAUV corresponding to the distances, and an estimated movement of MAUV in a period between two received LAUV messages, it is possible to estimate MAUV position.

Another solution in strategy no. 2 is to make LAUV responsible for estimating positions of MAUVs and for sending the positions to all the vehicles in messages M1, M2. To do so, MAUVs send LAUV their estimated movements in replies RM1, RM2. The example complete cycle of message exchange between LAUV and two MAUVs would be in this case as follows: M1 – position of LAUV, RM1 – estimated movement of MAUV1 for a time between two successive M1 messages, M2 – position of MAUV1 calculated by LAUV based on two distances to MAUV1, two successive positions of LAUV and estimated movement of MAUV1 sent in RM1, RM2 - estimated movement of MAUV2 for a time between two successive M2 messages, M1 – position of MAUV2. This solution makes estimated positions of each MAUV accessible to all swarm members.

Additionally, in strategy no. 2, there are also ad hoc messages generated by both LAUV and MAUVs. Like in strategy no. 1, they include: (i) parameters of a next waypoint – message generated by LAUV, (ii) maneuvers performed by LAUV, or (iii) events. However, in this case, all the messages (i)..(iii) require replies.

4. EQUIPMENT

Two different types of vehicles are considered in the project as the swarm members, i.e. LAUVs and MAUVs. The task of LAUVs is to lead the swarm whereas the task of MAUVs is to follow LAUV(s) based on available local information and to maintain a predefined formation. The difference in the roles which the vehicles are to fill within the swarm is a factor which decides about their equipment.

Because LAUVs are responsible for leading the swarm they have to be equipped with an accurate long-range dead reckoning navigational system, i.e. at least with DVL, FOG, pressure sensor, GPS compass. For the purpose of obstacle avoidance, LAUVs should be equipped with a sonar. Its visibility for MAUVs should be increased by a small glimmer mounted on the hull.

In turn, MAUVs should be smaller, simpler in construction, and lighter than LAUVs. Their short-range navigation system should rely on inertial and pressure sensors. In order to build a data driven model of MAUVs, each of them should be able to host two or three inertial units (inclinometer is also possible) mounted along the whole length of the hull. For the purpose of in-swarm navigation, MAUVs should be equipped with forward-looking sonar and camera.

All the vehicles, regardless of the type, should use the same communication system, both hardware and software.

5. HIGH-LEVEL SOFTWARE ARCHITECTURE

The high-level software architecture of the system is presented in Figure 5 and Figure 6. Figure 5 shows the architecture on the shoreside whereas Figure 6 on the side of vehicles. Both architectures have one feature in common, namely, they are both MOOS-IvP [4] architectures which use MOOSDB application to integrate all software components making up the whole system.

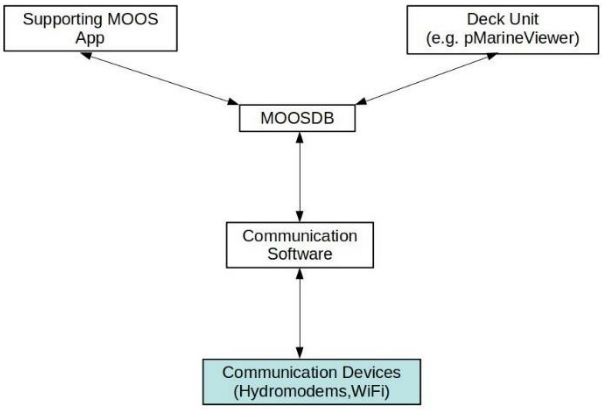


Figure 5: High-level software architecture – shoreside

The shoreside architecture has four primary components, i.e. (i) MOOSDB as a core and communication medium for all other applications, (ii) Deck Unit (DU), (iii) Communication software (CS), and (iv) Supporting MOOS Applications (SMA).

The task of the DU is: (i) to control each individual vehicle and the entire swarm both in the remote control and the autonomous mode, (ii) to monitor and visualize the state of each vehicle in the swarm – the state of LAUV should be available both on the surface and underwater, whereas the state of each MAUV should be available at least on the surface.

One seriously considered option in this regard is to use pMarineViewer MOOS application to fill the role of DU. If supported by other MOOS applications it is able to define a swarm mission by specifying either the operational area or the sequence of waypoints. Moreover, it also makes it possible to monitor and visualize the state of vehicles and their inner MOOS applications by handling the so-called AppCasts.

Since the primary task of the swarm, according to the project assumptions, is to cover a trajectory specified by the sequence of waypoints in a predefined formation(s), it seems that the simple pMarineViewer application should be enough to specify such task. Moreover, the application has also sufficient abilities in terms of visualization.

The task of the CS is: (i) to pass commands stored in MOOSDB (remote control and mission definition) to vehicles, and (ii) to pass the state of each vehicle to the DU via MOOSDB. The CS should work in two channels, i.e. the acoustic underwater and the WiFi surface channel. The CS component handling the acoustic channel will consist of two layers, i.e. the layer made up of ready components provided by German partners after appropriate configuration and the layer responsible for converting messages into MOOS variables and putting them into MOOSDB. In turn, the CS component handling WiFi channel can be implemented in the form of pShare MOOS application.

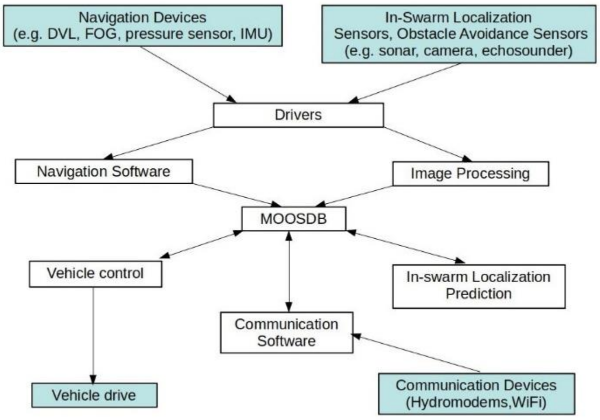


Figure 6: High-level software architecture – vehicles

The SMA applications, as their name implies, support the DU, i.e. they can handle a joystick or other manipulator, handle mouse events or even provide an additional options in terms of some parameters visualization.

The architecture of the software on the side of individual vehicles is a bit more complicated compared to the shoreside architecture. It assumes the existence of seven primary components, i.e. (i) MOOSDB as the communication medium for all other applications, (ii) Drivers (DR) of different vehicle devices and sensors (except communication hardware), (iii) Navigation Software (NS), (iv) Image Processing Software (IPS), (v) In-Swarm Localization and Prediction Software (ISLPS), (vi) Vehicle Control Software (VCS), and (vii) the CS with the same tasks and the architecture as in the case of the shoreside.

The role of DR is simply to read data from the devices and sensors and to forward it to NS and IPS. The forwarding data is performed without the use of MOOSDB, the stream of data is passed directly to NS and IPS. Of course, the solution which integrates DR apps with their counterparts in NS and IPS is also possible. DR also passes information from VCS to control thrusters of vehicles.

The task of NS is to estimate the state of each vehicle (position and angles) in the global coordinate system or/and the local invariable coordinate system established at the very beginning of the swarm mission. The estimated state is sent to MOOSDB.

The task of IPS is to extract information from the raw data acquired from the devices and sensors, e.g. sonar and camera, and to put it into MOOSDB for further processing.

The task of ISLPS is to estimate vehicle position in the entire swarm. To this end, the information from NS, IPS and CS is used. Moreover, some predictions of neighboring vehicles behavior are also performed.

In turn, the task of VCS is to control all aspects of vehicle operation based on the information produced by other systems and applications and stored in MOOSDB. The mentioned aspects include: (i) low-level control, (ii) remote control, (iii) swarm formation maintenance control, (iv) obstacle avoidance, and (v) handling emergency situations (e.g. exceeding an acceptable duration of the mission, exceeding an acceptable depth or operational area, breakdown of some vehicle hardware or software, leakage). VCS passes information (e.g. thruster speed) to DR which then produces signals to control each drive of the vehicle.

6. EVALUATION CRITERIA

The evaluation criteria are different for simulations and tests in real conditions. Since the objective of the simulations is to design an optimal swarm control algorithms and to determine the conditions that must be met for the swarm formation to be maintained, the most natural evaluation criterion seems to be the sum of formation deviation counted over the entire simulation. The formal definition of the formation deviation will be made later in the project. It will be adjusted to results of the simulations and appropriately modified.

In the case of the tests in the real conditions, and the impossibility to constantly monitor the state of each MAUV in an assumed coordinate frame (local or global), and in consequence, the impossibility to evaluate the maintenance of the formation continuously, a different criterion have to be used. The possible solution is to assess the final position of all swarm members after surfacing. Once the LAUV reaches the final waypoint it should send a message with the command to stop mission and to go to the surface. The quality of the solution will be evaluated based on the formation deviation on the surface.

7. SUMMARY

The paper presents preliminaries in European Defense Agency project category B called “Swarm of Autonomous Biomimetic Underwater Vehicles”. It specifies operational scenarios which according to assumptions define future possible operation of the swarm. The scenarios are mostly generic meaning that they do not refer to any specific task of the swarm. The exception is simple MCM scenario which is intended for final demonstration of the technology designed within the project. The generic scenarios differ in a type of formation (loos or rigid), trajectory, possible obstacle avoidance maneuvers, and in events generated by the vehicles and handled by the swarm.

Moreover, the paper also defines in-swarm communication strategy in which leader vehicles broadcast momentary parameters of swarm mission and their navigational parameters with a high frequency, and follower vehicles generate the events with a lower frequency.

The paper also specifies a required equipment of all the vehicles which differs for the leaders and followers. The leaders, due to their task, are mainly equipped with global navigation dead reckoning instruments whereas the followers with sonar and camera for in-swarm localization.

In addition to the required hardware, the paper also outlines high-level software architecture with a central role of MOOS-IvP.

The final section of the paper describes how different solutions designed and implemented within the project will be evaluated.

REFERENCES

[1] J. L. Molnar, C. Cheng, L. O. Tiziani, B. Boots and F. L. Hammond, "Optical Sensing and Control Methods for Soft Pneumatically Actuated Robotic Manipulators," 2018 IEEE International Conference on Robotics and Automation (ICRA), 2018, pp. 3355-3362, doi: 10.1109/ICRA.2018.8461110.

[2] M. Csencsits, et al. "User interfaces for continuum robot arms," in Intelligent Robots and Systems, 2005

[3] M. Giannaccini, et al. "Novel design of a soft lightweight pneumatic continuum robot Arm with decoupled variable stiffness and positioning," Soft robotics, vol. 5, no. 1, pp. 54--70, 2018.

[4] https://oceanai.mit.edu/moos-ivp/pmwiki/pmwiki.php

DETERMINATION OF MOORING AREAS FOR NAUTICAL VESSELS

Danijel Pušić
Zvonimir Lušić
University of Split, Maritime Faculty
Ruđera Boškovića 37, 21000 Split, Croatia
dpusic@pfst.hr

ABSTRACT

Significant and popular nautical destinations require an appropriate acceptance system for nautical tourism ships and boats. In addition to the marinas and other specialized or not specialized mooring places, mooring at a mooring buoy is very common and popular way of securing these vessels. It is much safer that standard anchoring but also much easier in comparison to ports, marinas, and other complex berthing structures. Mooring buoys should be placed within a well-defined area which should be on a safe distance from the shore, with enough space for intended ships; they should also provide protection from the high seas and the wind and must not interfere with the transit of other vessels; they should be environmentally friendly, etc. These factors are in conflict with each other, so the final choice of mooring area is always a compromise. In this work mooring areas in Split Dalmatia County area, which is located in the central part of the East Adriatic coast and also known as one of the top nautical destinations, will be analysed. Characteristics of already established mooring areas will be analysed as well as the criteria according to which they have been defined. In accordance with the obtained results, basic recommendations, and guidelines for the establishment of future mooring areas and general standardization of their selection will be given.

Keywords: Mooring area, mooring buoy, tourist vessels, nautical destinations

1. INTRODUCTION

The growth of nautical tourism inevitably leads to the need for increased mooring capacity for vessels, both on land and in water. In addition to marinas and other specialized nautical tourism ports, anchors and mooring buoys are most often used at sea, especially in remote and secluded locations. “Anchor mooring” means the use of anchor on board to moor a vessel to the bottom of a sea or river to resist movement, without connecting the vessel to the shore. Mooring at a mooring buoy means that a ship is moored to a buoy which floats (in the deep waters) and which is secured with a heavier weight (or special anchors) at the bottom of the sea. Anchoring as one of the basic techniques to secure a vessel to the bottom and to prevent movement, is available to all vessels, larger and smaller, and does not require any investment by third parties, but it has a major drawback due to the physical damage it makes on the seabed [1][2]. Therefore, in popular nautical destinations it is recommended to use mooring buoys as much as possible, and accordingly to define concession fields for accommodating vessels [2][3]. This way of mooring, in addition to protecting the seabed, prevents uncontrolled congestion, avoids critical approach to facilities and dangers, increases the safety of ships at berth, etc., and on the other hand allows additional revenue from charging. Mooring areas for smaller vessels, generally vessels of nautical tourism, are the subject of this research with its primary goal to determine the positioning of mooring buoys. The aim is to define basic criteria which should be taken into consideration in order to standardize future selection of mooring areas. The main criteria will be selected based on the analysis of existing mooring areas located in the area of Split Dalmatia County which is placed in the central part of the East Adriatic coast and is one of the most popular nautical destinations. These criteria will primarily refer to the size of a mooring area surface compared to the size of the total available area, minimal distance to the shore (or safety isobaths), minimal depths, vicinity of other vessels transit routes (if any), protection from the open sea and winds, and other site-specific criteria. The size of vessels will not be taken into consideration directly; assumption is that vessels of nautical tourism are mainly those with length of less than 20 m, although this does not exclude larger tourist vessels. In general, mooring areas will be divided into two groups: mooring areas within bays (or closed areas) and mooring areas along the shoreline (open areas).

2. PRESENT PRACTICE

Mooring area, and corresponding mooring fields area, selection is always a compromise solution between safety conditions and economic viability. Field managers, i.e., investors (generally concession holders) are always interested in having as much capacity as possible, in area as well as in number of vessels, which, by default, results in decreased safety. There are no standard criteria whatsoever in defining mooring area, but there are appropriate recommendations [2], good practice and certain guides which are more suitable for larger vessels and anchoring techniques in general [4][5][6][7]. All this results in a large variety of mooring areas selection.

Some of the general recommendations suitable for smaller vessels mooring fields and mooring area selection will be given hereafter.

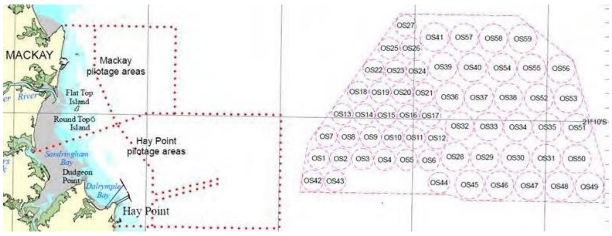
According to PIANC [4]: The design of an anchorage mainly depends on the following factors:

- Size, dimensions, and characteristics of the vessel(s) design.
- Type of operations expected to be undertaken.
- Time the vessel(s) is expected to stay at anchor.
- Site's general configuration and availability of manoeuvring space.
- Organization of the general anchorage area or defined anchorage positions.
- Number of defined anchoring points to be provided at the site.
- Marine environment in the area and operational limiting conditions.
- Site's physical characteristics and, in particular, depth and shape of the seabed and the ability of the seabed material for anchor holding.
- Availability of pollution combating resources, etc.

Also, an anchorage (mooring area) must be of a sufficient size to allow free movement from any obstacle; the bathymetry should be relatively flat and clear of any obstructions, away from busy shipping lanes, etc. An anchorage should be chosen so it has a suitable natural or artificial marking enabling the vessel to be accurately and safely positioned when approaching and whilst remaining at anchor. Swinging radius of a vessel at anchor should also take into account anchoring inaccuracies, length of the vessel, length of the chain/cable under load (horizontal projections), tides and finally safety clearance. Safety clearance may be 10% of the length of the vessel, with a minimum 20 m (except for fishing and pleasure crafts for which it may be reduced to 5 m) [4]. Length of the chain, for mooring buoy, should be around 1,5 max. depth [8]. The distance between vessels in multi-buoy mooring systems should not be less than the breadth of the largest vessel + 1,0~2,0 m [14]. An under-keel clearance (UKC) of 10% of the draught may be acceptable for sheltered location or alongside a sheltered port [6]. According to the Anchorage Area Design and Management Guideline [6] the key elements in anchorage (mooring area) design are:

- anchorage location (water depth, holding ground, weather, port layout and infrastructure, other waterway users, vicinity of populous area, communications to shore facilities, etc.
- anchorage size and layout (by utilising a mix of anchorage swing radius sizes to match the expected ship sizes, a smaller overall anchorage area footprint can be achieved).
- anchorage use.
- environmental considerations (environmental assessment, disturbance to seabed from anchor drop and chain drag, management of emissions, pollutants or wastes, aesthetic value, marine pest introduction, conservation-dependent species, local heritage values).

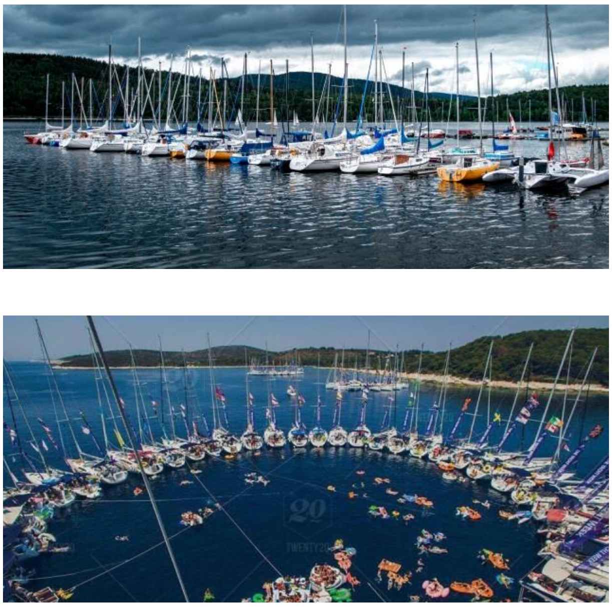
Designs of the mooring areas and mooring buoy fields generally tend to have simple geometrical shapes such as: circle, square rectangle, parallelogram, rhombus, etc. For smaller vessels anchorage mooring areas can be found in irregular geometrical shapes depending on the coastline and the size of the available water area.



Source: [6]

Figure 1: Example of a designated anchorage for different size ships

It is also possible to berth the vessels side by side using the Mediterranean mooring technique. This would enable the accommodation of a greater number of vessels on a smaller area, however it involves a great deal of other problems which will decrease its usage, especially in remote and less protected areas.



Source: [12][13]

Figure 2: Vessels side by side

3. MOORING AREAS OF SD COUNTY

The sea and islands make up to 67,5% of Split-Dalmatia County and represent a challenge and an opportunity for the development of nautical mooring based on ecologically accepted settings. Long-term problems in the area have been spatial disorder, numerous illegal moorings and berths, and a non-existing strategy which would enable mooring within a specific, safe, and clearly defined system. The first attempt to address the problem has been the making of “Study of mooring in Split-

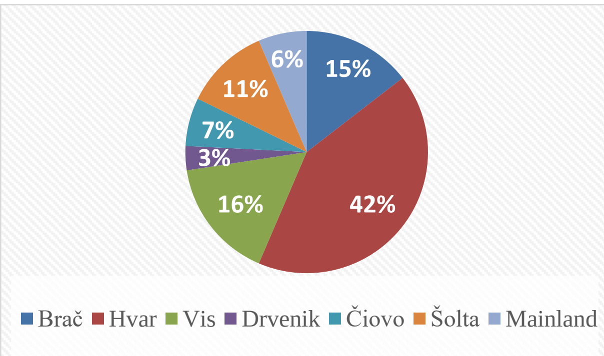
Dalmatia County, phases I, II and III". It has created an expert basis for additions and amendments, i.e., for making of the new Split-Dalmatia County Spatial Plan. The study was based on navigation and meteorological features, as well as technical-technological and traffic-navigation features, maritime security measures, ecological network Natura 2000 habitats map, the list of strictly protected species and technical-technological methods of anchoring. Organisation of nautical moorings has been made using the expert analysis method which determined possible concession fields for special purpose ports – anchorages, and conditions, which an investor has to meet in order to obtain all the necessary permits and decisions, have been specified.[9] Solution examples for 62 possible nautical mooring areas with the total of 98 mooring fields will be set out hereafter and further analysis will suggest the common criteria for nautical mooring area positioning. Nautical mooring areas are mainly located on Central Dalmatian islands 93.1%, with only 6.9% on the mainland. The study has shown that there are 4.3% of possible nautical mooring areas on the mainland, while on the islands there are 95.7% (Table 1).

Table 1: The number of possible mooring areas and fields

	Areas	Fields
Brač	9	14
Hvar	26	43
Vis	10	16
Drvenik V. and M.	2	4
Čiovo	4	5
Šolta	7	12
Mainland	4	4
Total	62	98

Source: Authors

With 26 possible nautical mooring areas, which is 42% of the total number, the island of Hvar has the largest number of areas and fields of all Central Dalmatian islands. The biggest Central Dalmatian island of Brač has 9 possible mooring areas or 15% of the total number (Figure 3).



Source: Authors

Figure 3: Areas in percentages

The largest number of possible nautical mooring fields, 43, are defined on the island of Hvar (Table 1) with 44% of the total number of mooring fields, while the smallest percentage, only 4%, can be found on the mainland (Figure 4).

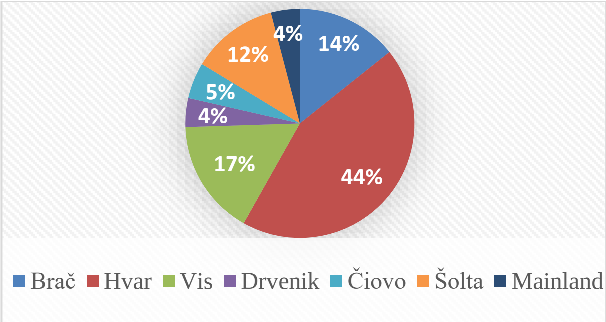


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Figure 4: Fields in percentages

3.1. Areas of nautical mooring fields

Nautical mooring fields on the island of Brač cover the area of 11,638.6 m^2 and in relation to the total area, which is 1.431.036,9 m^2, the ratio of fields coverage is 7.80% of coves (Table 2).

Table 2: Ratio of mooring fields to cove areas

	Fields m2	Area m2	Ratio
Brač	111,638.6	1,431,036.9	7.80%
Hvar	464,648.6	23,673,348.7	18.40%
Vis	144,427.7	5,919,905.3	2.44%
Drvenik V. and M.	103,808.8	708,334.8	14.66%
Čiovo	63,041.4	811,086.0	7.77%
Šolta	123,243.2	605,511.3	20.35%
Mainland	174,555.2	1,548,416.8	11.27%

Source: Authors

On the island of Hvar 43 mooring fields cover the area of 464,648.6 m^2, in relation to the total area, which is 3,673,348.7 m^2 the ratio of fields coverage is 18.40%.

On the island of Vis 16 mooring fields cover the area of 144,427,7 m^2, in relation to the total area, which is 5,919,905.3 m^2 the ratio of fields coverage is 2,44%.

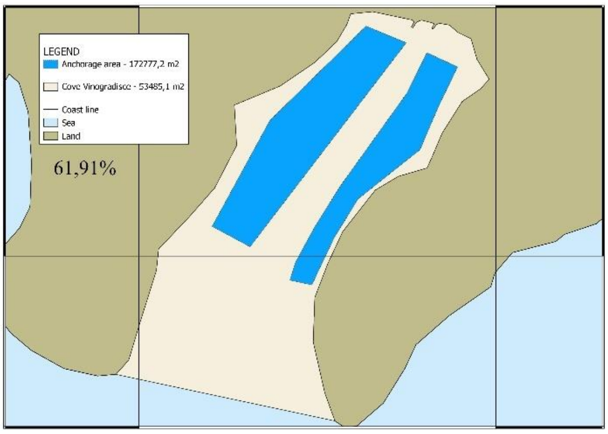
On the island of Drvenik 4 mooring fields cover the area of 103,808.8 m^2, in relation to the total area, which is 708,334.8 m^2 the ratio of fields coverage is 14.66%.

On the peninsula of Čiovo 5 mooring fields cover the area of 63,041.4 m^2, in relation to the total area, which is 811,086.0 m^2 the ratio of fields coverage is 7,77%.

On the island of Šolta 12 mooring fields cover the area of 123,243.2 m^2, in relation to the total area, which is 605,511.3 m^2 the ratio of fields coverage is 20.35%.

On the mainland (Marina, Vinišće) 4 mooring fields cover the area of 174,555.2 m^2, in relation to the total area, which is 1,548,416.8 m^2 the ratio of fields coverage is 11.27%.

Although the obtained results give an average ratio of fields coverage of around 20%, in some (closed) coves the percentage is considerably increased. Prime example of is Vinogradišće cove area on the Pakleni islands with the largest percentage (Figure 5).



Source: Authors

Figure 5: Area with the largest coverage percentage – cove Vinogradišće island Pakleni

In order to secure a safe accommodation of vessels on mooring buoys mooring fields have to be sufficiently distanced from the shore. Disparity in determining a safe distance is evident due to the diversity of coves, smaller coves, and nautical mooring areas configurations. According to the analysis of existing nautical fields the average distance from the shore is 28.4 m. Table 3 shows the average distances for all mooring fields in SD County.

Table 3: Average distances from the shore

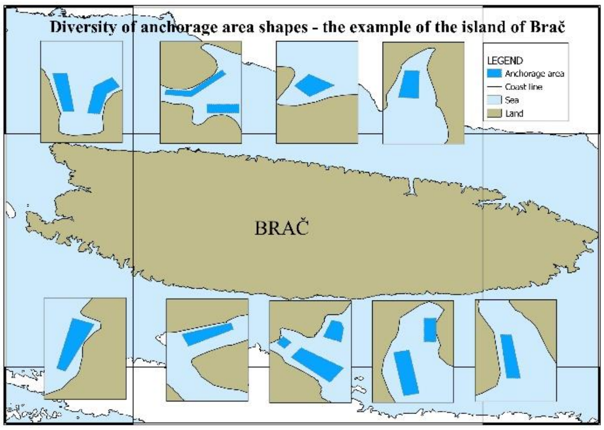
Mooring field	Average distance in m
Brač	11.0
Hvar	15.5
Vis	20.7
Drvenik V. and M.	48.5
Čiovo	32.7
Šolta	16.1
Mainland	54.0
Total	28.4

Source: Authors

The reasons for this disparity are conditioned by diversity and general coastline configuration, and ecological parameters (NATURA 2000), too. Distance from the shore also depends on the size, dimensions and characteristics of the vessel, time the vessel will be moored (daylight/overnight mooring), mooring field infrastructure with or without buoys and anchorages. [2]

Depths on analysed mooring areas are above 3 m, as a rule.

Most of analysed fields have no regular shape, irregular quadrilaterals that follow the coastline and radially expand towards the open sea predominate (Figure 6).



Source: Authors

Figure 6: Diversity of anchorage area shapes – the example of the island of Brač

Based on the analysis performed on the selected area it can be concluded that the primary factor for mooring area selection is economic, taking into account spatial and safety limitations. Namely, all selected areas are the ones where there is an initiative by the investor and that have appropriate service, tourist, and other facilities of public or private interest in their vicinity. The fact that certain areas are completely exposed to the open sea proves that commercial component overrules safety, however it does not mean that minimum safety conditions are not met. Particular restrictions are applied on mooring areas which are not well protected from the wind and the waves, such as daily berth only, summer season berthing only, safe berthing during certain winds, etc.

Mooring areas shapes, stretches and dimensions also confirm they are not in accordance with the previously defined vessels dimensions. This was expected given the fact that in the selected examples local government defines future concession fields areas, and it is left to the concession holders to choose, later on, between the larger or smaller vessels, i.e., to define the density of mooring buoys within the field taking care of the safety clearance between moored vessels in the future, according to the recommendations. [14]

All listed mooring fields are intended for nautical tourism vessels and their numbers according to length can be analysed from the traffic statistics (Table 4, data for Croatia in whole).

Table 4: Number of vessels in transit in nautical ports, 2020

Vessel length (m)	Number
< 6	2,458
6-8	8,025
8-10	15,574
10-12	34,552
12-15	42,213
15-20	12,765
>20	3,273

Source: [11]

4. THE MAIN CRITERIA

Fundamental assumption of every process is making decisions, therefore in this process of defining possible nautical mooring locations different decisions have been considered. On the strategical level of decision-making the first step is to define your objectives. The principal objective should be clearly defined, and, in this case, it is a safe and well-sheltered mooring place with enough depth and with as little impact as possible of hydrometeorological conditions (wind, waves, current). In defining a quality objectives definition, one should consider opinions of all collaborators in the process of decision-making (Figure 7) as well as the opinions of all future users of these areas (moorings).

After the objectives have been defined it is necessary to establish the criteria, including a set of possible solutions, which will enable a quality mooring area selection. Evaluation criteria are derived from ranking of set solution variants.

If we do not take already suggested mooring fields, i.e., the ones whose sites have already been determined, as the starting point, the selection criteria can be divided into the general ones, for mooring area selection, and the specific ones for mooring field selection.

The main criteria for mooring area selection, have been divided in five basic sets (Figure 8):

- Safety of Navigation criteria
- Hydrometeorological criteria
- Spatial criteria
- Economic criteria
- Environmental criteria

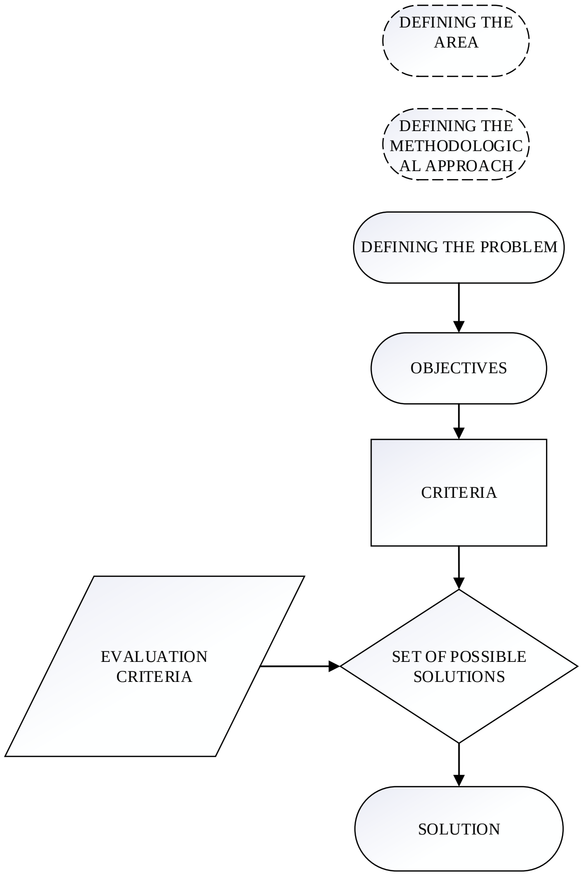


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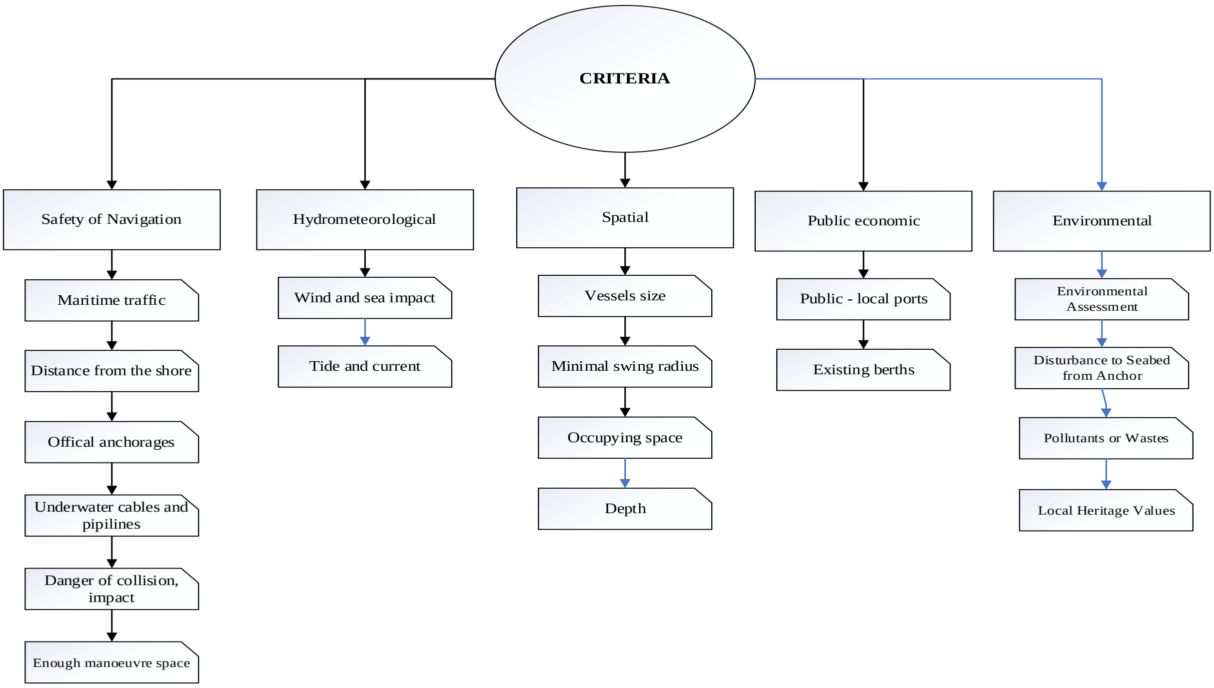
Figure 7: Objectives and criteria defining



Source: Authors

Figure 8: Distribution of the main criteria

The first set are safety navigation criteria:

- Avoid mooring in the immediate vicinity of underwater cables, underwater installations and other sites which imply prohibited anchorage.
- Avoid positioning of mooring fields which would pose a potential danger for a collision, impact, wounding, and other hazards.
- Mooring fields should not limit the manoeuvre space for vessels outside the mooring field that need to manoeuvre. Furthermore, they should ensure enough manoeuvre space for vessels coming in and going away from the mooring field.

The second set of criteria are hydrometeorological:

- Mooring fields should be in areas as sheltered as possible from the influence of bad hydrometeorological conditions, mostly from the wind and the sea.
- The fields have to be in the area with the least influence of tides, especially of currents.

The third set are spatial criteria:

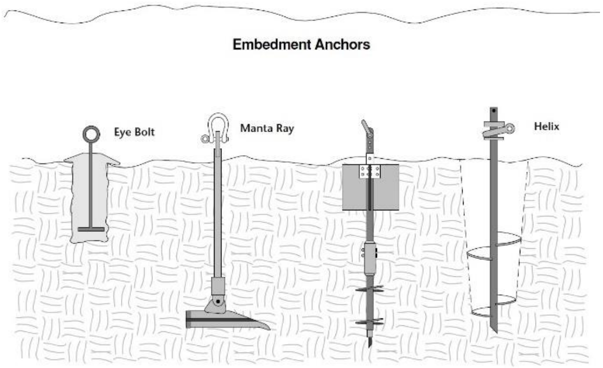
- The field has to be in the area with enough depth, on a safe distance from the shore, other installations, and transit routes of other vessels.
- The area has to be wide enough, so the swing radius does not cross the field boundaries, nor does it overlap with the swing radius of other vessels.

The fourth set are economic criteria:

- Mooring fields should be avoid in the harbour area.
- Mooring fields should not interfere with existing public berths.
- Mainland access to the mooring field should be without obstruction.
- Mooring fields should be in the vicinity of traffic and other infrastructure.
- Given the expected occupancy, mooring fields should be cost-effective.

The fifth set are environmental criteria:

- Environmental impact assessment should be as reduced as possible.
- Disturbance to seabed from anchor should be avoided by using embedment anchors (Figure 9) and anchoring equipment which do not disturb the seabed.
- Pollutants or wastes should be collected from the vessels and appropriately disposed on the mainland.
- Local heritage values should be preserved as much as possible.



Source: [2]

Figure 9: Type of the embedment anchors

Some of the specific criteria regarding size, shape, and position of the field are as follows:

- Strive for simpler geometric shapes: circle, square, rectangle.
- To accommodate vessels of different sizes, divide the field into groups according to their length, e.g., LOA to 10m, from 10 to 15m, from 15 to 20m, etc.
- Define mooring field boundaries in accordance with known vessel lengths, i.e., estimated swing radius.
- Not to take up more than 50% of the cove, or exceptionally 75% if it is a cove with no other berths, beaches, infrastructural or other objects or activities that would require a sea or mainland access.
- Minimal width should not be less than double swing radius of the largest vessel and not less than 20 m.
- The distance between buoys in single buoy mooring should be determined so that the swing radii do not overlap. Generally, not less than double swing radius of the largest vessel and not less than 20 m.
- Swing radius should not cross the mooring field boundaries, nor should it overlap with the swing radii of the neighbouring vessels.
- For safety reasons, the calculated swing radius should be increased by 10% of the vessel length, but not less than 5 m;
- For multi-buoy mooring (forward and aft) minimal distance between buoys should not be less than the breadth of the largest vessel + 1,0 ~2,0 m.
- The distance between mooring field boundaries and the coast should not be less than the length of the largest vessel, and not less than 20 m.
- In case of the transit traffic vicinity, the distance from the shore, i.e., from the safe isobath, should not be less than double length of the largest vessel and not less than 40 m.
-

- In the nautical mooring area towards the shore and 150 m from the nautical mooring field towards the open sea there should not be any other artificial installations nor objects, including moorings or maritime traffic control measures.
- The distance from the beach should be more than 100m.[1]
- The area should be deep enough, making sure that during mean low water spring the depth should never be less than 1 m more than the expected vessel gauge.

Efficiency and advantages of all criteria have been analysed while choosing them, with the primary aim of their reliability in mooring fields selection. All criteria have been chosen to minimise safety vulnerabilities, create equal spatial distribution and detect reliable hydrometeorological conditions.

Considering there is no structural and holistic approach to the analysis of the mooring field selection problem, the aforementioned approach solves the systematic criteria, and subsequently objectives, analysis in a quick and straightforward way. Environmental conflicts justify the implementation of this approach precisely to identify the best solution.

Furthermore, the criteria present the measure of those system features which are to be optimised in order to achieve the set objectives. [3]

5. CONCLUSION

Mooring areas have lately become an important factor in nautical tourism, and defining their location requires a complex and responsible process. This paper analyses the criteria which have been used in defining mooring area locations, and their comparison to prescribed recommendations for general vessels mooring. Although there is no precisely defined recommendation for nautical mooring establishment, it became evident that even the general criteria for larger vessels mooring can be used in procedures for nautical mooring selection.

Comparative analysis has shown that nautical moorings require a specific approach primarily due to the size of vessels, and the establishment of mooring within an already defined area. Given the spatial limitations, it is especially important to meet all the criteria, if possible, in determining mooring area location.

REFERENCES

[1] Davis A.R, Broad A, Gullett W, , Reveley J, Steele C, Schofield C: Anchors away? The impacts of anchor scour by ocean-going vessels and potential response options,(2016), Marine Policy 73, 1-7.

[2] Mooring Buoy Planning Guide, International PADI, Inc., (2005), Available from: https://www.coris.noaa.gov/activities/resourceCD/resources/mooring_buoy_g.pdf

[3] Mooring Buoys as a Management Tool for Controlling Visitor Impacts: An Introduction, (2015), Available from: https://octogroup.org/news/mooring-buoys-management-tool-controlling-visitor-impacts-introduction/

[4] PIANC. Report n° 121 - 2014. 2014th ed. PIANC, editor. Bruxelles: PIANC Secrétariat Général; (2014)

[5] Mooring Equipment Guidelines (MEG4), OCIMF, (2018).

[6] Anchorage Area Design and Management Guideline, Maritime Safety Queensland, (2019). Available from: https://www.google.hr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi8qpeivZD2AhUcgf0HHeVyCRgQFnoECAUQAQ&url=https%3A%2F%2Fwww.msq.qld.gov.au%2F-%2Fmedia%2FMSQInternet%2FMSQFiles%2FHome%2FAbout-us%2FRight-to-information%2FPublished-information%2Fanchorage-area-design-and-management-guideline.pdf%3Fla&usg=AOvVaw1CDyxDyOoWH6iPJLZJWM-E

[7] Technical standards committee-guidelines for moorings, GL Noble Denton, 0032/ND, (2016). Available from: https://rules.dnv.com/docs/pdf/gl/nobledenton/0032-nd%20rev%202.1%20%2028-jun-16%20guidelines%20for%20moorings.pdf

[8] McVinney R: Boat Mooring Guide, (2022). Available from: https://www.boattrader.com/resources/boat-mooring-guide/

[9] Račić N, Vidan P, Lušić Z, Slišković M, Pušić D, Popović R. Studija sidrišta Splitsko-dalmatinske županije I. i II. faza-podloga za Prostorni plan Splitsko-dalmatinske županije, Split; (2019), Available from: http://www.moreikrs.hr/ProjektiPdf/Sidrista/Studija sidrista Splitsko-dalmatinske zupanije – I. i II. faza, podloga za prostorni plan Splitsko-dalmatinske zupanije.pdf

[10] Kovačić M. Optimizacija izbora lokacije i sadržaja luke nautičkog turizma, (2009), Pomorski fakultet u Rijeci.

[1] In accordance with the Rules on the Conditions and Methods for Maintaining Order in Ports and Other Parts of Croatia's Internal Sea Waters and Territorial Sea, it is forbidden to swim more than 100 m off the shore.

[11] Nautical tourism-Capacity and Turnover of Ports, 2020, Croatian Bereau of Statistics, (2021). Available from: https://www.dzs.hr/Hrv_Eng/publication/2020/04-03-04_01_2020.htm

[12] https://www.twenty20.com/photos/f665d18a-3a55-4242-9f90-c506ac95d273

[13] https://www.twenty20.com/photos/fab390f2-bdce-4e51-990c-995188c72555

[14] Technical Standards and Commentaries of Port and Harbour Facilities in Japan, (2007), the Overseas Coastal Area Development Institute of Japan. Available from: https://ocdi.or.jp/en/download-pdf

MONITORING OF PERFORMANCE SPILL-OVER EFFECT WITHIN AIR TRAFFIC MANAGEMENT SYSTEM IN EUROPE

Zvonimir Rezo, Ph.D.
Institute of Transport and Communications
Kušlanova 2, Zagreb, Croatia
zvonimir.rezo@gmail.com

Sanja Steiner, Ph.D.
University of Zagreb, Faculty of Transport and Traffic Sciences
Vukelićeva 4, Zagreb, Croatia
ssteiner@fpz.unizg.hr

Tomislav Mihetec, Ph.D.
Croatia Control Ltd.
Ulica Rudolfa Fizira 2, Velika Gorica, Croatia
tomislavmihetec@crocontrol.hr

Andrea Tikvica, M.Sc.
Sedam IT
Koledovčina ulica 2, Zagreb, Croatia
tikvica.andrea@gmail.com

ABSTRACT

The difficulties in studying the cause-and-effect relationships between performance levels of neighboring Air Navigation Service Providers (ANSPs) stem from the multitude of different relations from which they are made. Monitoring of performance spill-over effect between neighboring ANSPs represents highly relevant business activity within domain of strategic planning and development of the Air Traffic Management (ATM) system. Within the ATM domain performance spill-over represents an exogenous factor that occurs when decision-made, phenomenon or some situation begins to affect another geographical area, organization, situation or group of people in an unpleasant or unwanted way. The most obvious examples are reflected when significant events occur. During an event such as Eyjafjallajökull volcano eruption, airspace closure due to military activities, periods of airspace saturation or during Air Traffic Control (ATC) industrial actions performance spill-over effect can be far more easily spotted. In that respect, this paper presents the research findings of monitoring of performance spill-over effect occurrence within the ATM system in Europe from a capacitive viewpoint. By studying three specific events triggered by different causes (ATC capacity shortage, ATC industrial action and ATC equipment failure), the paper simultaneously provides insights on the performance spill-over effect and on the resilience of the ATM system in Europe - both of which are highly relevant within domain of its strategic planning and development.

Keywords: Air Traffic Management; Strategic planning and development; Airstat; performance spill-over effect

1. INTRODUCTION

The convention on International Civil Aviation (known as Chicago Convention) states that every Member State has complete and exclusive sovereignty over the airspace above its territory [1]. Member States that do not have ANSP, delegate Air Navigation Service (ANS) provision to other Member State. Thus, in Europe, at relatively small geographical area, operates a relatively high number of ANSPs. As a result, the performance level of every ANSP in Europe may, in different performance areas, have a major or minor impact on the performance level of an entire ATM system in Europe [2].

Like any other system, the ATM system can be more or less efficient. However, the aviation industry is a capital-intensive industry. Hence, the scale of inefficiency caused by the inefficiency of the ATM system can be quite significant. For instance, it is estimated that every minute of Air Traffic Flow Management (ATFM) delay generates a network average cost of 100 EUR [3].

With a goal to maximize the efficiency of the ATM system in Europe, strategic planning and development at a national, local and regional level are continuously being performed. The main purpose of strategic planning and development is to create or obtain relevant information required for the purposes of decision-making processes.

In order to be able to spot, but also create changes and initiate trends within the ATM system, those dealing with the strategic planning and development, performance management and change management within the ATM domain should have relevant data, information and knowledge on endogenous and exogenous factors affecting ANS provision. That is of high relevancy as ANS provision represents a business activity where very few things are certain. That uncertainty frequently stems from exogenous factors coming from ANSPs' business environment. Uncertainty of the business environment implies a situation in which decision-makers perceive their business environment, or part of it, as unpredictable.

The establishment of the Single European Sky (SES) made performance data highly available. Thus, nowadays there is a need for know-how required to turn large sets of performance data into useful information. Within the ATM system in Europe, the uncertainty of the business environment is often a result of its dynamism. There are many causes initiating the dynamism of ANSPs' business environment. Consequently, that makes the strategic planning and development of the ATM system in Europe by no means an easy business task. By studying three specific events from a capacitive viewpoint, triggered by different causes, this paper presents research findings of monitoring of performance spill-over effect within the ATM system in Europe. Also, it provides a brief review of the performance management within the ATM system in Europe followed by a description of the performance spill-over effect within the ATM system. Before concluding a paper, research determinants are specified, the main outcomes are presented and briefly discussed.

2. PERFORMANCE MANAGEMENT WITHIN AIR TRAFFIC MANAGEMENT

Performance management is one of the main functions supporting strategic planning and development of the ATM system - which deals with planning of a medium to the long-term range [4]. As compared to earlier, it is nowadays easier to deal with performance management within the domain of the ATM system. Technological advances, the definition of Key Performance Areas (KPAs), indicators (KPIs) and their metrics, the adoption of open-access frameworks combined with greater data availability can be cited as the main reasons for the aforementioned. Establishment of Performance Review Body (PRB) and Performance Review Unit (PRU) can be also listed as contributing factors. PRB is established to support the European Commission in the implementation of the Performance Scheme, while PRU, as part of the European Organization for the Safety of Air Navigation (EUROCONTROL), is responsible for data sharing and a public reporting of the number of KPAs and KPIs.

The complexity of performance management within the ATM system in Europe stems from various aspects and sources. In principle, the performance level of every ANSP is a result of exogenous and endogenous factors. Exogenous factors are outside ANSPs' control, while endogenous factors are those entirely under ANSPs' control [5]. For instance, exogenous factors of every ANSP include legal and socio-economic conditions (e.g., taxation policy, exchange rates, cost of living etc.), operational conditions (e.g., traffic patterns, Area of Responsibility (AoR), weather conditions, traffic variability etc.) and governance arrangements including, among others, international requirements required by the SES initiative. Endogenous factors include financial aspects, organizational factors and aspects of the operational and technical setup of every ANSP.

Performance management within the ATM domain in Europe is based on a regulatory framework introduced to support the realization of the SES initiative. On the one hand, that has delivered certain benefits. However, on the other hand, it had irreversibly determined the further direction of the ATM system development. As a result of their close connection, a flaw in the regulatory framework reflects also as a flaw in performance management, i.e., of strategic planning and development of the ATM system. Figure 1 shows a simplified overview of the performance valorization framework applicable within the ATM domain in Europe.

3. PERFORMANCE SPILL-OVER EFFECT

One of the characteristics of the ATM system in Europe is that national ATM systems are not independent of their neighbors. Data review indicates that by applying the criterion of whether the ANS was provided to an international or domestic flight, in 2018 94.05% of the total ANS provided in Europe were delivered in cooperation with at least two neighboring ANSPs [6].

From a capacitive viewpoint, the performance spill-over effect between neighboring ANSPs may occur as a result of certain ATFM irregularities. Even though they may occur in one part of the ATM network such events may reflect also on remote geographical areas. However, a more significant impact is likely to be reflected in areas (known as first-order neighbors) closer to the site with ATFM irregularities. For instance, due to capacity shortage in a certain geographical area, it becomes detached from neighboring areas that do not face the issue of capacity shortage. In such a way area with a capacity, shortage represents a spatial outlier.

The repercussion of the performance spill-over effect manifests in a way that the aircraft fly through one of the neighboring areas instead through the originally planned, but capacity-saturated area. Thereby, the significance of repercussions depends on the significance of the event occurred. Figure 2 shows an example of repercussions of such event. The repercussions of performance spill-over effects include the generation of various effects. Most often they have a detrimental effect on the environment and contribute to higher operational costs for Airspace Users (AUs). Therefore, ANSPs, AUs and National Supervisory Authorities should monitor the occurrence of performance spill-over effects on a daily basis. Primarily with the goal to cope with the business risks and dynamism of their business environment [7].

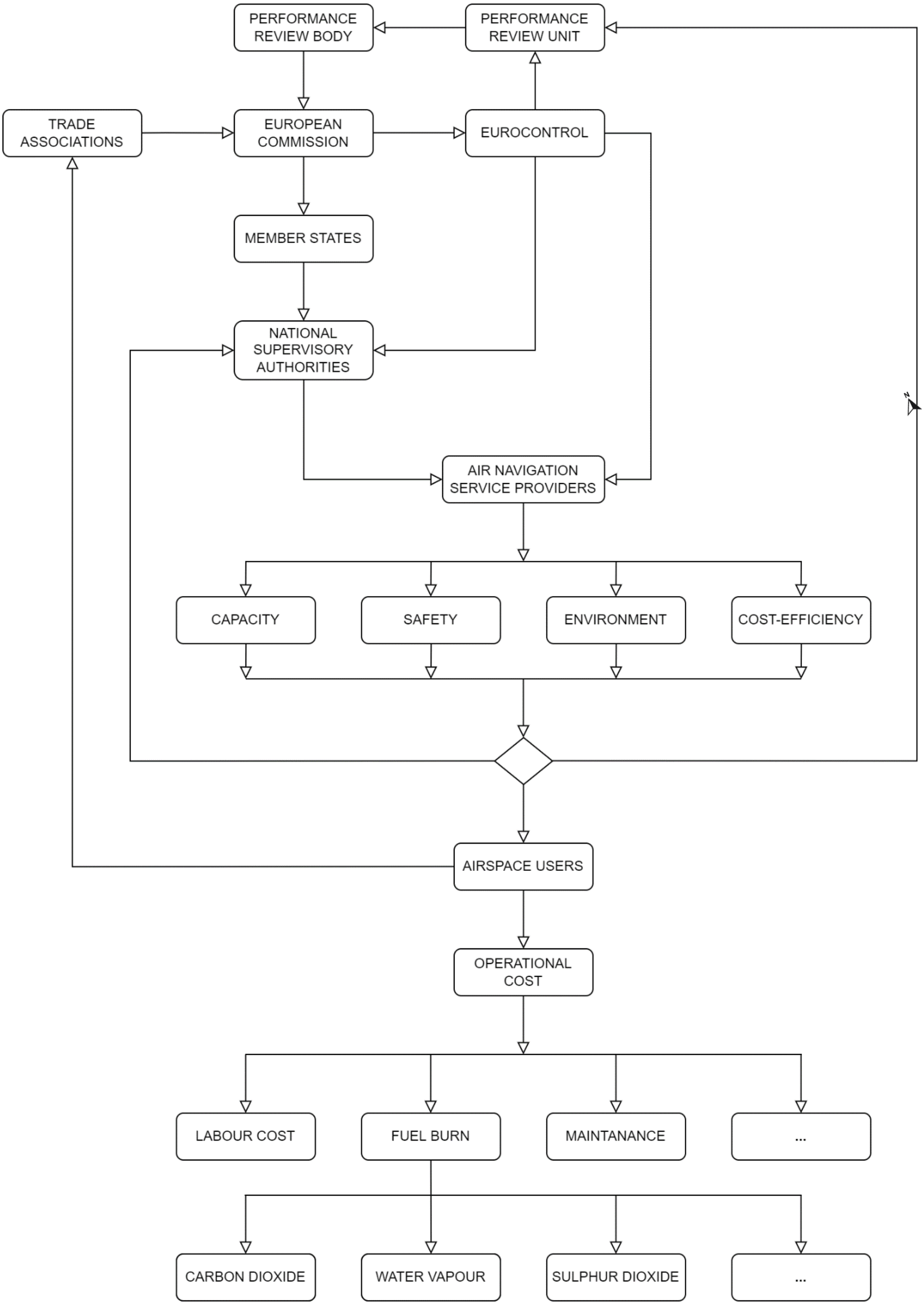


Figure 1: Simplified overview of the performance valorization framework

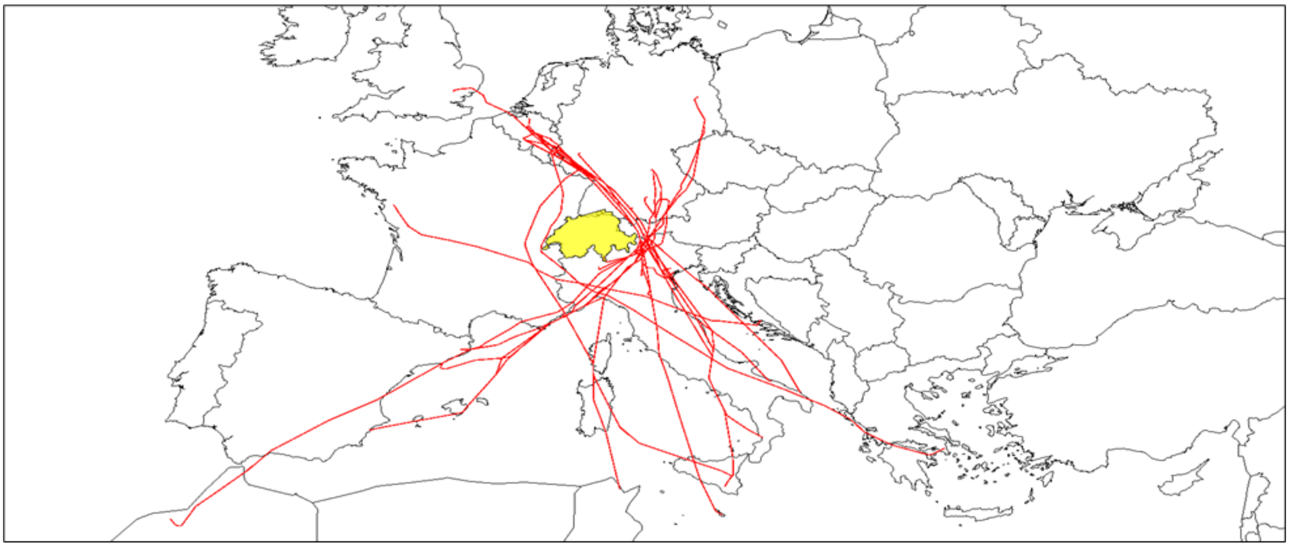


Figure 2: Simplified overview of performance spill-over effect manifestation on neighboring ANSPs

4. CAPACITY-BASED ASSESSMENT OF PERFORMANCE SPILL-OVER EFFECT

4.1. Research conceptualization

The conceptual framework adopted within this research is based on the application of the top-down approach in a way that the whole network has been analyzed first. Later on, research interest was placed on specific AoRs. The same approach has been applied to three separate events studied from a capacitive viewpoint in order to obtain a better insight into the performance spill-over effect. Accordingly, macro-level studies have covered the evaluation of performance levels of 38 ANSPs, while meso-level studies have included valorization of the effects of studied events. Figure 3 shows an overview of the geographical scope and boundaries of ANSPs' AoRs.

4.2. Tools applied

Monitoring of performance spill-over effect between neighboring ANSPs has been enabled by the utilization of desktop application Airstat. It represents a Geo-Business Intelligence (Geo-BI) solution developed based on the research of Rezo et al. [8-10]. By taking advantage of various integrated performance modelling techniques and approaches, it derives understandable insights from massive, dynamic and often ambiguous performance data sets and synthesizes business information. As such, it supports evidence-based decision-making processes and enables data-driven argumentations. Also, its utilization brings several benefits to its users - ranging from a better understanding of complex relationships of endogenous and exogenous factors to the opportunity to evaluate the effects of various events, decisions and projects relevant within the domain of strategic planning and development of the ATM system in Europe.

4.3. Materials used

In order to determine the performance spill-over effect between neighboring ANSPs from capacitive viewpoint, en-route (ENR) ATFM delay, denoting lack of ATC capacity, had been used as a reference KPI. All studies were conducted based on the input data obtained from the EUROCONTROL/PRU by using the 2016 NM v.20.0 software. Input data had been validated and verified by the data originator. Also, it had been subject to post-ops performance revision. Figure 4 shows ENR ATFM delay distribution of events further studied within case studies.

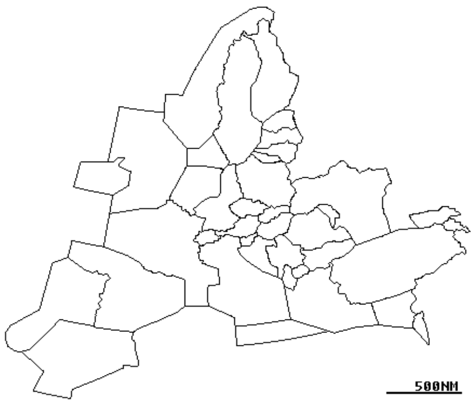


Figure 3: Spatial overview of studied geographical scope

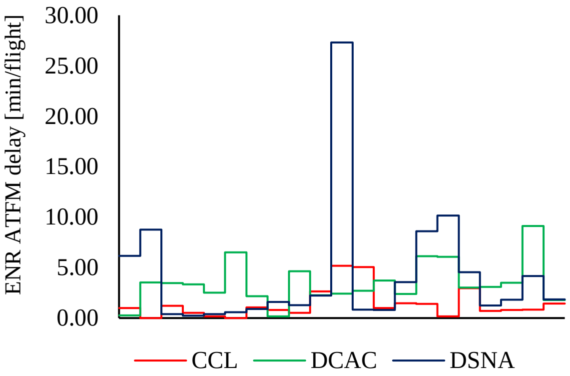


Figure 4: ENR ATFM delay distribution of studied events

4.4. CASE STUDY: ATC capacity shortage

Many successful aviation businesses manage to develop because they understand their business environment. Within the ATM system in Europe, it is of strategic importance to understand the business environment, know-how and when to optimize performances in respect to exogenous factors from the business environment.

In principle, airspace represents a limited resource and the way it is organized and managed has a strong impact on the airspace capacity. In the events when it is anticipated that the traffic demand will exceed declared ATC capacity, after coordination with Flow Management Position (FMP), the Network Manager Operations Centre (NMOC) decides on the activation of ATFM regulation(s). These regulations are imposed to adjust demand to the capacity of a given Area Control Centre (ACC). In such a way, ATFM regulation represents a safeguard method applied to match traffic demand to available ATC capacity. Thereby, ENR ATFM delay and associated costs represent one of the most obvious indicators of inefficiency in airspace and air traffic flow management from a capacitive viewpoint.

The first case study has included a study of performance spill-over effect between Department of Civil Aviation of Cyprus (DCAC) and neighboring ANSPs. A research motivation for a study was the frequent occurrence of ATC capacity shortages in the Nicosia Flight Information Region (FIR). DCAC represents a State-owned entity, i.e., government department of the Ministry of Transport, Communications and Works. For years DCAC represents spatial outlier from capacitive viewpoint [11] and as such acts as an entry-exit bottleneck of the South-East Axis. In 2018, because of significant capacity-demand imbalance, AUs had faced a significant amount of ENR ATFM delay and additional operational costs in AoR of DCAC. Thereby, during August 2018, DCAC has generated the highest amount of average ENR ATFM delay per flight in that year. Hence, the last 20 days in August 2018 were selected as the reference period to be studied. Measured by Local Indicator of Spatial Autocorrelation (LISA) and Global Indicator of Spatial Autocorrelation (GISA), Figure 5 depicts research findings of the comparative assessment of DCAC and network tendency towards spatial clustering. Figure 6 shows results of evaluation of DCAC's performance level during same period in respect to its business environment - denoted as spatial lag.

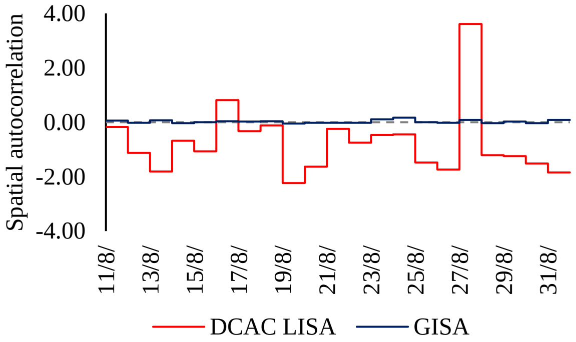


Figure 5: Comparative overview of DCAC and network performance in respect to spatial clustering tendency

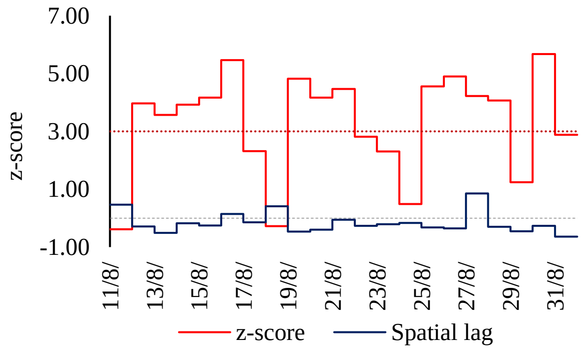


Figure 6: Performance spill-over effect occurrence between DCAC and its first-order neighbors

4.5. CASE STUDY: ATC industrial action

The ATM system in Europe is not prone to ATC industrial actions. Moreover, in 2018 they were the fourth most significant cause of ENR ATFM delay. The overall direct economic effect of the ATC industrial actions in 2018 approximately equals EUR 113,415,300 [12]. The overall economic effect for the same year and cause, including the multiplier effect, equals EUR 482,015,025.

Data review indicates that in 2018, compared to a year prior, ENR ATFM delay generated by the ATC industrial actions had increased by 59.72%, while a comparison with 2011 data indicates a 1154.98% increase. In addition, data breakdown of ENR ATFM delay caused by the ATC industrial actions indicates that three French ATC industrial actions in March, May and December, followed by local actions at Marseille ACC from April to June, were the main drivers of the ENR ATFM delay generation in that year. Accordingly, in 2018 DSNA, a French ANSP had generated 97.57% of the overall additional operational cost to the AUs from the aspect of ENR ATFM delay caused by the ATC industrial actions.

The second case study has evaluated performance spill-over effect between DSNA and neighboring ANSPs. A research motivation behind the second case study was to study the impact of the ATC industrial action taken by DSNA on 22 May 2018. For the purpose of comparative assessment, it had been studied period ten days prior and after a studied event occurred. Figure 7 shows results of a comparative assessment of DSNA respect to network tendency toward spatial clustering. Figure 8 depicts the scale and period of occurrence of the performance spill-over effect between DSNA and its business environment.

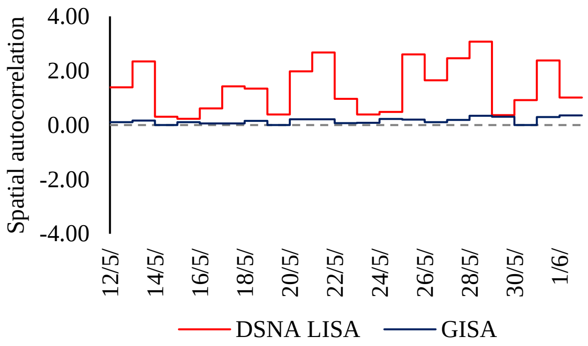


Figure 7: Comparative overview of DSNA and network performance in respect to spatial clustering tendency

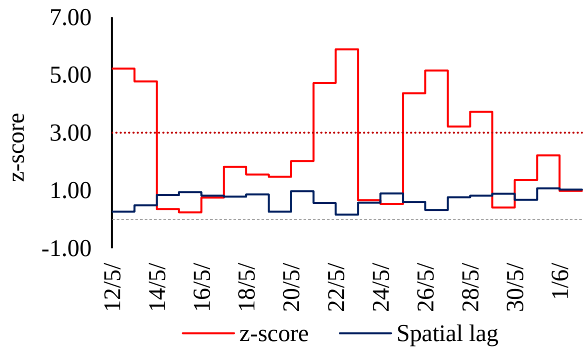


Figure 8: Performance spill-over effect occurrence between DSNA and its first-order neighbors

4.6. CASE STUDY: ATC equipment failure

Within the ATM system, the ATC equipment is used to facilitate safe navigation and flight operations. Thus, in order to fulfil their purpose, ANSPs must invest in various technical and technological solutions enabling ANS provision. However, such solutions come at certain cost. Amid the COVID-19 pandemic, the global market for ATC equipment, estimated at USD 5 billion in the year 2020, is projected to reach a size of USD 6.7 billion by 2026 [13]. In Europe, ANSPs cover investments into ATC equipment by charging ANS provision to AUs.

ATC equipment failure represents a reduction of expected or declared capacity due to the unavailability or degradation of equipment used to provide an ATC service [14]. Such failure can lead to an airport disruption on ENR disruption. From a capacitive viewpoint, the third case study deals with the study of the occurrence of performance spill-over effect between Croatia Control Ltd. (CCL) and its neighboring ANSPs. It had been studied the effects of sudden cessation of ANS provision in Zagreb FIR. On 30 July 2014, a large storm reigned in the wider area of Zagreb, during which heavy rain fell. Flooding of the premises in the CCL's headquarter represents the main cause of power outage - triggering ATC equipment failure. The immediate cause was the panic and inadequate manipulation of the Uninterruptible Power Supply system. At that time, there were 49 aircraft in CCL' AoR. Figures 9 and 10 show an overview of obtained research findings. Figure 11 shows a spatial overview of, at that time, CCL' and neighboring ANSPs' AoRs. Also, for the purpose of comparative assessment, analysis has included a study of performance spill-over effect ten days prior to and after a studied event occurred.

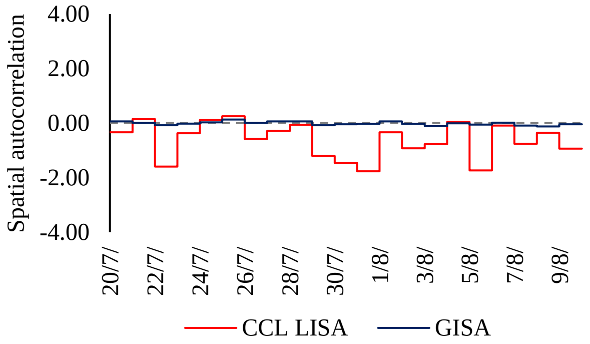


Figure 9: Comparative overview of CCL and network performance in respect to spatial clustering tendency

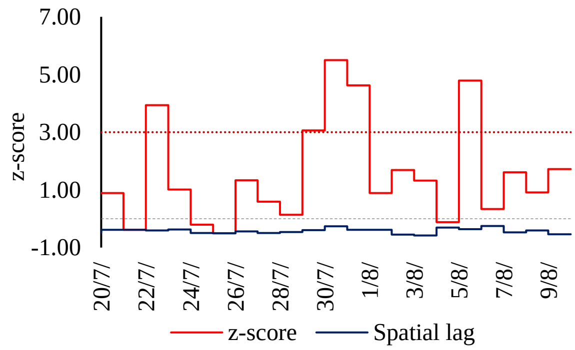


Figure 10: Performance spill-over effect occurrence between CCL and its first-order neighbors

5. DISCUSSION

The main research findings confirm that studied events were triggered by ANSPs' endogenous factors, while their occurrence had manifested as exogenous factor in their business environment. However, obtained research findings also imply that the performance spill-over effect continuously occurs within the ATM system in Europe, whereas no triggers are actually required to initiate its occurrence. Findings also point out first-order neighbors' resilience to studied effect – to a major or minor extent. Figure 12 and Table 1 show effects absorbed by ANSPs' business environments as a result of their resilience.

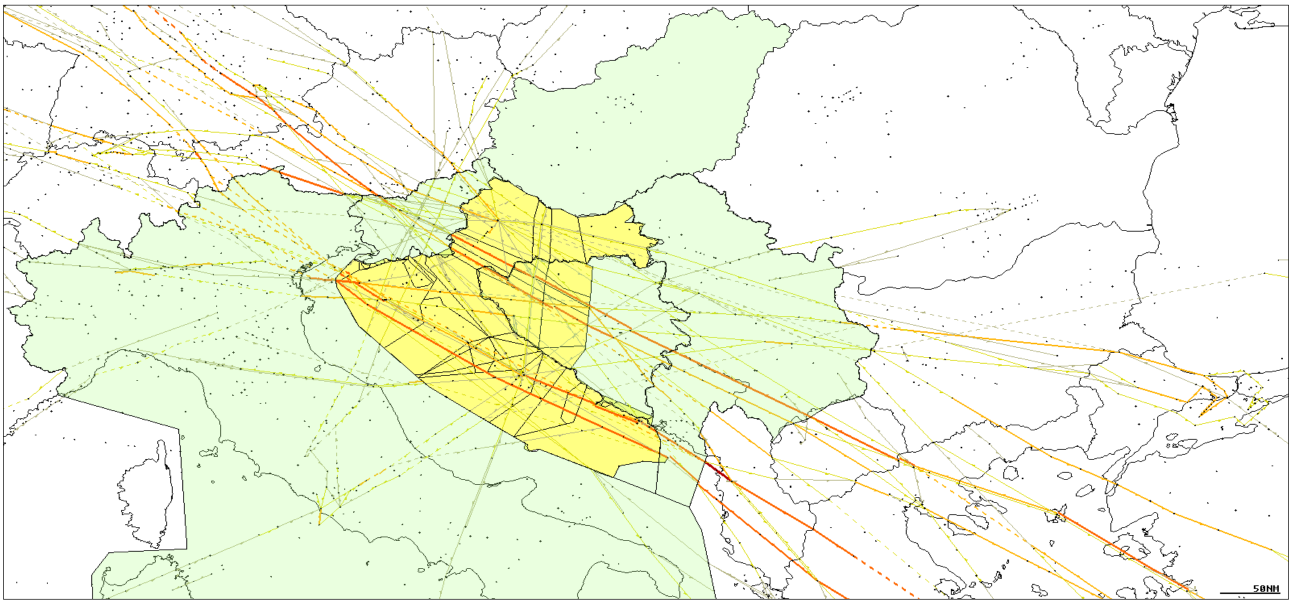


Figure 11: 2018 overview of CCL' AoR in respect to its first-order neighbors, main air traffic flows and their segment loads

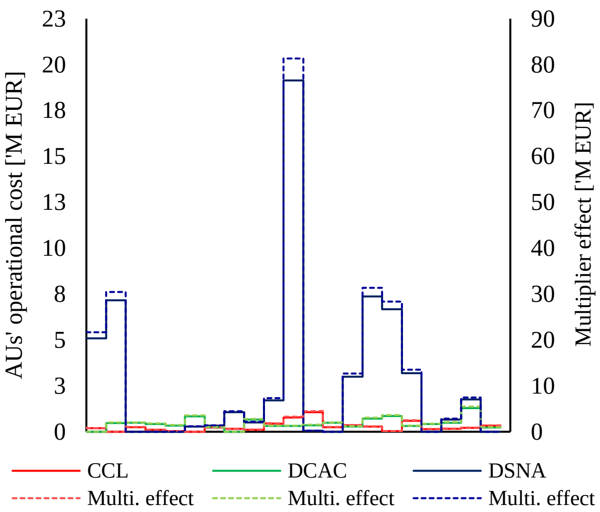


Figure 12: Additional operational cost absorbed

Table 1: Environmental repercussions absorbed

	Carbon dioxide [kg]	Water vapor [kg]	Sulfur dioxide [kg]
CCL	368,370.57	144,658.54	98.23
DCAC	599,848.80	235,559.67	159.96
DSNA	3,814,101.21	1,497,791.49	1,017.09

In principle, every time some organization undertakes a business activity or decision, its business environment changes and it begins a cycle of adaptation (learning), information gathering, interpretation and re-learning [15]. The ATM system is no exception in that respect. Spatio-temporal review of performance spill-over effect' significance outlines its variability over studied period. In addition, research findings also outline the different tendencies in spatial clustering of neighboring areas. As such, while over the studied period DSNA had tended to cluster with neighbors with higher values of ENR ATFM delay, DCAC and CCL had deviated from their neighbors and contributed to local instability in spatial associations.

6. CONCLUSION

As the risk existence can compromise the realization of the strategic goals, it is of utmost importance to mitigate identified business risks. In that respect, it can be outlined that strategic planning and development of the ATM system at a national level have two core tasks. The first one is to identify business threats coming from the ANSP's business environment. The second one is to allocate intellectual capital with the goal to turn identified business threats into business opportunities. Monitoring of performance spill-over effect between ANSP and its neighbors leads to a better understanding of its business environment - which consequently reduces the uncertainty of the business environment and leads to the reduction of the business risks.

Those involved in strategic planning and development of the ATM system in Europe need to be adequately informed, familiar with and understand how does the ATM system performs at a national, local and regional level. Accordingly, for them, it is of high importance and significance to systematically and continuously monitor changes occurring at a regional and local level as they also reflect on the strategic programs and plans of the national ATM system' development - and vice versa.

This research has included monitoring of performance spill-over effect between neighboring ANSPs from the capacitive viewpoint. The main research findings of three case studies indicate that the performance spill-over effect occurs almost continuously within the ATM system in Europe - with a major or minor significance. Accordingly, no triggers are required to initiate their occurrence. As such, obtained findings of monitoring performance spill-over effect point out its occurrence in days prior and after studied triggers took place.

The research confirms that the performance spill-over effect between neighboring ANSPs occurs at both, AoRs with a tendency towards spatial clustering as well as at AoRs representing spatial outliers.

Obtained findings also outline that ENR ATFM delay propagates differently between neighboring ANSPs. Consequently, its propagation can have a minor impact on one, but a major impact on other neighboring ANSP. As a result, the repercussions on the second-order neighbors also manifest differently. In that respect, over the studied period, it had been captured relatively high resilience of first-order neighbors to detrimental effects that occur as a result of performance spill-over effect.

Last but not least, it can be defined that data and information of appropriate quality are required to ensure safe, efficient and competent future development of the ATM system in Europe. Therefore, considering the aforementioned, data and information obtained by monitoring the occurrence and significance of the performance spill-over effect between neighboring ANSPs from a capacitive viewpoint can be outlined as highly relevant within the domain of the strategic planning and development of the national, local and regional ATM system in Europe.

REFERENCES

[1] International Civil Aviation Organization (1944). Convention on International Civil Aviation. Chicago, United States of America

[2] Rezo, Z., & Steiner, S. (2019). European airspace complexity and fragmentation correlation research. Fragmentation in Air Traffic and its Impact on ATM Performance(pp.31-38).Budapest,Hungary: FABEC

[3] EUROCONTROL (2020). Standard Inputs for Economic Analyses. Brussels, Belgium

[4] Standfuß, T., Deltuvaite, V., Whittome, M., & Fichert, F. (2020). Performance Target Setting for Air Traffic Management - Opportunities and Limitations of an Academic Assessment in a Complex Industry. Interdependencies within ATM Performance in the context of a dynamic environment (pp. 58-70). Rome, Italy: FABEC et al.

[5] Performance Review Unit & ACE Working Group (2009). ATM Cost-Effectiveness (ACE) 2007 Benchmarking Report. Brussels, Belgium

[6] Rezo, Z., Steiner, S. & Piccioni, C. (2020). Potential of Geospatial Business Intelligence Solutions for Air Traffic Management. Maritime, Transport and Logistics Science (pp. 276-281). Portorož, Slovenia: Slovene Association of Transport Sciences et al.

[7] Rezo, Z., Tikvica, A., Steiner, S. & Mihetec, T. (2021). Quantification of Spatial Relations in Air Traffic Management: From Theory to Applicative Solution.The Science and Development of Transport (pp.135-143). Šibenik, Croatia: Faculty of Transport and Traffic Sciences of University of Zagreb et al.

[8] Rezo, Z., Steiner, S. & Mihetec, T. (2021). European Airspace (De)Fragmentation Assessment Model. Promet - Traffic&Transportation, 33(2), 309-318.

[9] Rezo, Z., Steiner, S. & Piccioni, C. (2020). Application of Conventional Method in Dynamic Business Environment: Example from Air Traffic Management Domain. The Science and Development of Transport (pp. 167-177). Online event: Faculty of Transport and Traffic Sciences of University of Zagreb et al.

[10] Rezo, Z., Steiner, S. & Tikvica, A. (2020). Automated Aeronautical Data Processing: Recommendations Review and Lessons Learned. The Science and Development of Transport (pp. 179-189). Online event: Faculty of Transport and Traffic Sciences of University of Zagreb et al.

[11] Rezo Z. (2022). European Airspace Fragmentation Assessment Model. PhD thesis: Faculty of Transport and Traffic Sciences of University of Zagreb

[12] Rezo, Z., Steiner, S. & Brnjac, N. (2019). Cost Analysis of Air Traffic Flow Disruptions in Europe. Aviation Management and Economics Conference (pp. 1-10). Vienna, Austria: German Aviation Research Society (GARS) et al.

[13] Research and Markets (2021). Air Traffic Control (ATC) Equipment - Global Market Trajectory & Analytics. Global Industry Analysts, Inc.

[14] EUROCONTROL (2021). ATFCM USERS MANUAL, Edition: 25.0. Brussels, Belgium

[15] Hough, R. & White, A. (2004). Scanning actions and environmental dynamism: Gathering information for strategic decision making. Management Decision, 42(6), 781-793.

INSTRUMENTED TEST RIG: ANALYSIS OF THE PROCEDURE TO TEST RADIAL BEARINGS AND RELATED COMPONENTS

Liane Roldo, D.Sc.
Nenad Vulić, D.Sc.
Ivan Komar, D.Sc.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
lroldo@pfst.hr, nenad.vulic@pfst.hr, ivan.komar@pfst.hr

ABSTRACT

The so-called TEMPO Lab - Testing of Engineering Materials and Products Lab of the Faculty of Maritime Studies, University of Split, Croatia for a few years has been involved in the design, installation and testing of bearings and related components of an instrumented test rig worth over EUR 800 000.00. The next step after all of the test rig components have been manufactured and delivered is the commissioning of the instrumented rig, meaning its testing in accordance with the predefined procedure. In order to define the rig acceptance criteria, it is essential to analyse and eventually amend the procedure of testing the test rig itself. The aim of the paper is to present the analysis of the general procedure to identify possible failures, test steps that are not detailed or that can be optimized. This analysis focusses on different types of radial bearing materials (Babbitt metal or polyether PU), as well as different types of lubricants, that may be implemented in each bearing concept, taking also into account the various shaft diameters. The related rig components incorporated in these tests are pressure and temperature sensors, force probes, flow meters, filters, load actuators, etc. The paper critically reviews the procedure proposed by the designer of the rig, by looking into its details, in order to find out if there exist eventual drawbacks and problems that can be anticipated and solved in advance. The experience gained during the testing of the test rig within the scope of these acceptance tests will certainly be a solid base to perform actual tests later on in practice.

Keywords: Instrumented test rig, radial bearings, bearing materials, test procedure, shafting systems

1. INTRODUCTION

Design of modern marine engineering components relies on extensive software packages, enabling their static three-dimensional (3D) and/or dynamic numeric simulations (4D) to the extent where it is often difficult to distinguish between the photos of simulated components and actually produced ones. As is well known, bearings are parts that, when properly assembled and operating in proper conditions, can function for a long period of time. However, low shaft rotation speed can result in severe wear and early failure [1]. Therefore, regardless of how complex and extensive numerical simulations might be, validation of engineering components is the essential step in the last phase of their design, reliability and safety. Simply, validation is to confirm whether design is correct or not. Validation is always performed on the finished component, once after the component design has been reviewed and verified.

The instrumented sliding bearing testing device (test rig) is the central component in the Laboratory for the testing of engineering materials and products (TEMPO Lab) at the Faculty of Maritime Studies in Split. The test rig is capable of experimental validation of sliding bearings (also called plain bearings or sleeve bearings) of radial and axial type. Radial sliding bearings are commonly used in ships for intermediate shafts and propeller shafts, to enable their rotation, whereas axial sliding bearings are used for thrust shafts, to transmit thrust force to the ship structure itself.

The primary task of the test rig is to validate the data obtained in theoretical simulations. They are relevant to determine the behaviour of marine shaft bearings and to prove the veracity of either analytical or numerical models. Also, the bearings test rig shall enable the user to produce charts that can be compared with the ones obtained in a different way. In the experience of Li et al. [2], once the test rig is installed, it is necessary to align the test rig itself, apply certain loads and observe its fluctuation.

Understanding the test rig as the complex engineering component, the same approach with respect to validation of its design also applies to the rig itself. This means that the test rig design has also to be reviewed, verified and validated in order to produce reliable results in its later implementation and operation. The aim of this validation is to prove and confirm that the test rig will produce reliable results, during further tests of sliding bearings. It is essential to select proper parameters of sliding bearings subject to testing, within this process of test rig validation. Bearing parameters are as follows:

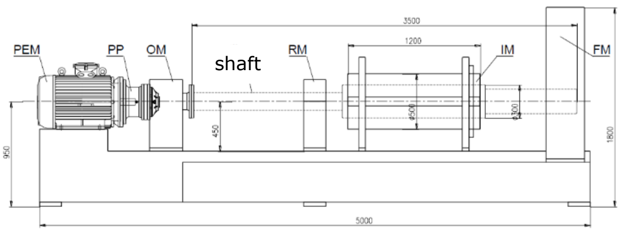
- Operating range in terms of shafting revolution speed (rpm).

- Relative position of the bearing axis with respect to the shaft journal axis (parallel or misaligned).
- Distribution of the hydrodynamic pressure within the lubricant layer for each position of the journal.
- Temperature of the bearing and lubricant.
- Lubricant flow.
- Forces and torques.

The test rig has been designed as the prototype. Its design office did not start the design of the rig by modifying an existing proven solution, but from their own concept. Validation of engineering prototypes shall always be performed in accordance with the proper and reliable testing procedure, prepared and developed in advance. Therefore, the aim of the paper is to present and review the general procedure for testing of the instrumented test rig, developed as the prototype and installed at the Faculty of Maritime Studies, University of Split, Croatia, in the scope of validation of its design.

2. REQUIREMENTS FOR THE RIG TESTING PROCEDURE

The test rig is a complex piece of equipment and also a prototype, as previously mentioned, composed of several modules: stern tube, radial and axial housing - Figure 1. There is a general procedure with several checkout items together with the necessary adaptations for each set up of the equipment layout.



PEM: drive module, PP: transmission module, OM: gearbox module, RM: radial module, IM: test module, FM: load module.

Source [3]: Technical specification for sliding bearing testing device.

Figure 1: Concept of the test rig

An important note is that safety protocols must be established and any problems related to safety must be resolved before any testing.

2.1. Standard requirements

The actual procedure, proposed by the test rig design office (Croatian company in charge of the rig design and assembly), takes into account the requirements specified in the international standard ISO 6281 for testing of plain bearings under conditions of hydrodynamic and mixed lubrication in test rig [4]. Among other values, related to bearing material properties and behaviour (running-in ability, wear resistance, resistance to adhesion, foreign particles absorption, resistance to journal scoring and abrasion, compressive strength, resistance to erosion, etc.) which have to be tested separately without the test rig in question, the standard ISO 6281 proposes the following properties to be tested in the test rig [4]:

- Static load carrying capacity;
- Dynamic load carrying capacity (fatigue strength);
- Friction characteristics;
- Lubricant flow rate characteristics; and
- Temperature increase characteristics.

These properties primarily depend upon the fluid dynamics variables of the tested bearings and also upon [4]:

- Fluid viscosity (primarily as the function of temperature);
- Energy dissipation in the lubricant film (heating and heat dissipation); and
- Elastic and thermal deformation of the bearing and journal, and hence change of lubricant film thickness.

2.2. General testing procedure

The criteria to be used in order to formulate the general testing procedure for validation of test rig itself strongly depend upon the above stated quantities and variables. However, the test rig is the mechanical device (machine) that shall operate safely and reliably during its entire operating life in laboratory, so the type testing criteria for general machinery components also apply here. Summarizing all of this, therefore, the steps and phases to be used in order to formulate the general rig test procedure are:

1. Verification whether the technical documentation exist for all the test rig stand-alone parts, components and subassemblies.
2. Supervising tests performed at manufacturers' premises (visual inspection, dimensional checks and pressure tests) or review of the reports that confirm that these tests have actually been performed with positive outcome.
3. Verification of the certificates provided with the ready-made components (such as test probes, pressure, temperature and displacement sensors, etc.), to check out their characteristics.
4. Verifying available parts and components by their identification and quantity, once they have been delivered to the laboratory.
5. Review and supervision of the components assembling into subassemblies and modules on the test rig stand.
6. Supervision of the alignment of the assembled modules of the test rig.
7. Safety tests, prior to the initial starting of test rig run, in order to keep the personnel, laboratory environment safe and secure.
8. Testing of the laboratory piping systems: cooling, lubricating and hydraulic systems.
9. Selecting and setting up of the module's layout for the test rig (intermediate shaft radial

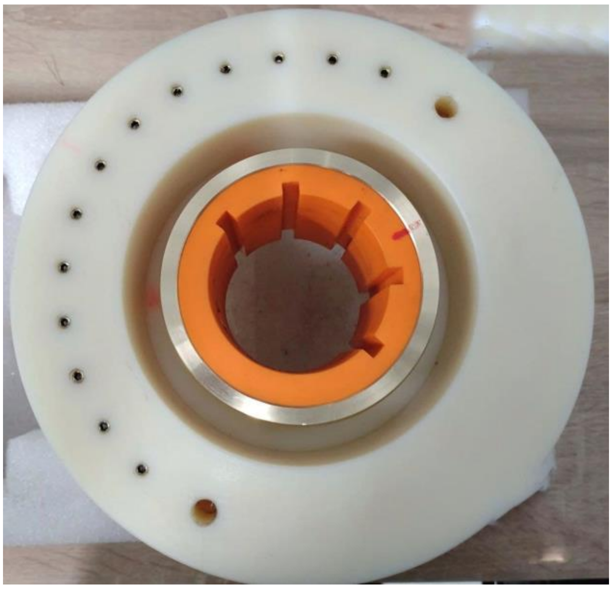
bearings, stern tube radial bearings or axial bearings), bearing diameter (between 60 and 300 mm), ratio of length per diameter, bearing material and lubricant type for each of the following cases:

a. Functional tests of unloaded test bearing (i.e., not exposed to external loading) in their operation.
b. Functional tests of loaded test bearings with their axis parallel to the shaft journals in their operation.
c. Functional tests of loaded test bearings with their axis misaligned to the shaft journals in their operation.
d. Disassembling of the test modules, taking out of the test bearings and their visual and dimensional review.
e. Preparation of the test report covering these prototype tests of the test rig.

3. PROPOSED RIG TESTING PROCEDURE

The testing procedure has been proposed by the instrumented test rig designer. It will satisfy type testing requirements with no doubt, as described in classification rules (see e.g., [5]), if the test rig is considered as a part of ship machinery. This is important to point out, because the bearings that are planned to be tested in the test rig need the properly conducted tests as essential components of the ship propulsion system.

The bearing material might be metal (tin, aluminium or copper alloys) as well as polymer and composite based bearings such as polyether PU or carbon reinforced composite [6][7]. The bearing diameters are between 60 and 300 mm, so these are the limit values for the shaft journal diameters as stated hereafter. Figure 2 shows a PU polyether bearing installed in the 60 mm housing.



Source: photo taken by L. Roldo.

Figure 2: PU polyether bearing (orange colour) mounted in the bearing housing (steel and polyamide – nylon 6).

In general, the proposed procedure has been composed of the following steps:

- Testing of hydraulic power units intended for load module cylinders and servo cylinders.
- Testing of hydraulic power units intended for hydrostatic pump(s).
- Testing of the test rig driving module (unloaded).
- Tests for the load modules arranged as intermediate shaft bearings (between supports of simple supported beam) for the two limit values of shaft diameters, different bearing materials and lubricant.
- Tests of the load modules arranged as stern tube bearings (simple supported beam overhang) for the two limit values of shaft diameters, different bearing materials and lubricant.
- Tests of the dynamic loading modules.

The tests, with few exceptions related to the journal bearing material and dimensions, have been proposed as basically the same or based upon a very similar approach.

Each of the steps begins with the request for recording of the ambient and outer temperature. The next item is always to check the existence of the proper documentation (hydraulic schematics, electrical schematics and instruction manuals) as well as of adequate spare parts. After that, the proposed procedure always requires to verify whether the test rig component in testing complies that particular technical documentation.

The most important details are the tests of the load modules for the limit sizes of bearings and shaft journals, different layouts, bearing materials and lubricants, so they may be briefly presented as follows:

1. According to the technical documentation, install the module with spindle, in place of the drive with the reduction gearbox.

2. After mounting, manually check the easy mobility of the shaft inside the module.

3. Fill the module with the lubricant (water or oil) and leave for 30 minutes without switching on the shaft drive. The purpose is the final check for leaks from the test module.

4. Switch on the shaft drive and gradually increase the rotational speed to the levels of one third, two thirds and 100% of the maximal rotational speed (e.g., for the stern tube bearing layout: 100 rpm, 200 rpm and 300 rpm) with the aim to cover the entire shaft rpm range. Monitor lubricant fluid flow and circulation.

5. To measure vibrations at fore end, in the middle and at aft end of the workbench for

each rotational speed and to compare them with the measured vibrations without the load modules (to be carried out by means of Hofmann-Machine Control MC 1100 equipment).

6. Test the 25 kN tensile/compression load cell.
7. Test the 100 kN tensile/compression load cell.
8. Install the preselected and previously tested load cell with the hydraulic cylinder in the support of the actual (intermediate shaft or stern tube bearings) module for further testing.
9. After 10 minutes of no-load operation (required for the running conditions to stabilize), by means of the servo valve, gradually increase the force on the hydraulic cylinder to load the test module to preselected values as parts of maximal load (e.g. 5, 10, 30 50, 70 and 100 kN in case of stern tube bearing layout). Simultaneously measure vibrations at fore end, middle and aft end of the workbench using the Hofmann-Machine Control MC 1100 for each set force. A Wilcoxon general purpose accelerometer can also be used to measure the vibrations at the test rig [8]. Monitor the lubricant fluid circulation and flow. Perform tactile checks out of heating for load module and the bearings, to prevent any adverse conditions that may suddenly arise. According to Litwin & Dymarski 0, to avoid overheating of the polymer bearing, the installation of flow sensors is advised. Various unexpected situations such as excessive friction or malfunction of the cooling system can cause overheating.
10. Perform temperature measurements of lubricant layer in the test bearing.
11. Perform pressure measurements of lubricant layer in the test bearing.
12. Perform oil layer thickness measurements of lubricant layer in the test bearing on the basis of the position of relative position of the test bearing and the shaft journal.
13. Perform measurement of oil/water viscosity at the inlet to the module.
14. Perform measurement of oil/water viscosity at the outlet of the module.
15. Perform particle number measurements.
16. Emergency stop system shutdown.
17. Emergency stop order record.

4. ANALYSIS AND DISCUSSION

The first and the most important remark to the proposed procedure is that the safety related tests (emergency stop, as proposed and specified in items 16 and 17 above) shall be moved forward after one of the previous steps (e. g. step 3) in the proposed procedure for the testing of the instrumented test rig (Figure 3). This has to be done to meet the basic principle that the safety related tests shall be done before the functional tests in order to keep personal, environment and the test rig itself and its equipment safe.

Source: photo taken by L. Roldo.

Figure 3: Layout of instrumented test rig prior to the installation of the shaft, test bearing and load module.

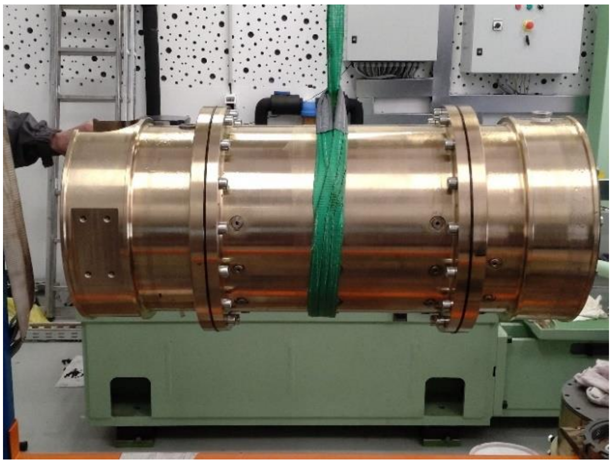
Other outcomes following hereafter have been noticed and notified during supervision of assembling of the test rig prior to the start of any tests. They certainly have a significant influence to amending the previously described testing procedure as proposed by the designers' office. These situations as observed deserve to be briefly described in order to understand the rationale for amendments in testing steps or even in some of the important design details.

4.1. Manufactured faulty components

Bronze components made of CuAl10Ni5Fe4 - test bearing housings and stern tube (Figure 4) presented leakage. In order to test the rig and its components, a preliminary repair has been done using a commercially available single component impregnation sealant enabling the bearing housings to work under pressure [10].

According to Kim et al. [11], the main component of the sealant is ketone (there are different types of ketones, acetone is the simplest followed by methyl ethyl ketone, and cyclohexanone).

After application of the sealant on the bearing housings, tests were carried out at 1.2 bar which, after careful monitoring, were approved. However, an extension of the warranty to 5 years was agreed with the device supplier for the replacement of components, as well as a warranty of one year from the day of handover for the entire test plant.



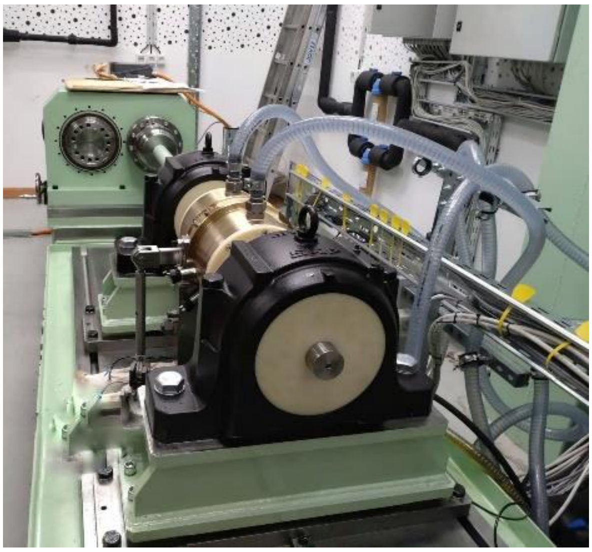
Source: photo taken by L. Roldo.

Figure 4: Stern tube after sealant application and ready to be installed on the test rig.

Proper preventive action would have been and, actually, should have been inspection, and pressure tests of these components at the manufacturers' premises.

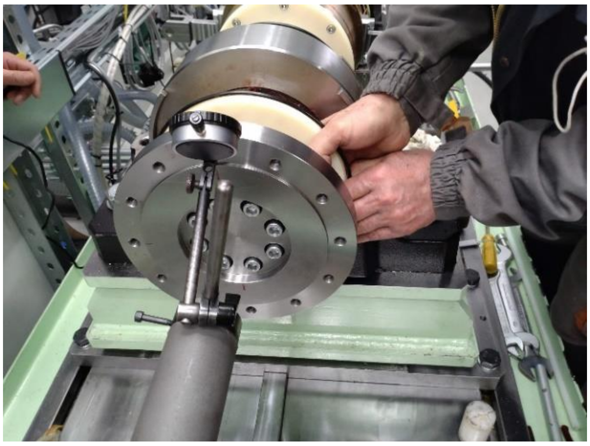
4.2. General alignment and vibrational issues

Excessive vibrations of transmission shaft have been observed and partially solved by proper alignment of the test rig shafts (Figure 5). According to Hassin et al. [12], it is understood that sources of vibrations are primarily due to nonlinear effects, such as roughness and abrasiveness of the surface and hydrodynamic interactions. These excitations, along with complicated vibration paths, are difficult to linearly characterize, but in the presented case keeping within the shaft alignment criteria of 0.05 mm was enough to practically solve vibrational problems (Figure 6).



Source: photo taken and modified by L. Roldo.

Figure 5: Assembly of the rig to verify vibrations.



Source: photo taken by L. Roldo.

Figure 6: Shaft and journal bearing housing alignment procedure.

According to the present experience the problems with transmission shaft vibrations may be reduced by strengthening of alignment tolerances, but it is essential to preserve the test rig components in their attained aligned position after their complete assembly. Because of the sensitivity of the entire alignment process, e. g. tightening of the bearing housing foundation bolts is not enough to keep the bearing assembly in the proper aligned position.

5. CONCLUSIONS

It is safe to say that, in order to compare the accuracy of the numerical models, a completely functional and well calibrated test rig is necessary as well as experimentally compare the behaviour of Babbitt, polymer and composite bearings.

Pressure is understood to be a cause for concern, as is the long-term usability of the rig and the safety of laboratory staff (including employee and non-employee personnel who perform research activities).

For a prototype it is impossible to design or define a procedure in advance and not to expect changes, i.e., there will certainly be adjustments to be made as a result of the learning process resulting from mistakes and successes throughout the execution of the initial steps of the procedure to make the instrumented test rig functional and safe. E. g. to preserve the obtained alignment it may happen that introduction of certain elements based upon form connection, such as pins, rather than friction only connections shall be used.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Litwin, W. (2019). Marine Propeller Shaft Bearings under Low-Speed Conditions: Water vs. Oil Lubrication, Tribol. Trans., 62(5), 839-849.

[2] Li, J., Xue, J., Han, K., Wang, Q., & Chen, W. (2020). Experimental Analysis on Skid Damage of Roller Bearing with the Time-Varying Slip and Temperature Distribution. Appl. Sci., 10:1(9), doi:10.3390/app10010009.

[3] Technical specification for the device for testing of radial journal bearings, ver. 001a (in Croatian) (2018). Split: Faculty of Maritime Studies.

[4] ISO 6281 (2020). Plain bearings - Testing under conditions of hydrodynamic and mixed lubrication in test rigs. Geneva: International Organization for Standardization.

[5] Rules for the classification of ships, Part 1 - General requirements (2021). Split: Croatian Register of Shipping.

[6] Roldo, L., Komar, I. & Vulić, N. (2013). Design and materials selection for environmentally friendly ship propulsion system. Stroj Vestn-J Mech Eng., 59(1), 25-31.

[7] Ginzburg, B. M., Tochil'ikov, G. D. Bakhareva, V.E., Anisimov, A.V., & Kireenko, O.F. (2006). Polymeric Materials for Water-Lubricated Plain Bearings. Russ. J. Appl. Chem., 79(5), 695- 706.

[8] Van Hooreweder, B., Moens, D., Boonen, R., & Sas, P. (2010). On the development of three instructive test rigs for efficiency determination of gear boxes and fault diagnosis of joints, roller bearings and gears. 7th International Conference on Condition Monitoring and Machinery Failure Prevention (247) Stratford-upon-Avon, UK: British Institute of Non-Destructive Testing.

[9] Litwin, W., & Dymarski, C. (2016). Experimental research on water-lubricated marine stern tube bearings in conditions of improper lubrication and cooling causing rapid bush wear. Tribol. Int., 95, 449–455.

[10] Dichtol WFT. Data sheet. (2015). Diamant the Metal Plastic Company. https://diamant-polymer.de/wp-content/uploads/2016/04/TD-dichtol-WFT-GB.pdf (accessed January 15, 2022).

[11] Kim, H-J., Lee, C-H, & Kweon, Y-G. (2001). The effects of sealing on the mechanical properties of the plasma-sprayed alumina-titania coating. Surf Coat Tech, 139 (1), 75-80.

[12] Hassin, O. A., Wei, N., Towsyfyan, H., Gu, F., & D. Ball, A. (2015). Journal bearing lubrication monitoring based on spectrum cluster analysis of vibration signals. 28th International Congress of Condition Monitoring and Diagnostic Engineering and 10th Regional Congress on Non Destructive and Structural Testing. Buenos Aires, Argentina: COMADEM International.

CAUSALITY ANALYSIS IN DYNAMIC POSITIONING INCIDENTS ACCORDING TO THE NATURE OF THE OPERATIONS IN PROGRESS

Zaloa Sanchez-Varela, Ph.D.
Zlatko Boko, M.Eng..
Ivica Skoko, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
zsanchezv@pfst.hr; zboko@pfst.hr; iskoko@pfst.hr

David Boullosa-Falces, Ph.D.
University of the Basque Country UPV/EHU, Faculty of Engineering in Bilbao
María Díaz de Haro 68, Portugalete, Spain
david.boullosa@ehu.eus

ABSTRACT

Previous research has established that loss of position when using dynamic positioning systems occurs more often when the weather conditions worsen while drilling operations are in progress. This research investigates which causes are predominant in each different operation carried out using dynamic positioning systems. With a 312 dynamic positioning incidents database, different offshore operations are categorized and cross-tabulated with the main causes described in the incident report. The results and discussion show that environmental causes mainly dominate drilling operations, and no other correlation was noted with the presented data.

Keywords: dynamic positioning; offshore; meteorology; drilling

1. INTRODUCTION

A dynamic positioning (DP) system is a piece of automation that helps the vessel to maintain her position by analyzing data received from wind, current and motion sensors and then sending a signal to thrusters and rudders. DP is also used for moving a vessel along a pre-set track [1].

It started to be used during the 1960s, and it is mainly applied in the offshore industry. The complexity and high accuracy requested for the different offshore operations make the dynamic positioning system a great asset for this sector. Not only the drilling platforms but also the vessels that handle the anchors and other vessels supplying different services to these offshore platforms and cable layers all have in common the accuracy of their positions using DP systems.

However, DP systems do not always perform smoothly. The study of the incidents reported by vessels is essential to discover any failures that could be corrected and improve DP operations' safety. Different institutions currently deal with these incidents and have contributed to the safety improvement of DP operations by publishing guidelines and circulars.

Among the organizations that have more actively provided feedback information to the industry regarding safety in DP operations, two professional groups should be highlighted: the International Marine Contractors Association (IMCA) and the Marine Technology Society (MTS). Other institutions, such as the International Maritime Organisation (IMO), classification societies, or flag states, base their guidelines on the documents provided by IMCA or MTS.

The IMCA is, without any doubt, one of the most prolific authors to the cause of safety in DP operations. They have published all kinds of different recommendations to the industry, along with guidelines for operations, sensors, personnel, and many more, which they have published [2].

It is also important to outstand the collection of DP incidents that IMCA has published since 1994 [3]. The high volume of DP incidents reported anonymously, and carefully published by IMCA, have been the base of this research. Different authors based their academic work on these databases; for example, Chen et al. [4] introduced the safety of DP operations through a model based on barriers. Previously, the same research team had already approached the research topic in an article about the safety of such units [5]. Chae investigated the human error in DP incidents [6] and applied formal safety assessment [7].

As per previous publications, the main causes of DP incidents are essentially technical in nature [8], although no distinction among the different operations has been made. Sanchez-Varela et al. [9] researched the DP incidents during drilling operations and found the riskiest causes are power-related and environmental.

This paper aims to identify the main causes contributing to the incidents during different DP operations. These conclusions could help to better understand the reasons leading to an incident and improve the prevention of such occurrences.

2. METHODOLOGY

The methodology followed for this research is explained in detail in this section.

The original database consists of 312 cases, and it is obtained by examining the Event trees provided by IMCA for the period 2007-2015. The following variables are categorized in this database: Main Operation and Main Cause.

The variable Main Operation has 19 different categories, as shown in Table 1.

Table 1: Frequency of incidents categorized by main DP operation in progress

Main Operation	Frequency	Percentage
Drilling	81	26.0
Cargo	54	17.3
ROV	54	17.3
Diving	48	15.4
Cable/Pipe lay	29	9.3
Stand-by	10	3.2
Personnel Transfers	7	2.2
Trials	7	2.2
Topside Works	4	1.3
Anchor Handling	3	1.0
Seabed	3	1.0
Approaching	2	0.6
Construction	2	0.6
Shuttle	2	0.6
Trenching	2	0.6
FPSO	1	0.3
Jacking	1	0.3
Rock dumping	1	0.3
Transit	1	0.3
Total	312	100.0

Source: Authors

There are some operations which registered only 1 or 2 cases. Because these data are not very significant for the research proposed, it is decided to eliminate the cases with less than 10 cases. Thus, the DP operations considered are drilling, cargo, remote-operated vehicles, diving, cable/pipe lay and stand-by. The new database comprises 276 incidents.

For this variable, a descriptive statistic is presented.

The variable Main Cause has 9 different categories, and a descriptive statistic is also performed.

According to the presented data, some categories have a significantly low number of cases, being zero in some cases (for example, there are no cases in which the main operation was personnel transfer and the main cause of the incident was due to human error). A correlation table is made with the observed frequencies (o_{ij}) for each operation and cause. Next, a table with the frequency of expected values is created. Each expected value e_{ij} is calculated by multiplying the total observed cases by row (i) and column (j) and dividing by the total number of cases.

The next step would be to calculate the empirical chi-square χ^2 value, obtained by the formula:

Chi-square $\chi 2$ represents the empirical chi-square, obtained by the formula:

$$\chi^2 = \sum_{i,j} \frac{(o_{ij} - e_{ij})^2}{e_{ij}} \tag{1}$$

Furthermore, the contribution (c) of each pair to the chi-square is then calculated as follows:

$$c_{ij} = \frac{r_{ij}}{\chi^2} \tag{2}$$

A bigger value of this contribution indicates a stronger correlation between the pair.

3. RESULTS

3.1. Descriptive Statistics

The database, comprising 276 cases, is categorized by the main DP operation that was in progress when the incident occurred. There are 19 categories in total, as shown in Table 1. The DP operations with a bigger frequency of incidents are Drilling, Cargo and Remote-Operated Vehicle (ROV), representing over 60% of the incidents.

The different main causes for each incident are also catalogued following the proposed categorization by IMCA, which is based on the DP segment in which the failure has taken place. They are represented in Table 2 below.

Table 2: Frequency of incidents categorised by main cause

Main Cause	Frequency	Percentage
Thruster	83	30.1
Power	44	15.9
Computer	40	14.5
Human	38	13.8
References	29	10.5
Environmental	22	8.0
Sensors	10	3.6
Electrical	8	2.9
External	2	0.7
Total	276	100.0

Source: Authors

With the data collected, a correlation table with observed frequencies is created. It is shown in Table 3.

Table 3: Correlation table between main operations and main causes, with observed frequencies

Main Cause	Main Operation: Cable/Pipe Lay	Cargo	Diving	Drilling	ROV	Stand-by	Total
Computer	5	6	9	11	8	1	40
Electrical	0	1	1	3	3	0	8
Environmental	1	2	1	17	1	0	22
External	0	1	0	1	0	0	2
Human	6	5	7	12	7	1	38
Power	4	7	7	18	5	3	44
References	3	11	3	4	7	1	29
Sensors	2	3	3	1	1	0	10
Thruster	8	18	17	14	22	4	83
Total	29	54	48	81	54	10	276

Source: Authors

The empirical chi-square obtained is 58.851, which is bigger than the critical chi-square 55.578 for a p-value of 0.05 and 40 degrees of freedom.

Table 4: Contributions to the experimental Chi-square

Main Cause	Main Operation: Cable/Pipe Lay	Cargo	Diving	Drilling	ROV	Stand-by	Total
Computer	0,15	0,43	0,60	0,05	0,00	0,14	1,37
Electrical	0,84	0,20	0,11	0,18	1,32	0,29	2,94
Environmental	0,74	1,23	2,09	17,22	2,54	0,80	24,62
External	0,21	0,95	0,35	0,29	0,39	0,07	2,26
Human	1,01	0,80	0,02	0,06	0,03	0,10	2,02
Power	0,08	0,30	0,06	2,00	1,51	1,24	5,20
References	0,00	5,00	0,83	2,39	0,31	0,00	8,53
Sensors	0,86	0,56	0,91	1,28	0,47	0,36	4,43
Thruster	0,06	0,19	0,46	4,41	2,04	0,33	7,48
Total	3,96	9,66	5,42	27,88	8,61	3,33	58,85

Source: Authors

The contributions to the chi-square are presented in Table 4. The cause contributing to the chi-square with a bigger value is Environmental, while drilling is the main operation contributing to the chi-square. From these results, it is clear that there is a strong correlation between environmental causes and drilling operations, with a contribution of 17.22, which stands for 29% of the total chi-square.

The main contributor to the chi-square seems to be the drilling operations, as the contribution of 27.88 seems to be bigger than any other cause.

The next step would be to corroborate this correlation by eliminating the drilling operations from the correlation table and studying the rest of the operations. This correlation is shown in Table 5.

Table 5: Contributions to the experimental Chi-square

Main Cause	Main Operation: Cable/Pipe Lay	Cargo	Diving	ROV	Stand-by	Total
Computer	0,11	0,51	0,49	0,00	0,16	1,27
Electrical	0,74	0,11	0,04	1,88	0,26	3,03
Environmental	0,09	0,27	0,04	0,11	0,26	0,77
External	0,15	1,89	0,25	0,28	0,05	2,61
Human	1,18	0,67	0,06	0,01	0,08	1,99
Power	0,00	0,01	0,06	0,67	2,08	2,82
References	0,14	2,40	1,62	0,00	0,06	4,22
Sensors	0,33	0,10	0,28	0,89	0,46	2,06
Thruster	0,50	0,06	0,00	0,44	0,06	1,06
Total	3,24	6,03	2,82	4,28	3,47	19,84

Source: Authors

This time, when eliminating the drilling operations from the correlation table, the experimental chi-square obtains a value of 19.84, which is then compared to the critical chi-square 20.072 (32 degrees of freedom, p-value 0.05). As the experimental value is less than the critical value, the null hypothesis cannot be rejected, and no cause significantly affects a given operation.

Next, the table will be divided into two columns, one representing the drilling operations' frequencies and the other the rest of the operations. Again, the same analysis is carried out, and an experimental chi-square of 39.45 is obtained. Compared to the critical chi-square 2.733 for 8 degrees of freedom and a p-value of 0.05, it can be assumed that the drilling operations are different from the rest and correlate with the main causes.

The following step is creating a correlation table with all the main operations and all the main causes, excluding the environmental ones. The objective is now to determine whether the other causes are correlated to the main operations. In this case, the experimental chi-square obtained is 14.27. Compared to the critical chi-square value of 2,167 for 7 degrees of freedom and a p-value of 0.05, it is much bigger, and points to other correlations between the main operations presented data.

4. DISCUSSION AND CONCLUSIONS

This paper's objective was to find out whether there were causes that were contributing more often in an incident while a particular DP operation was in progress. By eliminating the DP operations with less frequency from the research, the results presented are assumed to have a bigger significance. Assuming those values could have meant obtaining results leading to wrong conclusions.

The expected frequencies obtained from the observed frequencies presented in Table 3 have small values, which could increase the contributions to the chi-square. However, since the categories associated with those values are not showing the main correlations as discussed in the previous section, it is considered not to affect the conclusions presented herein.

The incidents occurring while drilling operations are in progress are clearly not equal for each cause. There is a clear and strong correlation between drilling operations and environmental causes. This result corroborates the conclusions shown by Sanchez-Varela et al. (toms), where the same correlation was obtained when applying a different method.

However, there is not enough evidence to conclude whether there are other causes also correlated to other operations. Further research should be performed in order to find other patterns.

The conclusions of this research could help improve the training of DP operators for these operations by recreating the incidents and discussing the outcome and possible DP protocols to follow under these circumstances.

REFERENCES

[1] Bray, D. (2015). DP Operator's handbook. 2nd Edition. London: The Nautical Institute, 2015. ISBN 9781906915254

[2] IMCA. (2021). Guidelines for the design and operation of dynamically positioned vessels. 5th Revision. London: IMCA.

[3] IMCA. (2012-2017) Station-Keeping Incidents reported for 2007-2015. London: IMCA.

[4] Chen, H.; Moan, T. & Verhoeven, H. (2008). Safety of dynamic positioning operations on mobile offshore drilling units. Reliability Engineering & System Safety, 93(7), 1072-1090. https://doi.org/10.1016/j.ress.2007.04.003

[5] Verhoeven, H., Chen, H., & Moan, T. (2004, September). Safety of dynamic positioning operation on mobile offshore drilling units. In Dynamic positioning conference.

[6] Chae, C. J. (2015). A study on Human Error of DP vessels LOP Incidents. *Journal of the Korean Society of Marine Environment & Safety*, *21*(5), 515-523. https://doi.org/10.7837/kosomes.2015.21.5.515

[7] Chae, C. J. (2017). A study on FSA application for human errors of dynamic positioning vessels incidents. *Journal of Navigation and Port Research*, *41*(5), 259-268. https://doi.org/10.5394/KINPR.2017.41.5.259

[8] Hurlen, L., Skjerve, A. B., & Bye, A. (2019). Sensemaking in high-risk situations. The challenges faced by dynamic positioning operators. In Proceedings of the 29th European Safety and Reliability Conference.

[9] Sanchez-Varela, Z., Boullosa-Falces, D., Larrabe-Barrena, J. L., & Gomez-Solaeche, M. A. (2021). Risk Analysis of DP Incidents During Drilling Operations. Transactions on Maritime Science, 10(01), 84-100. doi: 10.7225/toms.v10.n01.006.

SEDIMENT RESUSPENSION EVALUATION ON TWO MANOEUVRES AND TWO DIFFERENT PILOTS

Jure Srše, M.Sc.
Marko Perkovič, Ph.D.
Aleksander Grm, Ph.D.
Andrej Androjna, Ph.D.
Tanja Brcko Satler, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, 6320 Portorož, Slovenia
jure.srse@fpp.uni-lj.si, marko.perkovic@fpp.uni-lj.si, aleksander.grm@fpp.uni-lj.si, andrej.androjna@fpp.uni-lj.si, tanja.brcko@fpp.uni-lj.si

ABSTRACT

Competition between ports aims to accommodate high capacity ships, resulting in a deeper draught and thus a lower Under Keel Clearance. The rotation of the ship's propeller and rudder propellers, combined with the low under keel clearance, results in sediment being resuspended on the harbour bottom. The consequences are manifested in: Sediment resuspension, negative effects on flora and fauna, erosion on quay walls and piles. It's assumed that the main cause of the extent of sediment resuspension is the personal approach of harbour pilots during approach and departure manoeuvres. However, there are also other factors such as: optimal use of tugs, weather conditions. The first factor can be controlled by the tug's master and efficient communication between him and the pilot. The second factor was assumed to be constant due to weather conditions. In contrast, harbour pilot can prepare a better manoeuvre, divided into three sections: planning the approach and departure, using less propulsive power during the manoeuvre and controlling the vessel's acceleration. Two manoeuvres are performed with two pilots in the same weather conditions, vessel type and berth position. Evaluation of the manoeuvre performance in terms of reduced sediment resuspension will be carried out using the Full Mission Bridge Simulator.

Keywords: Sediment resuspension, ship manoeuvre, pilot performance, Full Mission Bridge Simulator

1. INTRODUCTION

The global trend in the shipping industry is to carry as much cargo as possible in a single unit to generate profits and maintain competition in the shipping industry. This requires the construction of larger ships that can carry larger amounts of cargo, resulting in ships with greater draft.

Ports also face the challenge of accepting larger ships calling at their berths, consequently leading to high competition level between ports to accommodate larger ships. The constraints are primarily: space to maneuver in the harbor, berth length, reach of crane arms, cargo space ashore, land transport connections, and available depth in the harbor. Ports are solving the latest problem with a variety of methods: extending piers into deeper waters, positioning berths away from land with conveyor belt connections, moving ships back from the lift into spoke ports, and dredging operations.

Maritime traffic has the greatest impact on the resuspension of material in the area of waterways and anchorages, as well as in the basins of the Koper Port. (Figure 1). Sediment resuspension (SR) has negative impacts on sea ecosystem, accumulation on resuspendet material and erosion around key pills, weakening berthing structure. Ships propellers with low under keel clearance (UKC) are also responsible for SR.

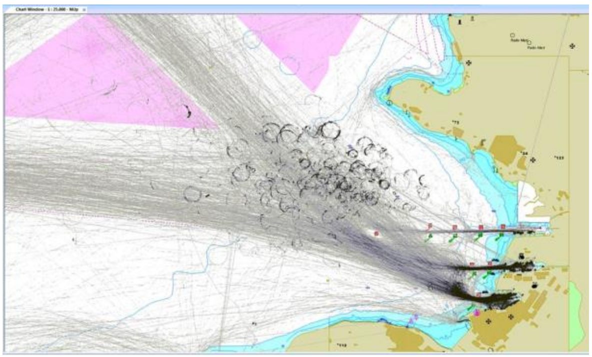


Figure 1: AIS based traffic density and anchorage locations - Koper Bay

The impact of shipping traffic on erosion of bottom sediments in the Gulf of Trieste was first studied by Perkovič et al. (2011), where an approximate amount of transported sediment was estimated for the case of a large intruding ship [1].

This article addresses the question; how SR can be lowered with alternative ship manoeuvres performed by two different pilots on the target ship (the type of ship causing a large amount of SR) using the Full Mission Bridge Simulator (FMBS).

2. TOOLS AND METHODS DETERMINATION FOR SEDIMENT RESUSPENSION

The main tool for determining SR will be FMBS, which will allow selection between different ship types and ports. Two ship manoeuvres will be carried out with two different pilots, the same ship and the same weather conditions. The Full Mission Bridge Simulator (FMBS) is a useful tool to recreate ship manoeuvres and obtain all the desired dynamic parameters for ship motion [2].

The calculations of the resuspended material volume estimation method are based on theoretical equations and on experimental studies with scaled propeller systems in test basins.

2.1. Tools

The main tool for assessing the volume of resuspended harbour bottom material is FMBS. Different types of vessels can be selected. The selected vessel type is a container vessel with the following data:

Table 1: Vessel type Container ship 4 used for simulation

Ship type	Container ship 4 TRANSAS version 2.31.32.0
Displacement	132540 t
LOA	346,98 m
LBP	332 m
Breadth (moulded)	42,8 m
Draft (midship)	14 m
Max engine power	60950 kW
Ship propeller type	FPP (Fixed Pitch Propeller)
Diameter (D_p)	9,5 m
Propeller immersion	9,2 m
Bow thruster capacity	2210 kW
Stern thruster capacity	1800 kW

Source: Authors

This type of vessel is considered to be the most affected in terms of sediment resuspension. During the manoeuvre of the target vessel, FMBS records the desired motion data, which is used to calculate the critical ground speeds:

- Vessel position,
- Course over ground (COG),
- Speed over ground (SOG
- Heading,
- Rudder angle (R_A),
- Rates per minute (RPM),
- Applied power (A_P),
- Depth (D),
- True wind speed and direction
- Relative wind speed and direction
- Sea state
- Used power of bow thruster in transverse direction
- Stern thruster force transverse to the direction of travel

During arrival manoeuver Container ship 4 was in both cases assisted with Tractor tug (Voith Schneider propulsion). Used Tractor tug propulsion forces will be evaluated for both manoeuvers.

Transverse forces form Bow and Stern thruster will be recorded and compared for both manoeuvers.

Two manoeuvers will be performed with the same vessel type, berthing position and weather conditions. Each manoeuvre (arrival) is performed by two pilots with different experience and the same tug operator.

2.2. Method

There are various methods for determining: the jet outflow velocity on the propeller surface, the jet velocity distribution on the x and y axis and the maximum jet velocities on the harbour bottom. An important factor affecting the bottom velocities is also the rudder angle. Some studies have introduced the equation (1) for the outflow velocity, which includes the thrust coefficient (C_T) [3].

$$V_0 = 1.59 n D_p \sqrt{C_T} \tag{1}$$

Sometimes the values for the thrust coefficient (C_T) and the number of revolutions per minute (n) are not available, so equation (2) comes into play.

$$V_0 = C_2 \left(\frac{P_A}{\rho_W D_p^2} \right)^{\frac{1}{3}} \tag{2}$$

The coefficient C_2 has a value of 1.17 for propellers with air ducts and of 1.48 for propellers without air ducts; engine applied power (P_A), density of seawater (ρ_w) and propeller diameter (D_p) [4].

Equation (3) predicts the maximum bottom speed ($V_{b,max=0}$) generated by the propeller jet.

$$V_{b,max=0} = E V_0 \left(\frac{D_p}{h_t} \right)^b \tag{3}$$

Where E = 0.71, b = 1.0 for seagoing ships with rudder; E = 0.42, b = 0.275 for sea-going ships without rudder; E = 0.52, b = 0.275 for sea-going ships with twin propeller and double rudder [4].

Distance between propeller axis and sea bottom is presented by value (h_t) in equation (4).

$$h_t = C + \frac{D_p}{2} \tag{4}$$

The clearance (C) is the distance between the propeller tip and the seabed.

The test container ship type 4 on FMBS has a propeller axis immersion of 9.2 m. The seabed in Luka Koper Bay is assumed to be a flat surface with a constant depth of 15 m. With these two data, the distance between the propeller axis and the seabed (ht) is 5.8 m.

Equation (3) is used when the ship's speed is zero. If the ship already has its speed (inertial motion), equation (5) is used [5].

$$V_{b,max\neq 0} = V_{b,max=0}\left(1 - \frac{v_s}{D_p n}\right) \qquad (5)$$

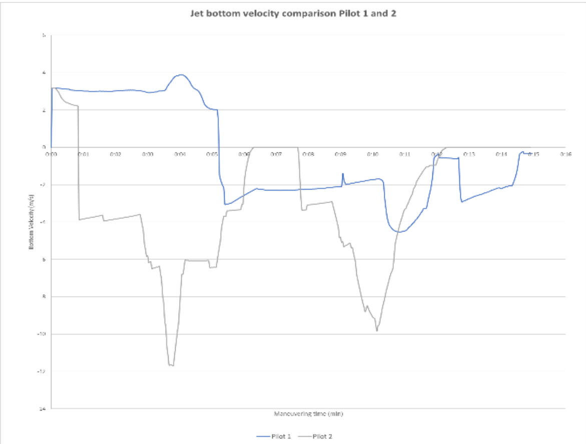
Vessel speed is marked by (v_s).

3. MAXIMAL SEA BOTTOM JET VELOCITY CALCULATION

Using the tools presented in chapter 2.1. and method 2.2.; maximal sea bottom jet velocity is calculated for the main propulsion of the ship. The ship motion data is recorded with a frequency of 0.5 Hz. Both manoeuvres have the same:

- Environmental conditions,
- Starting position and speed of the manoeuvre,
- The duration of the maneuver is 15 minutes.

Jet bottom velocity ($V_{b,max\neq 0}$) (non-zero vessel speed (V_s) in relation to the time interval 15 min; for two arrival manoeuvres are evaluated in Figure 3.



Source: Authors

Figure 2: Jet bottom velocity ($V_{b\ max\neq 0}$) comparison Pilot 1 and 2

Figure 3 shows that Pilot 2 generates higher bottom velocities than Pilot 1. For example; in the fourth minute, Pilot 2 generates a ground speed of almost 12 m/s, which results in a large SR.

According to research, the limit value for the jet bottom velocities is 0.35 m/s. After this limit, the sediment type d_{50}=0.007 mm in Luka Koper starts to resuspend from the seabed [1].

Figure 4 shows the comparison between the two manoeuvres of the tug. Produced ton force of the propulsion system as a function of time.

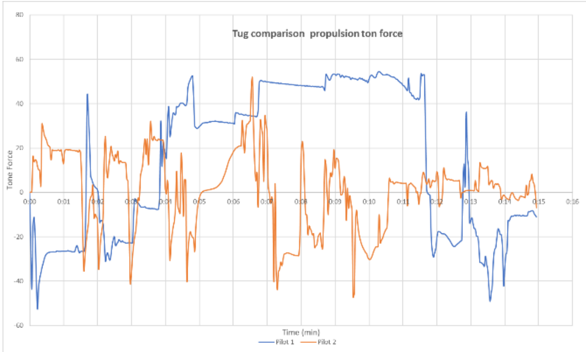


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Figure 3: Tractor Tugs comparison propulsion Ton Force (tF)

It is clear from Figure 4 that Pilot 1 uses far more assistance than Pilot 2 when comparing the results with Figure 3; Pilot 2 compensates for the reduced assistance from the tug by using more thrust from the vessel's main propulsion system.

Figure 5 summarises the thrust from bow and stern thrusters in tone force generated by Pilot 1 and 2 and shows the time ratios.

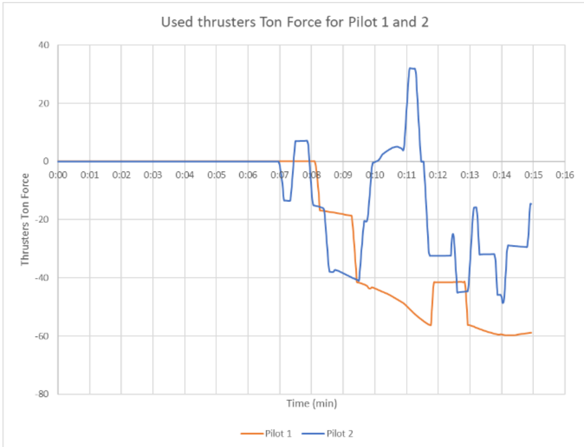

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Figure 4: Bow and stern thruster Ton force (tF) produced from Pilot 1 and 2

The figure shows in which direction and how much power the thrusters are used. Pilot 1 begins to use the thrusters in the eighth minute. The thrusters work in a sideways direction to move the ship to the port side, closer to the pier. Pilot 2 starts using the thrusters in the seventh minute to move the vessel to the port side. In the tenth minute, the thrusters change from the port to the starboard side, resulting in insufficient use of the thrusters. Which pilot uses more Tone Force thrust from the thrusters is difficult to tell from Figure 5. Therefore, in Figure 6 it is much clearer to see which pilot uses the thrusters more and consequently generates more thrust.

Figure 6 shows the combined thrust of the propulsion systems required to perform safe arrival manoeuvres.

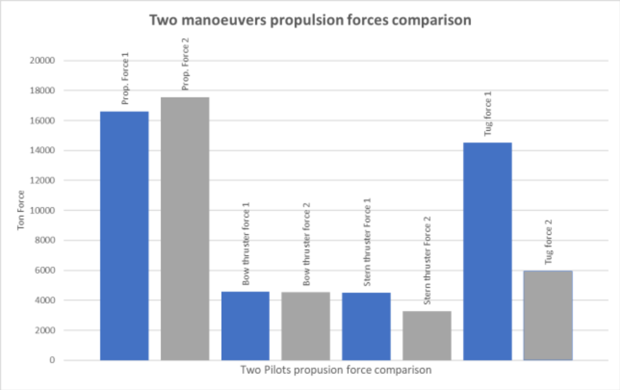

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Figure 5: Two manoeuvers propulsion forces comparison

Bar chart (Figure 6) in presenting summarized Ton Force thrust for next propulsion system for both manoeuvers:

- Main propulsion thrust force,
- Bow thruster thrust force,
- Stern thruster thrust force,
- Tug thrust force.

The first two bars show the comparison of the thrust of the vessel's main propulsion for two manoeuvres. Pilot 1 uses more power to perform the arrival manoeuvre, resulting in more sediment stir-up, which is also shown in Figure 3 (jet bottom velocities).

The next two bars show the thrust of the bow thrusters, which are essentially the same for both manoeuvres. Pilot 2's stern thruster produced more thrust compared to Pilot 1.

The biggest difference in the tonne force was observed in the tug assist. Pilot 1 required significant tug assist to perform a safe arrival manoeuvre compared to Pilot 2. Figure 6 clearly shows that Pilot 2 required less thrust when all propulsion systems involved in the manoeuvre were taken into account.

4. CONCLUSION

Port of Koper is one of many ports trying to except deep draft vessels and remain competitive among Adriatic ports. This leads to challenges that require innovative solutions. The article focuses on one important problem: the low UKC of ships. The volume of vessels is increasing to accommodate larger amounts of cargo, which leads to a deeper draft and also to increased length, width and height. Due to the deeper draft, the ships propulsion systems (main propulsion system, thrusters) are closer to the seabed, resulting in SR. Negative impacts are seen in: flora, fauna, sediment deposits leading to dredging operations. These lead to congestion in the port, additional costs and SR. Ports around the world solve this problem with techniques to protect the harbor bottom from scour. The most common of these is the riprap system.

The article examines the amount of sediment resuspension caused by the vessel's main propulsion system, bow thrusters and tug assistance during two manoeuvres with the same conditions. The only difference between these two manoeuvres is that two different pilots perform the arrival manoeuvre. The desired data is the summed tone force thrust of all propulsion systems involved in each manoeuvre. Analysis of the data obtained from the FMBS for each part of the propulsion system shows which pilot requires less thrust to perform a safe manoeuvre. It is expected that a higher thrust will result in a higher speed of the jet bottom speed, which will result SR. The results showed that Pilot 2 used slightly more thrust from the vessel's main ship propulsion system, while Pilot 1 used the tug's assistance more frequently, resulting in a significant increase in the tug's thrust. The thrust of the bow thrusters was essentially the same in both cases. For pilot 2, the thrust of the stern thruster was higher. The jet bottom speeds for the main propulsion system were calculated.

Further research is needed to determine the jet bottom speeds of the bow thruster and tug assist. In other words, it needs to be found out whether it makes more sense to use the vessel's main propulsion or tug assistance, and what the possible limits are for safe manoeuvring.

Port of Koper has tractor tug types. The Voith Schneider tug propulsion (VSP) exhaust plume study was carried out by Robert Allan Ltd (RAL; 214-014 CFD Analysis of Propeller wash Plume R1.) using computational fluid dynamics (CFD) analyses. These simulations were carried out with a maximum water depth of 18.8 m. Even at these shallower depths, it could be concluded from the CFD simulations that VSP tugs have negligible impact on the bottom [6].

Real recordings during a tug assisted manoeuvre in Luka Koper show that the tugs have a significant impact on the SR. Therefore, the statement from the previous paragraph needs to be further analysed in relation to the jet bottom velocities generated by tugs (Voith Schneider).

This article opens up further research on alternative vessel manoeuvres to reduce sediment resuspension, including the impact of tugs on jet bottom velocities.

REFERENCES

[1] Perkovič, M., Batista, M., Malačič, V., Žagar, D., Jankowski, S., Gucma., L., Gucma, M., Rostopshin, D. (2012). Bottom wash assessment using a full mission ship handling simulator. *V: MARSIM* 2012. Singapore: Singapore Maritime Academy, 2012. 11 str. [COBISS.SI-ID 2384739]

[2] Srše, J., Perkovič, M., Androjna, A., Brcko, T. (2022). “Solutions to minimize sediment resuspension in ports. Časopis Pomorskog fakulteta Kotor – Journal of Maritime Sciences (JMS), god. 1, br. 1/2022. Vol. 1, No. 1/2022.

[3] Fuehrer, M., and Romisch, K., "Effects on Modern Ship Traffic on Inland and Ocean Waterways," 24th International Navigation Congress, PIANC, Leningrad – Russia, 1977, pp. 236-244.

[4] PIANC Guidelines for Protecting berthing structures from caused by ships. Report n0180. The World Association for Waterborne Transportation Infrastructure, 2015.

[5] Moffat and Nichol (2005). Kitmat LNG import terminal. Revised propeller wash study. MN Project No. 5499.

[6] Pacific Northwest LNG – LNG Jetty Propeller Scour Analysis – December 11, 2014.

REPLACEMENT OF 2D SIMULATOR TRAINING WITH SHORTER 3D SIMULATOR TRAINING

Ladislav Stazić, M.Eng.
Igor Pavlović, M.Eng.
Tatjana Stanivuk, D.Sc.
Karlo Bratić, M.Eng.
The University of Split, Faculty of Maritime Studies
R. Boškovića 37, Split, Croatia
lstazic@pfst.hr, ipavlovic@pfst.hr, tstanivu@pfst.hr, kbratic@pfst.hr

ABSTRACT

This paper presents the second stage of the ongoing research into the impact of ER Simulator training on knowledge, behavior, and overall performance of students of Marine Engineering. The first stage had to establish measurements of the knowledge and practice without training, with initial 2D training, and with advanced 3D training. Final assessment after completion of training was measured and results showed very good final results. As training facilities are sometimes overbooked and not available, the idea behind this part of the research was to replace training on the 2D simulator with shorter training on a more advanced 3D simulator. Assessment of students showed that this replacement did not produce any significant difference and that shortening of the training is not an option. The final conclusion of this part of the research shows that all steps in the training must have their own course and despite a more modern approach, the required time for learning can not be replaced substituted, or shortened.

Keywords: Maritime training, Simulators, Virtual Engine Room, students

1. INTRODUCTION

“The STCW Convention requires that training and assessment of seafarers are administered, supervised and monitored in accordance with the provisions of the STCW Code” [1]. This sentence from the Convention on the Training, Certification, and Watchkeeping of Seafarers (STCW) is influencing the training and education of all seafarers worldwide. Those rules are included in Croatian national laws [2] and regulations governing the training and education of seamen. The Convention and National laws regulate the use of simulators for training and certification in Maritime Education and Training processes. Maritime schools, colleges, and faculties introduced simulators following changes introduced in 1995 in STCW Convention. The Convention adopted rules on the use of simulators in the training and education of seafarers and the evaluation/assessment of acquired competencies.

In accordance with the above rules and regulations, the Faculty of Maritime Studies in Split conducts training of its students on simulators. There are a variety of simulators on the Faculty, intended for use of different departments or studies and different courses of study. The Department of Marine Engineering, among other simulators, has three real-time engine room simulators. Those simulators are capable of simulating numerous different engine room configurations (for example steam propulsion, slow-speed diesel engine, medium-speed diesel engine, diesel-electric, ...), performing various tasks and simulating a multitude of different situations.

These simulators are Wartsila (Transas) ERS 5000W simulator (Figure 1), Wartsila (Transas) ERS 5000W 3D Full Mission Engine Room Simulator (Figure 2), and Kongsberg Neptune K-Sim Full Mission Engine Room Simulator (Figures 3 and 4). The engine room simulator training is conducted in two courses during the third year of undergraduate studies. The first course, which is held in the winter semester, combines the use of the Wartsila (Transas) ERS 5000W simulator and its classroom (Figure 1) and Wartsila (Transas) ERS 5000W 3D Full Mission Engine Room Simulator (Figure 2). The training is organized in such a way that the engine room itself and its systems are first explored and analyzed. During this

Figure 1: Wartsila (Transas) Simulator Classroom

course, special attention was paid to the detailed study of systems in the engine room, their performance as well as the starting of various devices and systems.

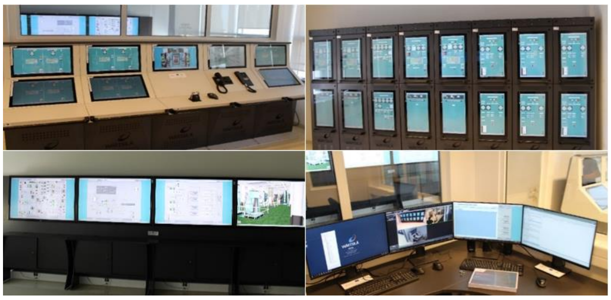

Figure 2: Wartsila (Transas) Full mission Simulator

After learning engine room systems and how to start them and use them, students are transferred in the summer semester to the Kongsberg Neptune K-Sim Full Mission Engine Room Simulator (Figures 3 and 4),

Figure 3: Kongsberg Simulator Engine Room

where they are trained in diagnostics and adaptation to changes in machinery operational parameters.

Figure 4: Kongsberg Simulator Control Room

Both courses are structured to create a challenge for students and to simulate a proper environment where they will demonstrate the capability to transform lessons learned in classes (the theory) into practice [3] ("real" environment).

Following STCW requirements for practical and simulator experience, all courses instructors are experienced Marine Engineering Officers and Chief Engineers (some of them are authors of this article) with years of sea experience as well as in-depth training on all three simulators. Instructors with their long time onboard and extensive practical knowledge are "*providing trainees with the necessary experience and self-confidence to carry out their roles, functions and tasks*" [4]. At the same time, assessments of students and their progress through courses are constantly monitored to enable instructors to improve their teaching strategies and improve student performance [5]. Six years ago, during one research, the following statement is written: "*Although the practice of using simulators is well regulated and widespread in Maritime Education and Training, it seems few studies address the pedagogical use and benefits of simulator-based training in this domain*" [6]. Since then, there were several different types of research into the use of simulators in Maritime Education and Training [7], [8], [9], [10].

The research presented in this paper is also considering the use of the simulators in Maritime Education and Training, analyzing different training approaches and comparing results after training on different types of simulators. The idea behind the research can be formulated in a simple question: "Is it possible to accelerate students' training by introducing more modern, 3D (Virtual reality) Simulator training instead of the classic, 2D?" Obtained results will fully confirm the conclusion given by Abd El-Hamid et al.: "*Ultimately, VR is irreplaceable, and has become a significant technique for the engineers of tomorrow*" [11], although will not provide results which were anticipated.

2. WINTER SEMESTER SIMULATOR TRAINING CONCEPT

Simulations of real engineering systems and usage can provide adequate training for students enabling them to practice even those actions which cannot be tried on real vessels like: "*fire or a loss of stability due to flooding*" [12]. 3D Real-time simulator training process is very useful for students as well as for marine engineers working on real vessels and can provide various types of training that are in accordance with industry needs. To be able to perform any task on the simulator (or in a real environment), one must fulfill two conditions. The first and the basic one is to have theoretical knowledge of ship and ship systems [3], to know operational principles of the surrounding equipment. The second condition is to be familiar with the machinery and systems, to know the surrounding environment.

This course is organized during the winter semester of the third year of the undergraduate study of Marine Engineering and at this stage, all students have learned during the previous two years about marine engineering systems and machinery. Regardless, classes are organized in such a way that the engine room itself and its systems are first studied on the Wartsila (Transas) ERS 5000W simulator (Figure 1). The simulator consists of three separate rooms, connected through the computer network. Those rooms are the Instructor Station where the main (instructor) computer is situated, the Engine Control Room (connected to the Bridge Simulator, which enables joint simulation with the nautical simulator), and the classroom with 10 independent student stations, each equipped with two monitors. Student stations are controlled from the instructor's station (Figure 5) i.e., "*each workstation is* *connected with the trainer independently of the other stations and performs individual tasks, the results of which are not related with the work of other stations*" [13].

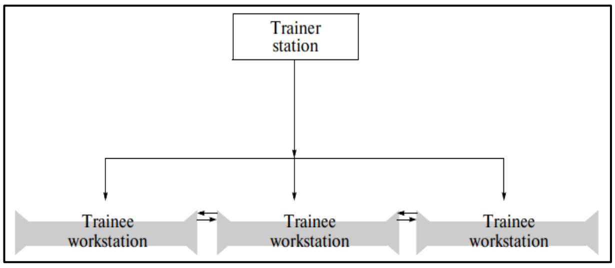

Figure 5: Simulator network configuration [13]

After completing the learning process of the characteristics of ER systems and ER equipment layout, students are transferred to the Wartsila (Transas) ERS 5000W 3D Full Mission Engine Room Simulator (Figure 2). This simulator consists of four separate rooms: Those rooms are the instructor station (Figure 2., bottom right) where the server and editor computer are situated, the Engine Control Room with Main Switchboard (Figure 2., top) consisting of a large number of computers and monitors, the engine room (Figure 2., bottom left) with large virtual reality screens are located, and a small room with an emergency generator. On this simulator, students are performing various training tasks, in an environment very similar to the real ER.

3. ASSESSMENT OF THE TRAINING

Instructors decided to evaluate the effects and benefits of simulator-based training which will be carried out at three stages of the training, starting at the beginning of the course. That evaluation was conducted in the academic year 2020/2021 with some additional checks and confirmations in 2021/2022. In total, sixteen students participated in the evaluation, training was performed in four small groups of four. This evaluation is very similar to the evaluation performed by Nazir and Hjelmervik [14] and consists of theoretical and practical tasks. The training for each group was conducted separately with a designated trainer, all topics and materials were the same, as well as the training place and schedule. The first part of the assessment consisted of a simple test intended to determine students' performance in the engine room during various course stages. At the beginning of the course, students have a brief introduction to the course, a brief presentation of the layout of the virtual engine room, and they receive a set of checklists containing all necessary instructions on how to perform all tasks.

Immediately afterward, students are given a questionnaire which is followed by a real task, like starting some machinery or system on the 3D simulator. Students are evaluated on both tasks separately, instructors are monitoring their theoretical knowledge and their capability to perform actual tasks. Results of the first evaluation are presented in Table 1.

Table 1: The first evaluation

The number of students who passed the evaluation								
	Group 1		Group 2		Group 3		Group 4	
	Skil	Ques	Skil	Ques	Skil	Ques	Skil	Ques
Initial	0	1	0	1	0	0	0	1

After finishing the initial evaluation students continue to attend the course where they are instructed on the Wartsila (Transas) ERS 5000W simulator (Figure 1). Course teaching is based on outcome-based education [15], meaning that all learning is performed through practice on the simulator. During this period students are practicing on the 2D simulator, analyzing engine room systems, starting them, and performing various tasks according to given checklists, modifying them to suit their needs and their way of thinking. Another evaluation is performed after this stage. The new questionnaire contains different questions, new tasks are slightly different, but the evaluation, in general, is very similar to the previous one.

Table 2: The second evaluation

The number of students who passed the evaluation								
	Group 1		Group 2		Group 3		Group 4	
	Skil	Ques	Skil	Ques	Skil	Ques	Skil	Ques
After Classroom	3	3	2	4	2	3	3	4

After the second evaluation, students continued their training and education. This final step is conducted in the Wartsila (Transas) ERS 5000W 3D Full Mission Engine Room Simulator environment where students are checking systems in the 3D simulator and performing practical tasks. This step is intended to create an environment more familiar and boost students' self-confidence in performing required tasks. Another part of this final training is to provide students with the chance to review their mistakes during the first two assessments and to learn from those mistakes. The final evaluation is conducted similarly to the previous after completion of the training. Results of the final (third) evaluation are presented in Table 3.

Table 3: The third evaluation

The number of students who passed the evaluation								
	Group 1		Group 2		Group 3		Group 4	
	Skil	Ques	Skil	Ques	Skil	Ques	Skil	Ques
At the end	4	4	4	4	3	3	4	4

4. RESULTS OF SIMULATOR TRAINING

Figure 6 presents student progress during this course on the engine room simulator.

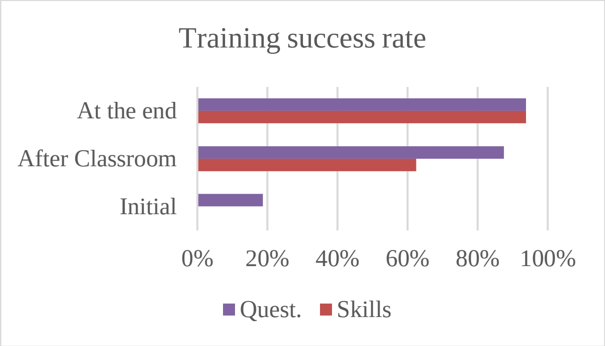

Figure 6: Course Evaluation success rate

From Figure 6, it is visible that the initial evaluation was a big surprise for students and that they did not produce satisfactory results. Only 18.75% of students managed to pass the theoretical part (questionnaire) and no one managed to complete the practical task. The overall conclusion of the first evaluation was that although students already learned about ship and ship systems, they are unable to demonstrate that especially when exposed to limited time (during questionnaire) and an environment they are not familiar with.

The second evaluation, after training on the 2D simulator produced much better results, now 87.50% of students passed the theoretical part of the evaluation and 62.50% practical. Also, students have much more confidence and are much more able to withstand the pressure they are exposed to.

The final evaluation produced very good results, with 93.75% of students (all but one) succeeding to pass the evaluation without any major difficulty.

5. THE QUESTION

This type of education and student training has been going on for the last three years. During that period instructors noticed that students during teaching and practical work concentrate much more on the 3D simulator than on 2D. This observation is fully in agreement with the conclusion published by Shen et al.: *"Although the traditional marine engine room simulator based on 2D simulation technology has achieved satisfactory training and learning effect, its inherent disadvantage that the training environment is far different from the real working environment limits the further promotion of the training effectiveness*" [16].

In addition, only during the last part of the classes on the 3D simulator did the students show the necessary self-confidence and the conditions to meet the evaluation. The stated reasons led the instructors to propose another training schedule and another set of evaluations to determine if the same evaluation results can be obtained by replacing teaching on a 2D simulator with somewhat shorter teaching on a 3D simulator (Virtual reality). The above-mentioned assumption that the training of students and marine professionals might be shortened was motivated by the need to decrease the load of teaching staff and consequently create the same learning effects with fewer efforts.

Therefore, training on the 2D Simulator was replaced with the 3D simulator. The training is performed with the same number of classes, the difference is that students are evaluated in a larger number of tests to monitor the progress of students in training and to try to determine the moment when students become capable of fulfilling all required tasks. In addition to the questionnaire and the assessment of the performance in the simulator, the students are evaluated on the preparation of their checklist and its functionality as seen by Moorhead and Pinisetty [17] who introduced into training the capability of students to prepare and follow the paperwork.

6. 3D TRAINING AND ASSESSMENT

Six students participated in this, modified course training and the evaluation. This program started in the same way as for all the aforementioned groups. This group of students also had a brief introduction to the course followed by a brief presentation of the layout of the virtual engine room. They received the same set of checklists as other groups, containing all necessary instructions on how to perform all tasks. After this short, introductory class, Students are evaluated by a questionnaire and in virtual ER in practice. Results of this group are presented in Table 4.

Table 4: The first evaluation of 3D training

The number of students who passed the evaluation			
	Skill	Questions	Paperwork
At the start	0	1	n/a

Students started their training on ER systems and machinery on the 3D simulator after this evaluation. After half of the designated training, another evaluation has been performed, results are presented in Table 5.

Table 5: The second evaluation of 3D training

The number of students who passed the evaluation			
	Skill	Questions	Paperwork
Half through	2	3	1

Training on 3D simulator continued after this evaluation, students are more and more involved in analyzing engine room systems, starting them, and performing various tasks according to given checklists. They are continuously modifying checklists, finding inconsistencies in initial lists. After completion of this stage of the training, students are at the same stage as students who were evaluated for Table 2. As they were training on the 3D simulator it was expected that their evaluation results (Table 6) surpass the results shown by their colleagues which are presented in Table 3.

Table 6: The third evaluation of 3D training

The number of students who passed the evaluation			
	Skill	Questions	Paperwork
Systems finished	4	5	5

The last stage of training is consisting of reviewing their mistakes during previous evaluations and repeating already learned lessons. The final evaluation took place at the end of the course, results are presented in Table 7.

Table 7: The final evaluation of 3D training

The number of students who passed the evaluation			
	Skil	Questions	Paperwork
Systems finished	6	6	6

7. COMPARISON

A comparison of evolutions is made to determine the difference between these two training approaches. Some results are expected and some of them are somewhat different than expected. It is important to point out that all results of this analysis should be considered with a significant dose of caution, long time ago Tversky and Kahneman pointed out that it is not advisable "*gambling research hypotheses on small samples without realizing that the odds against him are unreasonably high*" [18].

Initial evaluation of the 2D and 3D evaluations is presented in Figure 7. showing similar results. Students

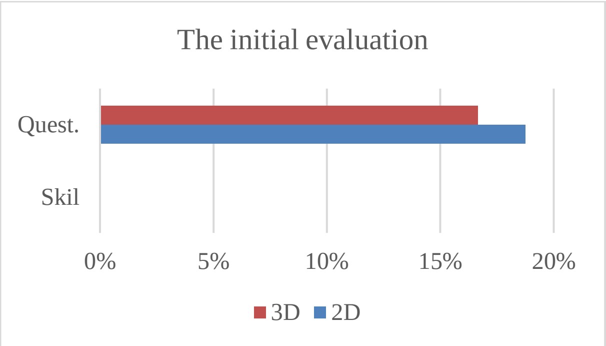

Figure 7: Comparison of the initial evaluation

completely failed to pass practical tests while theoretical evaluation was a little bit better and brought a very low success rate. The success rate in both pieces of training is similar, showing consistency of success of less than 20%.

The next stage where the comparison is required is at the end of learning ER systems, where students have the same number of classes behind them. Results of the comparison are presented in Figure 8.

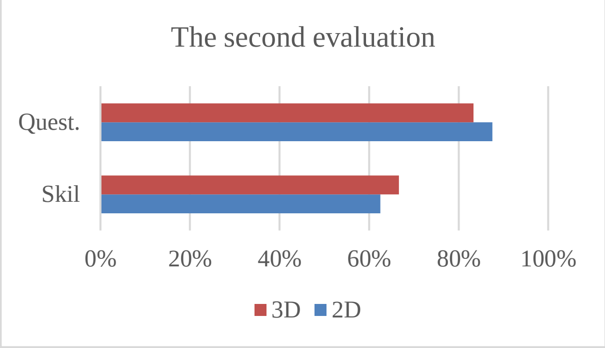

Figure 8: Comparison of the second evaluation

From this comparison it is visible that results are similar, there are no notable differences between students' success rates although instructors expected much better results.

The final comparison of evaluations taken at the end of training is presented in Figure 9.

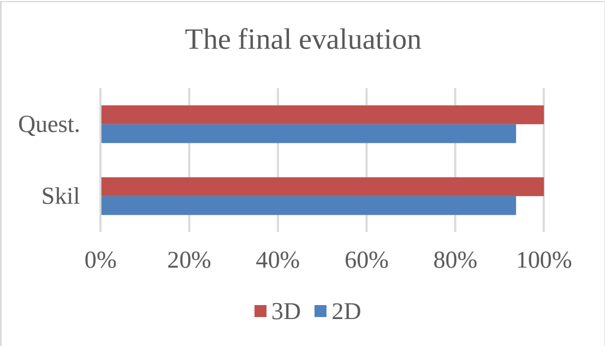

Figure 9: Comparison of the final evaluation

Comparison of final evaluation results show also similar results, success rate is almost the same, one student failed in 2D training while none failed during 3D. Considering the size of both groups, it can be considered that the results are almost the same.

8. CONCLUSIONS

From obtained results of the evaluations performed during combined 2D and 3D training, it is visible that proficiency and skills gained allow students to better understand the working principles of various equipment in the Engine room as well as to promote easier adaptation to practical tasks. The high success rate of students (93.75% at the end of the course) who passed the test justifies all efforts of the instructors and promises that future members of the engine room watch will have the necessary knowledge, skills, and competencies. Results of the initial evaluation also show that although students began the course with full theoretical knowledge of systems and machinery operating principles, they are unable to convert learned theory into practical tasks. After finishing this course on the simulator, they gained the required skills and proficiency required to convert their knowledge into practice and successfully passed evaluations. These conclusions also confirm that the course is well-designed and that students are making significant progress through it.

The main research target, the analysis into the possibility of replacing established 2D simulator training with shorter 3D equivalent brought different results from those expected from course instructors. As was expected, the knowledge of all students at the beginning of the course was almost the same, which was confirmed with teste. Results at the end of the first training stage, when the next comparison was performed did not show any significant difference between the two models of the training. In both models, there were still students unable to pass the evaluation, the number of those is similar (in this very limited experiment). Results of both models were much better at the end of the course, almost all students showed good knowledge, skills, and competence enabling them to fulfill all required tasks.

Several secondary conclusions can be derived from these results. The first secondary conclusion is already presented and verified through the article as well as by many other researchers in this field, that the use of the Engine Room simulator is beneficial as a tool for teaching and assessing. Students during Engine Room simulator training succeed to combine knowledge learned through various subjects and applying them in practice, therefore, this part of the learning experience is vital for a good and proper teaching process.

The second secondary conclusion is that this teaching model produces a satisfactory level of success and that a large majority of students will receive good training.

The main conclusion, targeted with this research, is considering the replacement of 2D training with shorter 3D training. As the number of students who fulfilled all required tasks was very similar in both training programs and as there was no visible difference in students' behaviour during the training, the whole analysis obtained through this research is indicating that the type of simulator is not crucial for the development of the skills and competences in students. If all analyzed is correct, then it can be concluded that skills and competencies develop with repetition and in time. This indication, which must be verified on a much larger sample, is not the result that was expected at the beginning of the research but it might help to shape the training in the best mode for students.

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REFERENCES

[1] International Maritime Organization. (2020) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). available at: https://www.imo.org/en/OurWork/HumanElement/Pages/STCW-Conv-LINK.aspx, accessed on 02nd January 2021.

[2] The Ministry of Science and Education of Croatia. available at: https://mzo.gov.hr/, accessed on 18th December 2021.

[3] Clarke, H. L., & Winch, C. (2004). Apprenticeship and Applied Theoretical Knowledge. Educational Philosophy and Theory. Vol. 36(5). pp. 509–521. doi:10.1111/j.1469-5812.2004.087_1.x.

[4] Malik, A., & Zafar, N. (2015). Applications of simulation technology pitfalls and challenges. TransNav, International Journal on Marine Navigation and Safety of Sea Transportation. Vol. 9. doi: 10.12716/1001.09.03.12.

[5] Klinger, D. (2008). The evolving culture of large-scale assessments in Canadian education. Canadian Journal of Educational Administration and Policy. Vol. 76.

[6] Sellberg, C. (2016). Simulators in bridge operations training and assessment: a systematic review and qualitative synthesis. WMU Journal of Maritime Affairs. Vol. 16(2). pp. 247–263. doi: 10.1007/s13437-016-0114-8.

[7] Mangga, C., Tibo-oc, P., & Montaño, R. (2021). Impact of engine room simulator as a tool for training and assessing BSMARE students'performance in engine watchkeeping. Pedagogika. Vol. 93(S6). pp. 88-100. doi: 10.53656/ped21-6s.07eng

[8] Kandemir, C., & Celik, M. (2021). A Human Reliability Assessment of Marine Engineering Students through Engine Room Simulator Technology. Simulation & Gaming. Vol. 52-5. pp. 635-649. doi: 10.1177/10468781211013851

[9] Bratić, K., Vidović, F., & Stazić, L. (2020). Use of Merlin System and Recorded Instructions in Engine Room Simulator Training. In International Scientific Conference Technics and Informatics in Education. pp. 282-285.

[10] Zincir, B., Dere, C., & Deniz, C. (2017). Scenario based assessment method for engine room simulator courses. In: Proceedings of the 13th International Conference on Engine Room Simulators. pp. 20-21. Odessa, Ukraine

[11] Abd El-Hamid, A., Salama, A. A., Hassan, S. I., & Ayad, N. M. A. (2020). A Glimpse of Virtual Reality Publications in Engineering Disciplines. Egyptian Journal of Applied Sciences. Vol. 35. pp. 75-83. doi. 10.21608/EJAS.2020.120573

[12] Lee, D., Kim, S., Lee, K., Shin, S., Choi, J., Park, B. J., & Kang, H. J. (2021). Performance-based on-board damage control system for ships. Ocean Engineering. Vol. 223. pp. 108636. doi: 10.1016/j.oceaneng.2021.10863

[13] S. D. Aizinov, S. D. & Orekhov, A. V. (2010). Simulator training for the high technology ship crews. Gyroscopy and Navigation. Vol. 1(4). pp. 258–262. doi: 10.1134/s2075108710040048.

[14] Nazir, S., & Hjelmervik, K. (2017). Advance Use of Training Simulator in Maritime Education and Training: A Questionnaire Study. In: Proceedings of the International Conference on Applied Human Factors and Ergonomics - AHFE 2017. pp. 361–371. doi:10.1007/978-3-319-60018-5_35.

[15] Elliott, J. (2001). Making evidence-based practice educational. British educational research journal. Vol. 27(5). pp. 555-574. doi: 10.1080/01411920120095735

[16] Shen, H., Zhang, J., Yang, B., & Jia, B. (2019). Development of an educational virtual reality training system for marine engineers. Computer Applications in Engineering Education. Vol. 27-3. pp. 580-602. doi:10.1002/cae.22099

[17] Moorhead, K., & Pinisetty, D. (2021). Simulator Training in the Marine Engineering Technology Curriculum. In: Proceedings of 2020 CIEC. Virtual. doi: 10.18260/1-2-370-38726

[18] Tversky, A., & Kahneman, D. (1971). Belief in the law of small numbers. Psychological Bulletin. Vol. 76(2). pp. 105–110. doi: 10.1037/h0031322

PORT RECEPTIONS FACILITIES FOR SLUDGE OIL – PRACTICE AROUND THE EUROPE

Valter Suban
Unioversity of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorščakov 4, 6320 Portorož, Slovenia

Rita Avram
Naval Academy Mircea cel Batran Constanta

Taner Albayrak
Piri Reis University, Istanbul

Vilma Locaitiene
Lithuanian Maritime Academy, Klaipeda

Radu Spataru
French Maritime Academy, Marseille

ABSTRACT

Oils are one of the most important pollutants at sea. One of the sources of oil pollution is the illegal discharge of oil sludge by ships. During normal operation, ships produce a certain amount of oil sludge, which is stored in separate tanks. One of the measures to prevent illegal discharges is facilitation the discharge of sludge in ports. The MARPOL Convention, Guidelines for the Implementation of MARPOL Annex V, Consolidated guidance for port reception facility providers and users provide technical guidance to States on the organisation of reception facilities. DIRECTIVE (EU) 2019/883 on Port reception facilities for the delivery of ship-generated waste goes deeper into the matter in hand and provides guidance on the economic approach as well. This paper takes a closer look into ship oil waste on board and in ports, namely in the Port of Koper (Luka Koper), the Port of Marseille (Grande Port Maritime de Marseille), the port of Istanbul (Haydarpaşa Port), the Port of Constanta and the Port of Klaipėda.

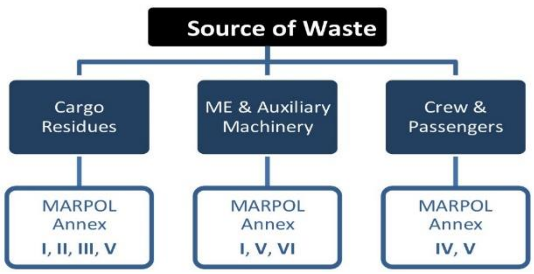
Keywords: Oil pollution, sludge oil, port reception facilities, B4S

1. INTRODUCTION

The shipping industry is the blood system of the global economy. According to UNCTAD, more than 80 per cent of world trade is carried by sea [1], other sources even speak of more than 90 per cent [2], [3], [4]. The entire fleet must operate safely, securely,efficiently and in an environmentally sound manner [2].

2. SHIP WASTE HANDLING

Like any industry, the shipping industry produces waste during its operation. The waste comes from different sources. Generally, we divide it into waste generated by operations, maintenance waste from ship engines (main and auxiliary) and equipment, cargo and waste from people (crew, passengers).

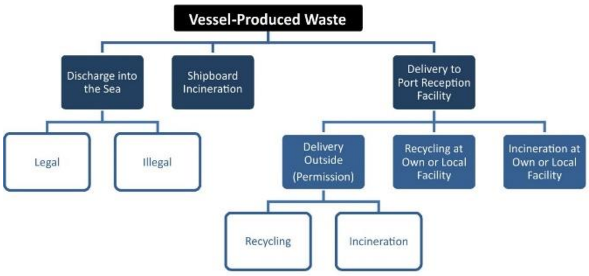


Source: Author

Figure 1: Sources of ship's waste

When a ship is at sea, waste can either be disposed of into the sea itself, incinerated in the shipboard incinerator, or kept on board until reception in port is possible (**Error! Reference source not found.**). Which of these actions are permitted and which are prohibited for a particular substance at a particular place and time is governed by Annexes from I to VI of the IMO MARPOL Convention. The Convention was adopted in 1973 to protect the marine environment following a series of serious tanker accidents involving major oil spills [5]. Most ship-generated waste (**Error! Reference source not found.**) is hazardous waste. This includes bilge oils with different water content. The hazardous wastes are handed over to authorised organisations for further processing or disposal. Bilge oils could be handed over for use as substitute fuel in other countries.

When a ship is at sea, the waste can either be disposed of at sea, incinerated in the shipboard incinerator or kept on board until it is possible to accept it in port (Figure 2). Which of these measures are permitted and which are prohibited for a particular substance at a particular place and time is regulated in the Annexes from I to VI of the Convention IMO MARPOL. The Convention was adopted in 1973 to protect the marine environment after a series of serious tanker accidents involving major oil spills [5]. Most of the waste generated by ships (Figure 1) is hazardous waste. This includes bilge oils with different water content. The hazardous waste is transferred to authorised organisations for further processing or disposal. Bilge oils could be handed over for use as substitute fuel in other countries.



Source: Authors

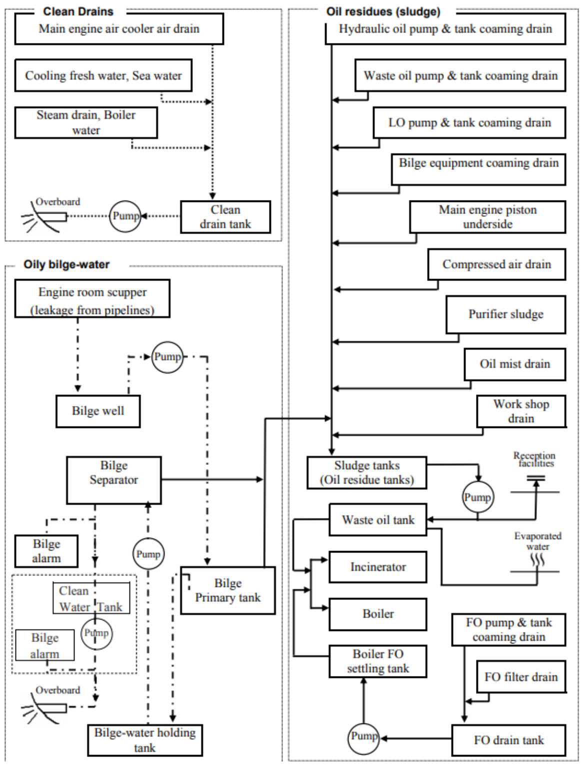
Figure 2: Flow chart of ship-generated waste

Annex I of MARPOL defines oil as: "Petroleum in any form, including crude oil, fuel oil, sludge, oil refuse and refined products (other than petrochemicals, which are subject to the provisions of Annex II of the mentioned convention)." For this reason, companies that receive liquid waste do not make any distinction and their means of collection are versatile [5].

Annex I of the MARPOL Convention regulates all types of waste related to oil and oily mixtures, namely oily bilge water, oily tank wash water, dirty ballast water and sludge. The demand for oily tank wash residues (a result of tank cleaning and ballast water transport in dirty cargo tanks on tankers) usually arises in the oil loading ports, so the demand for discharge such effluents is negligible. Oily mixtures are generated as oil leakages in the machinery spaces. With good separation (15 ppm oil content), clean water can be pumped directly into the sea, while the residues have to be pumped into sludge tanks and stored. The greatest quantity of oil sludge produced on board is generated during the purifying of the ship's fuel. The official definition of oil sludge includes sludge from fuel or lubricating oil separators, as well as lubricating oil waste from main or auxiliary machinery and waste oil from bilge water separators, oil filtering equipment or drip trays [5].

A typical ship discharge volume is between 30 and 80 cubic metres of oily waste. The volume depends on the storage capacity on board and the requirement to maintain sufficient storage space. The oil content in the sludge varies between 30 % and 70 %, depending on the efficiency of the on-board oil-water separator. So the weight of a cubic metre of oily waste varies depending on the oil content. For example: Tex crude oil has a density of 873 kg per cubic metre and water has a weight of 1,000 kg per cubic metre. A typical 70:30 mixture of oil and water would have a weight of about 900 kg [6]

A system on the ship is designed to treat sludge from oil treatment systems in diesel engine plants. The system separates the sludge into its three main components: Oil, sludge and water. The recovered oil is fed into a boiler feed tank, the concentrated separated sludge is fed into a sludge tank for disposal and the water flows into the oil water separator [7].



Source: [7]

Figure 3: Flow Diagram of Integrated Bilge Water Treatment System

Sludge occurs in two forms: liquid and dehydrated. The solution of delivering dehydrated sludge is not included in the flow chart in Figure 3, but it does exist, even though it is usually burnt in the incinerator. The latter can be discharged ashore in drums, which are eventually passed on to authorised organisations.

Each port facility has its own way of dealing with sludge collected from ships. The port can either conduct that by itself or contract competent companies to collect it.

How to do this is recommended in some international guidelines such as "Revised guidelines for systems for handling oily wastes in machinery spaces of ships incorporating guidance notes for an integrated bilge water treatment system" [7].

3. SHIP WASTE DELIVERY NOTIFICATION

In some ports, for logistical reasons, the providers of port reception facilities may require the ship to give advance notice of its intention to use the facilities. This is regulated by IMO MEPC Circular 644/Rev.1 entitled "Standard format for the advance notification form for waste delivery to port reception facilities". According to this, the master of a ship should forward the information below to the designated authority at least 24 hours before arrival or upon departure of the previous port if the voyage is less than 24 hours [8]. The notification form is also mandatory for ships calling at EU ports and is regulated by the EU Commission Directive 2015/2087 on port reception facilities for ship-generated waste and cargo residues [9].

MARPOL Annex I – Oil	Quantity (m^3)
Oily bilge water	
Oily residues (sludge)	
Oily tank washings	
Dirty ballast water	
Scale and sludge from tank cleaning	
Other (please specify)	

Source : [8] [10] [11]

Figure 4: Type and amount of waste for discharge to facility

Waste management is subject to regular inspections. To facilitate these, the ship must indicate the approximate quantity of waste and residues remaining on board and the percentage of the maximum storage capacity on a recommended form.

Type	Maximum dedicated storage capacity (m^3)	Amount of waste retained on board (m^3)	Port at which remaining waste will be delivered (if known)	Estimate amount of waste to be generated between notification and next port of call (m^3)
MARPOL Annex I – Oil				
Oily bilge water				
Oily residues (sludges)				
Oily tank washings				
Dirty ballast water				
Scale and sludge from tank cleaning				
Other (please specify)				

Source : [8] [9] [10] [11]

Figure 5: Declaration of approximate amount of waste and residues remaining on board

In the case that the master of a ship has difficulty in discharging waste in reception facilities, he should forward the following information to the flag State administration together with the relevant documentation [11].

Type of wastes/residues	Amount for discharge (m^3)	Amount not accepted (m^3)	Problems encountered Indicate the problems encountered by using one or more of the following code letters, as appropriate. A No facility available B Undue delay C Use of facility technically not possible D Inconvenient location E Ships had to shift berth involving delay/cost F Unreasonable charges for use of facilities G Other (please specify in paragraph 3.2)
MARPOL Annex I - related			
Oily bilge water			
Oily residues (sludge)			
Oily tank washings (slops)			
Dirty ballast water			
Scale and sludge from tank cleaning			
Other (please specify ....)			

Source : [11]

Figure 6: Format for reporting alleged inadequacies of port reception facilities

4. SHIP WASTE COST RECOVERY

Port authorities need to provide information on fees/costs for the use of the facilities. The reception facility services should be offered at a reasonable cost [11][12].

In principle, port reception facilities can collect fees directly from port users based on the polluter-pays principle. However, such a system can sometimes discourage people bringing marine litter to the reception facilities. In order to overcome this matter, some countries have adopted an indirect fee system ("no special fee" system"), whereby the relevant costs of disposing of marine litter (garbage) generated by ships are included in a harbour fee, regardless of whether the ships use reception facilities or not [13].

States that agree on a regional framework can set their own fees. For example, the European Union (EU) adopted the Directive on Port reception facilities for the delivery of ship-generated waste 2000/59/ EC, which was amended by Directives 2010/65/EU, 2015/2087/EU and the currently applicable 2019/883/EU [9][10].

The Directive ensured that all ships contribute to the costs of port reception facilities in a fair and transparent manner and provided sufficient and comparable incentives for ships to deliver their waste.

5. SLUDGE HANDLING IN THE PORT OF KOPER

The port of Koper has established port reception facilities in accordance with the EU Directive [10] and Slovenian national regulations [14][15].

The subsidiary Luka Koper INPO collects marine oils in the bilge facility and delivers them to authorised organisations. As a collector of such waste, the company has obtained an environmental permit for this activity. The facility is in the process of obtaining a construction permit to increase its collection capacity.

Liquid oily waste collected from ships is stored in a designated area. The tank farm for liquid oily waste has a storage capacity of 109 m^3, which will increase to 201 m^3 in the near future. From there, the oily waste is shipped to authorised collector for further treatment.

The existing tariff for the provision of mandatory utility services for waste collection from ships in the Port of

Koper is published on the basis of the Ordinance on the Establishment of Prices for Mandatory Utility Services for Waste Collection from Ships in the Port of Koper [14].

In the Port of Koper, the collection of liquid waste from a ship is charged by volume (Table 1); the minimum chargeable quantity is 1 m^3.

Table 1: Tariff for the liquid waste collection in Koper

Type of liquid waste	€ per cubic meter (€/m^3)
Wastewater, including transfer of same into the municipal sewage system	45.07
Oil/water mixtures and similar liquid wastes	77.20

Source : https://www.luka-kp.si/wp-content/uploads/2021/06/zbiranje-odpadkov-javna-sluzba-EN_star-2006.pdf

The transport of solid and liquid waste by auxiliary vessels from the ship to the port facilities is calculated on the basis of the cost of removal by auxiliary vessels (Table 2).

Table 2: Tariff for the collection of solid and liquid waste by an auxiliary vessel.

Service	Cost
Use of auxiliary vessel for the removal of solid waste from a vessel at anchor	40.06 €
Per hour (or part thereof) charge for the removal of oil/water mixtures and similar liquid wastes from a vessel by an auxiliary vessel	751.13 €/h

Source: https://www.luka-kp.si/wp-content/uploads/2021/06/zbiranje-odpadkov-javna-sluzba-EN_star-2006.pdf

6. SLUDGE HANDLING IN THE PORT OF MARSEILLE

The Grand Port Maritime de Marseille, or GPMM, bases its waste management exclusively on Directive 2000/59/ EC (amended by Directive 2007/71/ EC of 13 December 2007 and Directive EU 2015/2087 of 18 November 2015) on "Port reception facilities for ship-generated waste and cargo residues" [10]. The port only treats sludge, oil waste and solid waste

As it is the case with all international conventions, the responsibility for implementing the provisions of MARPOL lies with the government. As a result, the provision of waste reception services can be carried out by private companies (for which this may provide a business opportunity) or by public enterprises under government responsibility, as is the case with GPMM.

The latest available waste oil statistics are shown in the figure below (quantity in m^3):

Table 3: Waste oils delivered in Marseille

Sludge oil	Bilge water	Oils	Others
15105,162	3798,180	94,685	106,750

Contractors are free to charge rates as they see fit, provided that:

- they inform the ship's agents in a timely and transparent manner,
- comply with the Commercial Code,
- do not engage in unfair competition, and
- notify the G.P.M.M. of the tariffs applied.

Any ship that does not have its operational waste collected by one or more of these approved contractors will be required to pay a fee in euros, which constitutes a port fee and is equivalent to 30% of the cost estimated by the Grand Port Maritime de Marseille for the reception and treatment of the ship's operational waste.

The "Waste Fee" applicable to ships is made up of the sum of two taxes:

- a "fixed" tax applied to operational waste covered by MARPOL V; a lump sum evaluated at €190;
- a "liquid" tax applied to operational waste covered by MARPOL I by applying a coefficient of €0.0102 per cubic metre to the taxable volume of the vessel.

The amount of the liquid tax is limited by a minimum collection amount of € 64 (Article R.* 5321-51 of the Transport Code) and may not exceed a ceiling of € 675.

The deficiency reports for the reception facilities for ship-generated waste and cargo residues are made on the IMO deficiency notification forms (see figure 6). The notifications are forwarded to the Harbour Master's office where they are the subject of a case study, which may involve corrective action or even a modification of procedures. Corrective action should be taken as soon as possible. To date, no notifications of deficiencies have been reported by vessels or shipowners. It should be noted that no vessel has been prosecuted for pollution by the GPMM since 2013.

7. SLUDGE HANDLING IN THE PORT OF ISTANBUL

The main body for waste collection in Istanbul Port or Haydarpaşa Port is ISTAÇ (Marine Services Directorate of the Department of Environmental Protection and Control of Istanbul Metropolitan Municipality). ISTAÇ is a member of EUROSHORE, the association of port reception facility providers in Europe, which started collecting waste from the vessels in 2005. Since 2005, more than 2,110,000 m³ of waste has been collected from around 95,000 ships that have passed through the Istanbul Strait and ports, contributing to the protection of the Istanbul Strait.

ISTAÇ collects and manages ship-generated waste in a controlled manner in accordance with the provisions of international agreements. As a member of the

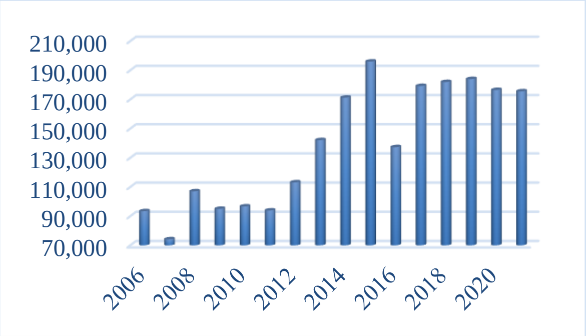
Association of Port Reception Facility Providers, EUROSHORE, ISTAÇ follows the latest local and international regulations and their implementation.

At the Haydarpaşa Port Reception Facility, oil and oil-derived waste from ships is recycled and reused. In this way, the port makes an important contribution to the economy while keeping pollution in the Istanbul Strait under control. At the plant, which has an annual waste treatment capacity of 110,000 m³, oil and oil derived wastes such as bilge, slop oil and oil sludge are treated through chemical processes. Of this, 20,000 m³ of waste oil is recycled for economic purposes.

The Port of Istanbul has a 1040 m2 waste reception facility. The facility was put into service in 2006. The Haydarpaşa Waste Reception Facility is the first and largest facility in this area in Turkey. The main units include:

- waste receiving and storage unit,
- heating unit,
- decanter (de-sedimentation) unit,
- separator (dewatering) unit,
- chemical treatment unit,
- electrical and automation unit,
- firefighting unit and
- laboratory unit

In 2021, a total of 149,110 m³ of petroleum-derived waste was collected from ships and recycled or disposed of at the relevant Istanbul Metropolitan Municipality facilities.



Source : Authors

Figure 7: Graph of oil collected in Istanbul

The upper graph shows the quantities of oil-derived waste taken to the waste recycling plant.

8. SLUDGE HANDLING IN THE PORT OF CONSTANTA

In Romania, port authorities must ensure that port reception facilities are able to take over the types and quantities of ship- generated waste, the formalities and practical issues related to the use of port reception facilities, and that the fees for delivery are not discouraging for ships requesting to use the facilities. Port reception facilities shall ensure environmentally sound management of ship-generated waste and separate collection of ship-generated waste in accordance with the provisions of Government Emergency Ordinance No. 92/2021 [16]. The port reception facilities collect the separate fractions of waste according to the waste categories defined in the MARPOL 73/78 Convention [2].

It is estimated that the average daily volume of waste generated by ships calling at Romanian seaports must ensure the following take-over capacities:

- Oil waste: 32 m^3/day
- Wastewater: 1.5 m^3/ day
- Garbage: 3.5 m^3/day

The takeover of oil residues, wastewater and liquid cargo residues is carried out by the Port Administration.

The capacity of the port reception facilities regarding sludge management is as follows:

- Reception capacity for oil waste: 880 m^3 and
- Temporary storage capacity for oil waste: 970 m^3.

For sludge treatment, the Port of Constanta has its own wastewater treatment plant with a total capacity of 814000 m3 per year. The wastewater treatment plant aims to treat oil wastewater and bilge water from the Oil Terminal's area of activity, as well as oil waste from ships. The biological water treatment system includes a low-density material separator and sand and activated carbon filters. The treated wastewater is within the permitted emission limits for discharge into seawater.

The wastewater treatment process in the port of Constanta includes the following stations.
The treatment plant operates with two treatment stages. The first is mechanical and the second is biological.
Mechanical pre-treatment station has the task of removing suspended solids and rough materials from the wastewater before the purification treatment. The treatment is carried out with a grate system mounted in a stainless-steel box. Each grate is coupled with a propeller compaction plant for dehydration and evacuate the material retained in a waste container.
Leachate treatment plant has a capacity of 20 m^3/day and includes storage tanks and equipment for the technological stages of physical-chemical and biological wastewater and sludge treatment.

The treatment process includes the following steps:

- storage and homogenization of the leachate,
- biological stage,
- precipitation stage,
- treatment with activated charcoal powder and
- mud treatment.

The treated water is discharged into the sewerage system of the area. The wastewater must meet the quality conditions set out in the regulations in force for the disposal of wastewater into the sewerage networks.

Subsequently, this wastewater is mixed with the other types of wastewater collected in the port's sewerage network. The port of Constanta has also been equipped with 5 mini-stations for the mechanical and biological treatment for sewage.

The tariff for wastewater treatment is 1.43 €/m3. The tariff for taking oil waste from ships is 7 €/t.

9. SLUDGE HANDLING IN THE PORT OF KLAIPEDA

In the State Port of Klaipeda, the procedures for the reception of ship-generated waste are governed by:

- Directive (EU) 2019/883 of the European Parliament and of the Council of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU and repealing Directive 2000/59/ EC [10];
- Regulations on the Management of ship-generated waste and cargo residues from ships, approved by Order No 3-552/D1-708 of the Ministers of Transport and Environment of the Republic of Lithuania of 6 December 2021 [17].

There are also other documents regulating the procedures related to ship generated waste, such as the Shipping Rules of the Klaipėda State Seaport [17]. The rules set out the procedures and requirements for ships entering the port of Klaipėda, including the procedure for submitting notifications regarding ship-generated waste.

It should be noted that the Baltic Sea is designated as a special area for the regulation of discharges from passenger ships under Annex IV of the MARPOL Convention. Under HELCOM 92, all countries that have ratified HELCOM 92 have developed and applied general requirements for reception facilities for ship-generated waste, taking into account the special needs of passenger ships operating in the Baltic Sea. HELCOM 92 obliges ports and terminals in the Baltic Sea region to install waste water reception facilities without disrupting ships' schedules and to meet the needs of ships using these facilities. Therefore, the waste reception facilities in the port of Klaipeda and the waste discharge procedures must also be in accordance with this convention [2].

The Port of Klaipeda has three types of reception facilities for ship-generated waste: fixed (or stationary), floating and mobile (Fig.8). The stationary reception facilities belong to the stevedoring company "Klaipėdos Nafta", an international owner and operator of LNG and oil terminals. The oil terminal of this company is additionally responsible for receiving and handling of waters polluted with petroleum products (oil bilge water, sludge, dirty ballast water, oily tanks washings). The company has a Hazardous Waste Management Certificate for these activities..

During treatment, process involves the separation of the concentrated fraction of petroleum products and water is separated from the contaminated mass. The resulting concentrate is certified and marketed as fuel oil, while the separated water is treated in the terminal's treatment plant. Waste treatment takes place in two 4200 m3 tanks. The company has its own treatment plant. The annual treatment capacity is up to 400 000 m3 or 160 m3/h. The company has installed a biosorptive water treatment system. This is a unique technology developed by the company for the treatment of collected water. The biological water treatment system purifies wastewater to the required level of purity.

To collect the liquid waste from the incoming vessels, the waste management company uses the vessels (inland tankers) "Banga", "Flora" and "Dane". The collection is carried out by centrifugal pumps. The capacity of the pumps ranges from 18 m3/h to 100 m3/h. Shipboard tanks are designed to collect and store lighter water contaminated with oil products and at the same time to carry out the separation of oil products by means of separation. The process of separating oil-contaminated water in the ship tanks follows the technological principle of buffer tanks. Buffer tanks separate about 90 to 95 % of the oil-containing materials.

With this capacity, the volume of handling oil, bilge water and other liquid waste containing petroleum products increases from 14k to 37.3k tonnes per year.

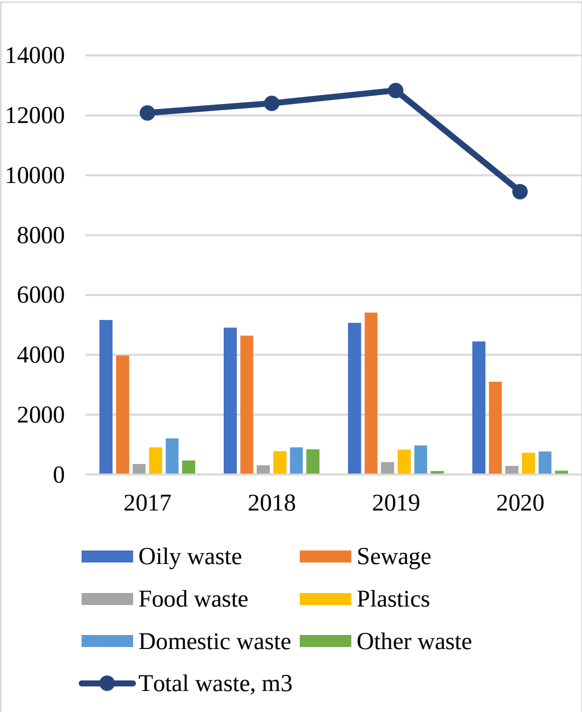


Figure 8: Graph of waste collected in Klaipeda

Source : Authors

The total amount of MARPOL I waste collected and recovered from ships from 2017 to 2020 was 19583 m3. The Port Control Department stated that about 2200 ships per year used the waste reception service. In the future, the wastewater reception rate is expected to be around 200 m3/h and at least 300 m3 of waste will be received at any given time. The indicative annual quantity of oily waste and sludge is about 3900 m3 according to MARPOL 73/78 Annex I.

10. CONCLUSION

There are different practices in the ports in Europe. What all ports have in common is that they comply with the requirements of MARPOL. In the countries that are part of the European Union, EU Directive 2019/883 is also complied with. Each port takes a different approach to dealing with waste oil and charging ships that discharge this type of oil. The next logical extension of this paper is to find out the best practices also in other ports and find the best solution for the environment around the world.

REFERENCES

[1] UNCTAD: Review of Maritime Transport. United Nations Conference on Trade and Development (UNCTAD), Geneva, 2020, p. 146.

[2] IMO:. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended. International Maritime Organization (IMO), London, 2017, p. 384

[3] ILO: Conditions in the maritime industry, International Labour Organisation. 2001; https://www.ilo.org/global/about-the-ilo/multimedia/video/video-news-releases/WCMS_074526/lang--en/index.htm (accessed 20.04.2022)

[4] ICS: Shipping Fact - Shipping and World Trade: Predicted Increases in World Seaborne Trade, GDP and Population, International Chamber of Shipping, 2022; https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-predicted-increases-in-world-seaborne-trade-gdp-and-population/ (accessed 8.05.2022)

[5] IMO: International Convention for the Prevention of Pollution from Ships, 1973, as modified by the 1978 and 1997 Protocols with amendments,. IMO Publishing, London 2017, ISBN 978-92-801-16571

[6] ReCycled Refuse International Ltd.: Marine Oily Water and Sludge Treatment, https://rcrcommodities.com/ (accessed 8.05.2022)

[7] IMO: Revised guidelines for systems for handling oily wastes in machinery spaces of ships incorporating guidance notes for an integrated bilge water treatment system (IBTS), MEPC 54/21 Annex 17, 2012 (https://www.crclass.org/chinese/download/ti-tc/27/mpec-circ511.pdf (accessed 8.05.2022)

[8] IMO: Standard format for the advance notification form for waste delivery to port reception facilities, MEPC.1/Circ.644/Rev.1; London 2013

[9] EU COMMISSION: Directive (EU) 2015/2087 amending Annex II to Directive 2000/59/EC of the European Parliament and the Council on port reception facilities for ship-generated waste and cargo residues; Official Journal of the European Union 19.11.2015; https://eur-lex.europa.eu/legal-content (accessed 8.05.2022)

[10] EU COMMISSION: Directive (EU) 2019/883 of the European parliament and of the Council of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU and repealing Directive 2000/59/EC; Official Journal of the European Union 7.6.2019; https://eur-lex.europa.eu/legal-content (accessed 8.05.2022)

[11] IMO: Consolidated guidance for port reception facility providers and users, MEPC.1/Circ.834/Rev.1, 2018; https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/MEPC.1-Circ.834-Rev.1.pdf; (accessed 8.05.2022)

[12] IMO: Guidelines for ensuring the adequacy of port waste reception facilities (resolution MEPC.83(44)), 2000, https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.83(44).pdf (accessed 8.05.2022)

[13] UNEP, IMO: Guidelines for providing and improving port reception facilities and services for ship-generated marine litter in the Northwest Pacific region, 1999 https://wedocs.unep.org/bitstream/handle/20.500.11822/26160/guidelineprovideportrec.pdf (accessed 8.05.2022)

[14] Republic of Slovenia: Regulation on the establishment of prices for obligatory utility services for waste collection from vessels in the Port of Koper (Official Gazette No 120/05 of 29 December 2005) and the amendment to the said Regulation (Official Gazette No 17/06 of 17 February 2006).

[15] Republic of Slovenia: Regulation on the establishment port facility reception services for waste collection from vessels in the Port of Koper (Official Gazette No 78/08) with amendment

[16] Republic of Romania: Government Emergency Ordinance no. 92/2021

[17] Republic of Luthuania: Order No 3-552/D1-708 of the Ministers of Transport and Environment of the Republic of Lithuania of 6 December 2021.

[18] Republic of Luthuania: The Shipping Rules of the Klaipėda State Seaport

INVESTIGATION OF THE MODAL SHIFT OF ROAD FREIGHT TRANSPORT TO RAIL AND WATERWAYS

Norina Szander, Ph.D.
Tamás Jenei
Zsolt Lévai
András Munkácsy, Ph.D.
KTI Institute for Transport Sciences Non-profit Ltd
3-5 Than Károly, Budapest 1119, Hungary
szander.norina@kti.hu, jenei.tamas@kti.hu, levai.zsolt@kti.hu, munkacsy.andras@kti.hu

ABSTRACT

Fit for 55 is the current motto of the transport policy and decision-makers. To reach the targeted level in emissions reduction, several considerable challenges should be tackled in the transportation sector. Promoting the usage of renewable energy and alternative fuels in most vehicles as a policy is seemingly not enough yet, partially due to the maturity level of these technologies and the (financial) obstacles of adopting them. Modal shift is another way to support the reduction of GHG emissions by increasing the share of environmentally friendly modes of transport. In our contribution, based on an ongoing research, we are focusing on the field of freight transportation and aiming to explore the incentives of the modal shift in Hungary. Several European and national consortia have been arranged to encourage the use of rail and inland waterways transport. Exploring these methods via the review of literature and research reports is only the first step. It is also necessary to assess their efficiency and opportunities/limitations in their adaptability. We are defining the evaluation criteria and designing a framework for the multiple criteria decision making (MCDM) method. This method is suitable for decision--makers in national and other contexts to create an appropriate regulatory environment that supports modal shift and the transition phase that precedes the targeted entirely zero-emission transportation.

Keywords: Modal shift, freight transport, sustainable freight, multiple criteria decision making

1. INTRODUCTION

In 2017, road transport accounted for 93% of total energy consumption in transport in the EU, and 94% of it was based on fossil fuels [1]. In all scenarios currently being examined, freight transport is growing at a slower pace than passenger transport, but could still triple by 2050 compared to 2010 levels [2]. According to the European Green Deal, net greenhouse gas emissions should reach zero by 2050 [3], in order to make Europe the first climate-neutral continent. At the same time, decoupling (breaking the link between economic growth and environmental pressures) must be achieved so that individuals and regions cannot be the losers of the transformation. As a first step, the "Fit for 55" package, through a series of legislative proposals and legislative changes, aims to help the EU Member States reach their first milestone of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels [4]. Even more urgent is that road transport will fall under the scope of the emissions trading scheme from 2026 onwards, focusing on upstream fuel distributors and making fuel manufacturers responsible for complying with the scheme. Through this, the proposal imposes a payment burden on the polluter, encourages cleaner fuels and recycles the proceeds into clean technologies [5]. It may put pressure on freight companies of applying more energy-efficient solutions in their operations, whether it be alternative fuel trucks or usage of transport modes considered greener than traditional road transport, such as rail and inland waterways (IWW).

In this paper, we explore some options to encourage the modal shift towards rail and waterways, including the hindrance factors that should be overcome to facilitate the modal shift.

2. LITERATURE REVIEW

The literature on the modal shift about road freight transport versus other more environmentally friendly options focuses predominantly on the attributes that play a role in the decisions of the users and their associated importance. The results expected by policymakers of modal shift are quite clear and generally commendable, reducing congestion on the roads and lowering emissions [6,7], or even increasing road safety [8,9]. However, the challenge remains to make rail and water transport more competitive, becoming more attractive in terms of the various criteria of modal choice.

Generally, the qualitative attributes of transport mode decision are well defined – as seen in [10] –, based on the literature review on transport attributes considered by decision-makers, they listed price/cost, transit time, frequency, flexibility and reliability, both in terms of time and losses and breakages as commonly used, however, there was no differentiation on the importance of each attribute.

A study [11] registered the preferences of the freight shippers (the person responsible for managing the transport shipments in the studied corridor in the Pyrenees), with a stated preference survey (orthogonal design), using a discrete choice experiment. They analysed the election criteria on the services offered by the different transport modes (road, rail and maritime transport). Based on the responses, transport cost was ranked third after punctuality first and absence of losses and damages secondly, followed by transit time, flexibility, schedules, track&trace, and frequency. However, based on the elasticities transport cost changes, it was the most influential factor in the shippers' decisions. Some authors investigated the preferences in relation to the specific freight transportation modes or in comparison to each other. The Australian domestic freight transport was studied [12], especially the decision between land-based transport and coastal shipping, with a stated choice experiment. Respondents were managers in charge of shipping goods between Australian cities in the predefined three corridors. In their context, maritime becomes competitive a little over 1200 km, as it is 2-days sailing time and with the mandatory stops and rest periods for truck drivers it is also estimated to be completed in 2 days. Therefore, the competitive advantage of maritime depends solely on port operations speed and price. Aside from transport cost being the most influential factor (based on a Willingness To Pay analysis), the authors concluded that the most significant potential is in reliability for rail and short sea (defined as arrival within 3 hours of schedule and reductions in the probability of long 1-day delays), transit time and integrated (door-to-door) services.

Analysing specifically intermodal transport as an alternative to road transport, using fuzzy-AHP technique [13], it was reported that critical factors –in the order of importance– were logistics costs, service quality, reliability and security. A recent study [32] concluded the promotion policy of modal shift –from road to rail– could be more effective with supporting containerisation compared to tax incentives. Through 50 interviews with logistics managers of cement sector firms, a study concluded [14] that intermodal transport is only competitive against road transport in the cost aspect, everything else (transportation time, time reliability, damages and losses) is seen as worse. In the view of the respondents, the significant shift could be achieved if the policies focussed on the reliability improvements of intermodal transport.

In the meantime, with the exuberant highway developments and road freight sector expansion in terms of the number of companies operating, the competition became quite intense. Therefore, rail and waterway transport need to present their comparative advantage in a field, where even the hauliers are looking to innovate and be creative to keep their position on the market. A study [15, 28] listed price, dynamic capability-deployment, quality, dependability, speed and flexibility being the areas where their customers pose very high expectations and reported that hauliers not only facilitate the movement of goods but contributing to the value creation in supply chains. To do that, „traditional" services are complemented with more and more sophisticated information technology (IT) solutions and data management techniques, all of them offering a higher level of customer satisfaction [30]. In our previous work [16], the views of 300 companies were gathered that frequently ordered road freight transport services: the most important criteria (in order) for these customers were the *delivery of goods intact to destination, reliability, punctuality, price range, speed, flexible, fast adaptation to needs*.

A different direction of research points toward variation in preferences based on commodity type or industrial sectors. Authors [17] noted the explanatory variables, such as transport time, number of transshipments, reliability (on-time delivery), flexibility (handling requests on short notice), probability of damage during transport, tracking and tracing, environmental aspects and transport affect the decisions differently with relation to commodity types (e.g. bulk versus general cargo), shipment sizes, industries, firm sizes, transport equipment used (e.g. containers) and geographic distance. Researchers administered 63 customer responses of China Railway Express (CRE) – which is an emerging mode to transport goods between China and Europe – using the Best Worst Method (and its variants) and, based on their preferences, created *two clusters* and their corresponding preference lists [21]. The respondents' profile in *Cluster 1* (63.5% of the sample) differed in the '*Destination Type*' variable (62.5% warehouse), and '*Customer Type*' with freight forwarders in the majority (72.5%). Cluster 1 cared more about the cost followed by reliability, whereas *Cluster 2* (with more shippers in it) considered reliability more important than costs. Time and safety by Cluster 1 was ranked 3rd and 4th, while Cluster 2 safety was more relevant. Frequency and traceability was placed 5th and 6th in the ranking of Cluster 1, conversely, Cluster 2 put more emphasis on the latter. Regarding flexibility and sustainability, both of the clusters agreed to rank them 7th and 8th, respectively. Researchers [18] described the differences in preferences expressed by the companies operating in different industries. Table 1 demonstrates their results. Similar results were reached in a study [19], with the difference of labelling the commodities as manufacturing, agriculture, perishable and chemical.

Table 1: Ranking of mode election criteria

Criteria ranked by importance	Electronics	Pharmaceutical	Machinery	Construction
1	Quality	Speed	Price	Price
2	Speed	Convenience	Reliability	Scheduling
3	Price	Safety	Punctuality	Punctuality
4	Convenience	Fluency	Speed	Convenience

Source: [18]

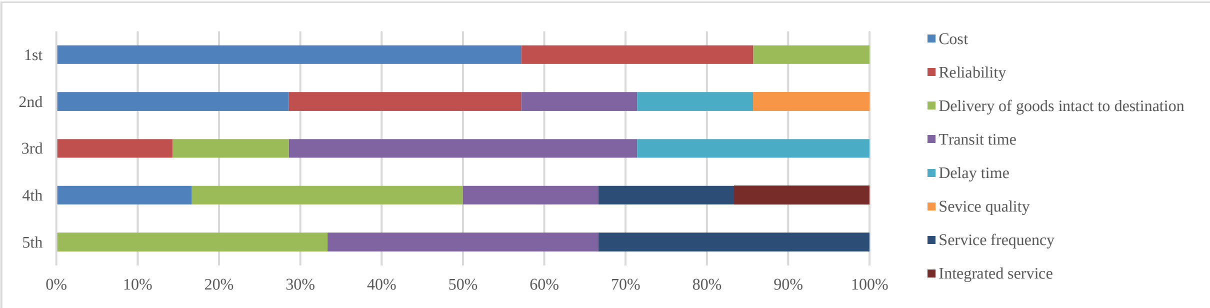


Figure 1: Proportion of freight transport attributes mentioned in the order of importance based on [11, 12, 14, 16, 20, 21] (source: authors' edition)

In Figure 1, we summarised the importance of the most frequently cited attributes from the above studies, based on the number of studies mentioning them in the first, second, third etc. place in the ranking *(please note: unique attributes that were mentioned by only one study or at the 6th or lower ranks were omitted)*.

Altogether, the studies mostly agree on the list of attributes, but very few considered environmental aspects [6, 11, 16, 19, 21], or IT solutions [10, 11, 15, 16, 21]. Although sustainable logistics has not only penetrated the logistics industry but is also starting to be one of its most relevant shaping forces [22] that should be dealt with eventually. The digitalisation process reached a high level in all industrial sectors, and logistics is no exception. It is even said to become the norm soon [23]. With the EU Mobility Packages, the regulatory environment is shifting more and more to the direction of enforcing both of the above aspects, not only to reach the target values of the Green Deal but to enhance international cooperation in transport [31].

3. METHODS

After analysing and organising the relevant papers on modal choice decision attributes, we chose a combined comparative process to analyse the preferences regarding the transport of different product types and the transport mode characteristics. In our view, to plan adequate policies and incentives for the modal shift to less polluting means of freight transport, these two aspects should be considered together. Through these lenses, we hypothesise that it is possible to assess those *aspects in which rail and inland water need to be more competitive*.

We created a four-step process, that assists the evaluation of national freight transport processes compared to the general practices (regardless of geographical location). The method looks for deviations and specific characteristics to derive custom solution proposals.

Step 1: Modal split (in general→national)
Step 2: Sectorial preferences of freight transport (in general→ national context)
Step 3: Sectorial preferences/modal advantages (in general→national context)
Step 4: Sectorial preferences/policies (in general→ national context)

The methodology is presented with further details in Figure 2. Following the execution of the steps, we have delimited two possible directions for policy development, one for machinery transport on railways and the other for agricultural products and water transport. In the frames of this article, we refrain from the details of the whole process. The paper only presents the most important data supporting the conclusions.

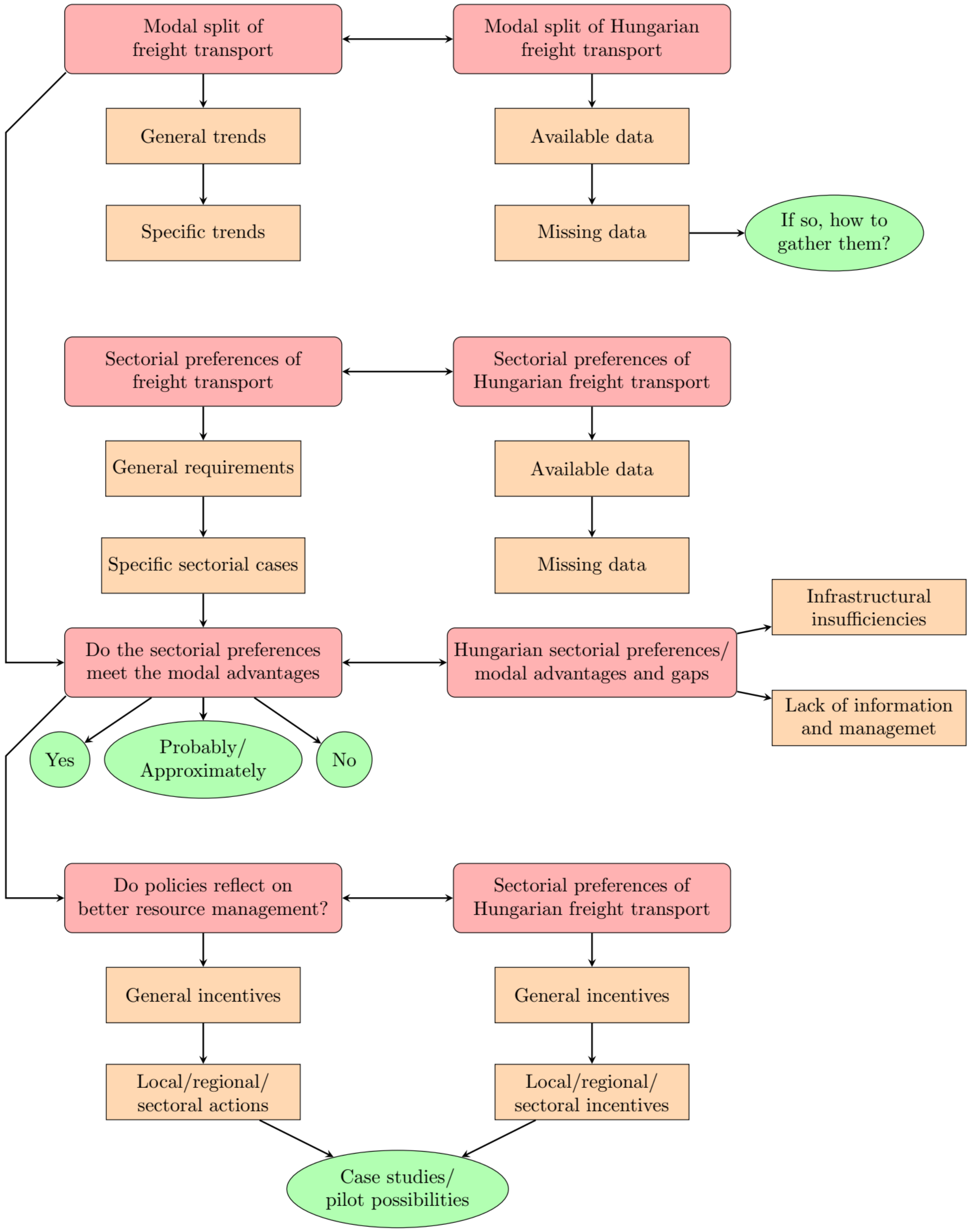


Figure 2: Visual representation of the methodology (authors' edition)

4. RESULTS

For the analysis, we chose to use the 2019 statistical data, as it was the last year that was not influenced by the pandemic situation, which was especially disruptive in the logistics sector. Figure 3 presents the modal split of freight transport both in Europe and Hungary (Step 1).Then, Step 2 explores the sectorial preferences for freight in connection to the modal advantages, and if they are used efficiently. Rail transport is generally more used in the case of motor vehicles and parts, mineral fuels and plastics [6], while on the waterways, mostly coal, sand, stones, gravel, mineral oil products, and iron ore and agricultural products (bulk) are transported [24]. However, the Hungarian transport statistics suggest that on railways, mostly metal ores, agricultural products and coal are transported (machinery is transported in tiny amounts). On the Hungarian waterways, the largest proportion of transport is of agricultural products (mostly cereals).

Compared to the preferences shown by other researchers regarding the above-highlighted commodity types (agricultural and machinery products), there are no such conspicuous differences that would cause such different transport patterns. The only difference *in the case of machinery is the high importance of flexibility* in the view of the Hungarian logistics professionals (in general, it was only listed as an "important" factor), which is most likely the product of just in time production and the very strong connection of the Hungarian automotive industry to Germany. In the agricultural sector, the preference for service frequency was much stronger stated by the Hungarian shippers, whereas, in general, it was viewed as an "important" factor. Table 2 shows the preferences of the above two sectors in general and in Hungary.

In our view the differences in transport practices are caused by the following characteristics (Step 3):

Inland waterway and agriculture:

- the agribulk products are very cost-sensitive (the transport fees must be low and predictable);
- also have a strong seasonality (reliability and flexibility play a very important role in their transport);
- the harvest is a very intense period in terms of workforce and storage capacity (frequency of transport can alleviate it).

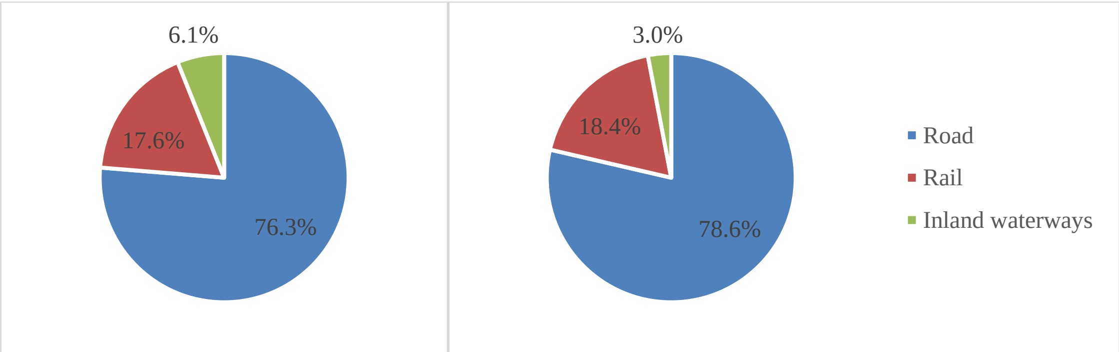


Figure 3: Modal split in Europe 2019 (left) and in Hungary (right) (source: EUROSTAT)

Table 2: Sectorial preferences of freight transport

Attributes/ Product type	Products of agriculture[1]	Products of agriculture in Hungary	Machinery and equipment[2]	Machinery and equipment in Hungary
Cost	Most important	Highly important	Most important	Highly important
Reliability	Very important	Most important	Highly important	Most important
Transit time	Highly important	Very important	very important	Highly important
Flexibility	Important	Important	Important	Highly important
Service frequency	Important	Highly important	Important	Important
CO_2 emission	Least important	Least important	Least important	Important

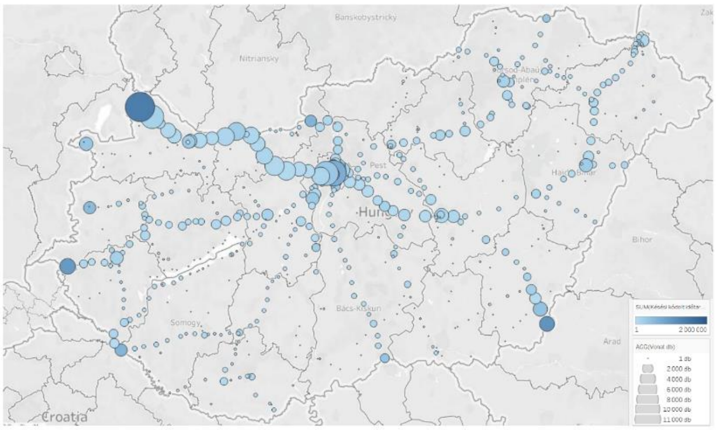
Source: [16, 19, 29]

[1] „Products of agriculture, hunting, and forestry; fish and other fishing products" by the Standard goods classification for transport (NST 2007).
[2] „Machinery and equipment n.e.c.; office machinery and computers; electrical machinery and apparatus n.e.c.; radio, television and communication equipment and apparatus; medical, precision and optical instruments; watches and clocks" by the Standard goods classification for transport (NST 2007).

Railways and machinery:

- in the automotive industry, reliability is the most important factor, because production plans are rigorous, and even a short downtime is a huge (monetary) loss.
- The strong transport and economic connection to Germany is an advantage and a constraint simultaneously. The flow of goods is rather balanced and relatively predictable. That is a perfect alignment with railway transport as it is based on time windows and strict schedules.
- In Hungary, passenger transport has increased significantly in the last few years, and passenger traffic on railways always enjoy priority. Meaning that it is very sensitive to disturbance, and the effects can amplify and cause disruptions in the freight traffic.

Figure 4 shows the delay focal points in the Hungarian rail freight transport, which (not coincidentally) perfectly overlaps with the busiest lines (both passenger and freight).



Source: https://www2.vpe.hu/teljesitmenyosztonzo-rendszer-tor/hipotezis

Figure 4: Delay focal points 2020/2021. Schedule period – Freight transport

5. DISCUSSION

Based on the results, shifting the transport of machinery from road to rail seems a viable option in terms of industrial preferences and modal advantages. The most prominent automotive companies can afford to operate blocktrains as they have an adequate amount of products to fill them and have the most predictable production plans. In Hungary, however, there are only a few companies that can take advantage of blocktrains, and the rest of the industry uses road hauliers. In our view, this is not a drawback inherent to the mode, but a lack of an overarching transport policy for the more efficient usage of resources. If there was willingness from the side of the more powerful companies to share their transport capacities with the smaller companies, a more efficient rail transport practice could be created.

Our proposal (Step 4) is a virtual platform that facilitates coordination and cooperation in rail freight transport. In many cases, the blocktrain system provides door-to-door transport: the rail wagons move between company sites, with goods being loaded and unloaded at the sites. The wagons are transported on a side track to the first station of the open network, then on the open network to the last station, from where they are again transported on a side track to the unloading point. The advantage of this closed system is that trains do not have to be marshalled en route, so the journey time consists almost exclusively of the actual running time (including the rail-technological times). However, because of this closed system, the parameters of the trains do not always reach the maximum transport capacity, so it would be theoretically possible to add additional wagons to the trains. The owners of the blocktrains are likely to conclude exclusive contracts with the rail freight transport companies for the forwarding of their wagons, which is not always cost-effective, as it also ties up spare capacity that could be leased to other companies.

It is worth examining the use of multi-group trains already used in passenger rail transport. The idea is that wagons with different origins and destinations run in the same train on part of the route so that less capacity (path), fewer engines and less traction energy are needed at the level of the overall transport. The possibility of extending the system to rail freight transport depends mainly on the consistency of the individual transport routes and the time needed for additional shunting. In passenger transport, such cooperation is commonplace because timetables are public, but not in freight transport, where the timetable of each freight train is a trade secret. The question arises about how the traffic data of freight trains running (partly) in the same direction can be known. Currently, apart from the owner, only the infrastructure manager has the parameter data of a train so it can allocate the remaining capacity. To do this, the freight train path ordering system has to be modified so that the customer may declare at the time of ordering whether it requires an exclusive train path or is willing to share the train capacity with other companies. The capacities offered in advance (based on the production plan) could be displayed on a platform managed by the infrastructure manager (e.g. governmental body), where the train path with the appropriate parameters for the company wishing to connect can be selected. In this way, the costs for the company operating the blocktrain are reduced, the costs for the connected company cannot be higher than the costs of road transport, and the State can come closer to meeting its climate targets. Further investigation is needed on how to integrate the platform into the One Stop Shop (OSS) system (for further information, the reader is kindly referred to OSS platform, https://www.era.europa.eu/content/one-stop-shop-online_en), so the search for excess capacity is taken over by the rail route manager.

Such a solution would not only be beneficial in terms of progress made towards the "fit for 55" goals, but tackles several problems, which are needing a solution in the near future:

- the revitalisation of the single wagonload transport segment, which has declined during the last decades;
- increasing shortage of truck drivers;
- increasing road congestion [6].

The explored differences from the point of view of agricultural product shippers in relation to inland waterway transport leads us to the conclusion that this transport mode can provide service to a sector that needs most of all a cost-efficient, reliable and frequent transport, but is less sensitive to flexibility and transit time. Considering the geographical characteristics of Hungarian inland waterways, and all the difficulties that are frequently mentioned by subject matter experts – such as the hardly predictable water level –, it is less likely to shift the transport of coal, sand, stones, gravel, mineral oil products and iron ore to waterways in a similar proportion to other, e.g. Western European countries. Nevertheless, professionals and experts unanimously state that the Hungarian and Romanian section of the Danube due to the recent development projects funded by the EU improved the water freight transport options in the recent years [25]. It is important to note that IWW is a highly suitable mode for container transport, as per the estimations of the Wuppertal Institute [26], container throughput will increase in the future, and the already congested road network will most likely have difficulties with the distribution of those higher amounts of cargo in Europe.

Table 3: Container throughput in the major NWE ports (mio)

Year	Hamburg	Bremerhaven	Rotterdam	Antwerp
1990	1,9	1,198	3,666	1,549
2000	4,3	2,737	6,290	4,082
2010	7,9 (2,0 rail in 2012)	4,888	11,148 (0.8 rail)	8,468
2020	10,000-12,500			
2030	16,300-20,500			Max. 22,700
2050			20,000	

Source: [26]

The reason for the expected growth in containerised goods transport are the following:

- globalisation and increasing GDP (globalisation is expected to continue) [6];
- growth of containerisation (for the transport of scrap, waste and timber, using a container the door-to-door concept can be more efficient and faster [27]);
- change in manufacturing and consumption patterns: in Europe, the focus is even more on low-density-high-value (LDHV) goods as the consumption of more luxury goods like electronics and conditioned goods as exotic fruits is increasing [27].

6. CONCLUSIONS

European rail freight is the target area of most transport policies due to its ability to transport huge amounts of commodities to great distances. At the same time, it also has its drawbacks, being a closed network and sensitive to disruptions. Our investigation, though, showed that in the European context, the machinery sector it has untapped potentials, and the modal characteristics match the preferences of the industry. In the automotive industry, time is a very important factor, therefore, blocktrains are the most suitable rail transport segment for time-sensitive commodities. We propose a co-operative resource allocation platform, where further wagons would be added to blocktrains where possible, with minimal modifications in their transit time.

For its implementation, other than the inclination of the blocktrain users, the cooperation of the transport policymakers is essential. A platform that is open for the industry actors, but provided by a governmental body with the appropriate incentives for usage can lead to the shift from road to rail transport in the case of the machinery industry, however, further investigation is necessary. We also need to note that improvements that optimise reliability, transit time and flexibility will be indispensable, to meet the expectations of the automotive industry.

IWW are suitable for the transport of goods that have similar requirements of those transported on railways, but are less sensitive to flexibility and transit time.

Therefore, in the current situation we concluded that in the short run no further product types (in a significant amount) can be shifted from road to IWW in the Hungarian context. In the long run, however, with the earnest development of water regulation and improved road connections to the ports would support the climate goals.

All things considered, the transport of containerised goods is an excellent option for both rail and inland water transport (in the European geographic context), firstly, because of the well-fitting modal characteristics, and secondly, due to the recent environmental trends and policies. The coal and liquid fossil fuels will be gradually phased out. Additionally, the European steel production is declining, which will affect the transported amount of iron ores. The transport need of those above will eventually convert into excess capacity. Both modes will be eager to fill this gap for the sake of environmentally friendly future of freight transport.

Finally, we suggest the investigation (as a future research direction) of more customer-friendly solutions, such as easy and flexible booking, electronic consignment notes, and tracking and tracing in case of both rail and water transport. Having figured out the technical solutions to the above will improve the bottlenecks caused by the lack of human resources in road transport and congestion problems.

REFERENCES

[1] Bioenergy Europe (2020). Bioenergy Statistical Report.

[2] Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2014). Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] European Commission (n.d.). The European Green Deal.https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_hu

[4] European Commission (n.d.). Fit for 55. https://www.consilium.europa.eu/hu/infographics/fit-for-55-how-the-eu-delivers-the-green-transition/

[5] European Commission (2021). 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=CELEX%3A52021DC0550

[6] Eelco den Boer, Jacobine Aalberts, Eric Tol, Maarten ‘t Hoen, Huib van Essen (2018). Modal choice criteria in rail transport. Delft, CE Delft. https://ce.nl/wp-content/uploads/2021/03/CE_Delft_4S52_Modal_choice_criteria_in_rail-transport_Def.pdf

[7] Demir, E., Huang, Y., Scholts, S., & Woensel, van, T. (2015). A selected review on the negative externalities of the freight transportation: modeling and pricing. Transportation Research. Part E: Logistics and Transportation Review, 77, 95-114. https://doi.org/10.1016/j.tre.2015.02.020

[8] A. Baykasoˇglu and K. Subulan (2016). A multi-objective sustainable load planning model for intermodal transportation networks with a real-life application. Transportation Research Part E: Logistics and Transportation Review, vol. 95, pp. 207–247.

[9] Y. Bontekoning, C. Macharis, and J. Trip, (2004). Is a new applied transportation research field emerging?—a review of intermodal rail–truck freight transport literature. Transportation Research Part A: Policy and Practice, vol. 38, no. 1, pp. 1–34.

[10] María Feo-Valero , Leandro García-Menéndez & Rodrigo Garrido-Hidalgo (2011). Valuing Freight Transport Time using Transport Demand Modelling: A Bibliographical Review, Transport Reviews: A Transnational Transdisciplinary Journal, 31:5, 625-651. http://dx.doi.org/10.1080/01441647.2011.564330

[11] Ana Isabel Arencibia, María Feo-Valero, Leandro García-Menéndez, Concepción Román (2015) Modelling mode choice for freight transport using advanced choice experiments. Transportation Research Part A 75 (2015) 252–267.

[12] Mary R . Brooks, Sean M. Puckett , David A. Hensher and Adrian Sammons (2012) Understanding mode choice decisions: A study of ustralian freight shippers. Maritime Economics & Logistics Vol. 14, 3, 274–299. Macmillan Publishers Ltd. 1479-2931 www.palgrave-journals.com/mel/

[13] Pichet Kunadhamraks and Shinya Hanaoka (2008) Evaluating the logistics performance of intermodal transportation in Thailand.

[14] Sevil Kofteci, Murat Ergun and H. Serpil Ay (2010) Modeling freight transportation preferences: Conjoint analysis for Turkish Region. Scientific Research and Essays Vol. 5(15), pp. 2016-2021. ISSN 1992-2248

[15] Borgström, B., Gammelgaard, B., & Bruun, P. (2016). Competitiveness in Road Transport: The Market Liberalized Haulier. Paper presented at 11th European Research Seminar on Logistics and SCM. ERS 2016, Vienna, Austria. https://research.cbs.dk/en/publications/competitiveness-in-road-transport-the-market-liberalized-haulier

[16] N. Szander and G. Albert (2021) The competitive position of Hungarian hauling companies in the road freight transportation sector. International Conference on Business Logistics in Modern Management, Osijek, HR.

[17] Mode Choice Models. In Tavasszy, L. A., & In Jong, G. . (2014). Modelling freight transport. Pages 117-141, Elsevier. ISBN 9780124104006, https://doi.org/10.1016/B978-0-12-410400-6.00006-9.

[18] Punakivi, M. & Hinkka, V., 2006. Selection criteria of transportation mode: A case study in four finnish industry sectors. Transport Reviews, 26(2), pp. 207-219.

[19] Liu, W., 2016. Determining the Importance of Factors for Transport Modes in Freight Transportation, Delft: Technische Universiteit Delft

[20] P. Kunadhamraks and S. Hanaoka (2008). Evaluating the logistics performance of intermodal transportation in Thailand. Asia Pacific Journal of Marketing and Logistics, vol. 20, no. 3, pp. 323–342.

[21] Qinglin Li, Jafar Rezaei, Lori Tavasszy, Bart Wiegmans, Jingwei Guo, Yinying Tang, Qiyuan Peng (2020) Customers' preferences for freight service attributes of China Railway Express. Transportation Research Part A 142 (2020) 225–236.

[22] DHL Trend Research. (2020). The logistics trend radar 5th Edition Delivering Insights Today, Creating Value Tomorrow. DHL Customer Solutions & Innovation. https://www.dhl.com/global-en/home/insights-and-innovation/insights/logistics-trend-radar.html

[23] PwC, Transportation & Logistics CEE. (2019). Five Forces Transforming Transport & Logistics—PwC CEE Transport & Logistics Trend Book 2019. https://www.pwc.com/hu/hu/kiadvanyok/assets/pdf/transport-logistics-trendbook-2019-en.pdf

[24] Central Commission for the Navigation of the Rhine. (2021). Annual Report: Inland Navigation in Europe: Market Observation https://www.ccr-zkr.org/files/documents/om/om21_II_en.pdf

[25] Gergely, Andó (2021) Now the Danube is navigable almost all year round [Most már szinte egész évben jól hajózható a Duna]. Navigátorvilág. https://www.kozlekedesvilag.hu/hir/hajozas/dunai-hajozas/

[26] Wuppertal Institut (2018). Deep Decarbonisation Pathways for Transport and Logistics Related to the Port of Rotterdam, Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie gGmbH.

[27] Notteboom, T. & Rodrigue, J.-P., 2009. The future of containerization: Perspectives from maritime and inland freight distribution. GeoJournal, 74(1), pp. 7-22.

[28] Zanne, M., & Borkowski, P. (2021). Comparative analysis of two seaports in the Baltic-Adriatic corridor. Transactions on Maritime Science, 10(01), 171-177.

[29] Zanne, M., & Twrdy, E. (2021). The Economic Feasibility of Port Air Emissions Reduction Measures: The Case Study of the Port of Koper. Economic and Business Review, 23(3), 1.

[30] Majerova, J. (2022). Cognitive rationality and sustainable decision based on Maslow's theorem: A case study in Slovakia. Cognitive Sustainability, 1(1). https://doi.org/10.55343/cogsust.8

[31] Aminzadegan, S., Shahriari, M., Mehranfar, F., & Abramović, B. (2022). Factors affecting the emission of pollutants in different types of transportation: A literature review. Energy Reports, 8, 2508-2529.

[32] Bulim Choi, Su-il Park, and Kang-Dae Lee (2019) A System Dynamics Model of the Modal Shift from Road to Rail: Containerization and Imposition of Taxes. Journal of Advanced Transportation. https://doi.org/10.1155/2019/7232710

AIRCRAFT SELECTION FOR AERIAL FIREFIGHTING OPERATIONS

Muharem Šabić, D.Sc.
Edvin Šimić, MA
University of Sarajevo, Faculty of Traffic and Communications
Zmaja od Bosne 8, Sarajevo, Bosnia and Herzegovina
muharem.sabic@fsk.unsa.ba, edvin.simic@fsk.unsa.ba

ABSTRACT

To extinguish wildfires in Bosnia and Herzegovina, this study will analyze several fixed-wing firefighting aircraft, which may be selected for the new Aerial Firefighting Brigade. For the analysis of firefighting aircraft, it is necessary to pay attention to the specifics of fire zones in Bosnia and Herzegovina and also determine the state capabilities for aircraft purchase, maintenance and managing all logistics which accompany such operations. The selection of firefighting aircraft is a very complex process, as such aircraft remain in the fleet for a longer period and is more demanding in terms of operation and maintenance compared to scheduled passenger air service. This paper aims to select the most optimal firefighting aircraft based on several selected criteria using the AHP (Analytic Hierarchy Process) method. After conducting an analysis, we identified optimal aircraft for this purpose.

Keywords: Aerial firefighting, Analytic hierarchy process, selection, aircraft, decision making

1. INTRODUCTION AND LITERATURE REVIEW

The characteristic of all Western Balkan countries, including Bosnia and Herzegovina is that wildfires appear in the warm and dry periods of the year, especially between May and September, when the largest number of fires was registered. Bosnia and Herzegovina is one of the most forested countries in Europe in terms of forest cover. They are characterized by exceptional biodiversity of flora and fauna and the prominent presence of endemic plant species. A large number of forest parts are not accessible by road, so it is very important to establish an Aerial Firefighting Brigade. Forest and biodiversity protection is based on effective fire protection. Generally, the fleet planning process is a very complex task and is necessary to consider many different factors, such as aircraft economies, commonality, market evaluation, aircraft performances, finance, etc. Researchers often use Multi-criteria analysis to select aircraft. The goal of the paper [1] was to solve aircraft type(s) selection problems for a known route network and forecasted air travel demand by using the Analytic Hierarchy Process (AHP). The authors in [2] aim to select the best helicopter to be acquired by the Brazilian Navy (BN), applied the AHP-TOPSIS-2N, a hybrid multicriteria method composed of the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and two normalization procedures (2N). Article [3] provides decision support to airline planners on the selection of commercial aircraft by using an Interval Type-2 Fuzzy Analytical Hierarch Process (IT2FAHP) and Interval Type-2 Fuzzy Technique for Order Preference by Similarity to an Ideal Solution (IT2FTOPSIS) hybrid methods. In [4] researchers develop an MCDMA model to evaluate different aircraft alternatives and to support efficient priority decision selection using TOPSIS and PARIS. Authors in [5] used Fuzzy AHP (FAHP) and Efficacy methods for selecting the regional aircraft. The proposed framework considering purchase cost, design, environmental criteria based on future standards gives new insight to the airliner procurement team, while [6] applied multiplicative MCDMA in the military aircraft selection problem. Article [7] aimed to choose the most suitable technology-cargo helicopters widely used in many countries in line with the need of the Turkish Armed Forces, which is crucial for evaluating the opinions of many decision-makers.

2. AIRCRAFT SELECTION USING THE AHP METHOD

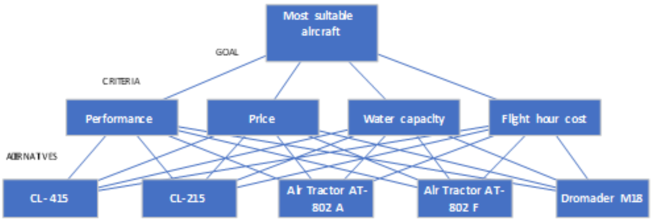
Analytical Hierarchy Process (AHP) is structured as a mathematical technique that facilitates the decision-making process. In the last few years, it has become extremely popular among managers within larger organizations, but it is rapidly expanding to other business sectors. It is currently one of the most widely used methods for multicriteria decision-making. The method is based on criteria and alternatives pairwise comparison. Since the final solution obtained by the AHP method is mainly manifested through user preferences, larger deviations from the ideal solution are possible. This method is considered a method of multi-criteria decision-making because it is based on the initial definition of criteria. Evaluation of criteria enables the recognition and selection of criteria according to their importance. The elements of the AHP method are objective, criteria, sub-criteria, and alternatives, where all the above elements represent input values. For open fire extinguishing purposes in Bosnia and Herzegovina, this Study will analyze fixed-wing firefighting aircraft, which may be selected for use in aircraft for firefighting operations. The process of analyzing firefighting aircraft should be approached in a way that takes into account all the specifics of fire zones in Bosnia and Herzegovina, as well as conditions in society, opportunities for procurement and maintenance of aircraft.

For this case study, using the AHP method next firefighting aircraft will be analyzed: Canadair CL-415, CL-215, Air Tractor AT-802 Fire Boss, Air Tractor AT-802F, and Dromader M-18 B, and their analysis will be performed through the AHP matrix. After the analysis, we will propose and describe the most optimal solution. It is very important to take the appropriate parameters for the selection of the aircraft in the areas where it will operate. Therefore, it is especially important to take into account the performance of the aircraft as it will operate most of the time in a very mountainous area. Surrounding terrain has a great influence on wind direction and intensity, which makes operations even more difficult [8]. Also, places, where water fill can be done, are mostly rivers and lakes that are surrounded by uneven terrain.

By analyzing the different problems in other countries related to aircraft types flying in similar conditions, the set of alternatives and criteria for aircraft is determined. The criteria this paper has taken into consideration are:

- **Cost of a new or used aircraft** - some of the aircraft variants that appear in the analysis is no longer produced but are available on the market, so the price currently prevailing in the markets has been taken into account.
- **Aircraft performance**-takeoff run, climb rate, engine power, airspeed, etc.
- **Water capacity**-the amount of water that can be expended per hour significantly depends on the distance between the fireplace and the water intake site.
- **Operating hourly cost** -includes fuel cost, maintenance, and work of flight crew

The criteria hierarchy structure is shown in the next figure



Source: Authors

Figure 1: Problem decomposition into a hierarchy

The first level of the AHP decision-making system begins with selecting the most important criteria. The decision-making process showed that the most important criteria are the initial price cost as well as the price of the aircraft's operating hour.

The criteria pairwise comparisons matrix is shown in Table 1 with its priority vectors. Vector of priorities is the principal eigenvector of the matrix and the priorities are calculated from pairwise comparisons using the AHP online calculator[1] with the eigenvector method. The highest priority is given to performances and purchase price. The consistency ratio (CR) indicates an acceptable level of inconsistency.

The following table (Table 2,3,4,5) represents a comparison of aircraft according to each of the previously selected criteria. AT-802 has the highest priority with respect to price and performance and while the highest priority with respect to total water capacity and initial attack efficiency has Cl-415 but with much higher operating cost.

Table 1: First level pairwise comparison matrix

	Performance	Price	Water capacity	Flight hour cost	Priority vector
Performance	1	1	4	2	0,358384
Price	1	1	5	1	0,30958
Water capacity	0,25	0,2	1	0,2	0,0663
Flight hour cost	0,5	1	5	1	0,265736
	λmax =4.086.808	CI = 0.031818			

Source: Authors

[1] https://bpmsg.com/ahp/ahp-calc.php

Table 2: Comparison of aircraft according to the criterion performance

Performance	CL-415	CL-215	AT-FB	AT-802F	Dromader M18	Priority vector
CL-415	1	3	0,25	0,5	2	0,173284
CL-215	0,333333	1	0,5	0,5	1	0,108615
AT-802F FIRE BOSS	4	2	1	1	3	0,344746
AT-802F	2	2	1	1	3	0,278978
Dromader M18	0,5	1	0,333333	0,333333	1	0,094377
	λmax =5.271.594	CI = 0,060378				

Table 3: Comparison of aircraft according to the criterion of initial purchase price

Price	CL-415	CL-215	AT-802FB	AT-802F	Dromader M18	Priority vector
CL-415	1	3	4	5	5	0,56267
CL-215	0,333333	1	3	2	2	0,225963
AT-802F FIRE BOSS	0,25	0,333333	1	2	2	0,096255
AT-802F	0,2	0,5	0,5	1	2	0,067531
Dromader M18	0,2	0,25	0,5	0,5	1	0,047581
	λmax =5.032.769	CI =0.007285				

Table 4: Comparison of aircraft according to the criterion of water capacity

Water capacity	CL-415	CL-215	AT-802FB	AT-802F	Dromader M18	Priority vector
CL-415	1	2	5	5	7	0,472763
CL-215	0,5	1	3	3	5	0,272214
AT-802F FIRE BOSS	0,2	0,333333	1	0,5	2	0,086158
AT-802F	0,2	0,333333	2	1	2	0,114381
Dromader M18	0,142857	0,2	0,5	0,5	1	0,054484
	λmax = 5.079.195	CI =0,017606				

Table 5: Comparison of aircraft according to the criterion of hour operating cost

Flight hour cost	CL-415	CL-215	AT-802FB	AT-802F	Dromader M18	Priority vector
CL-415	1	0,5	0,25	0,25	0,333333	0,066404
CL-215	2	1	0,25	0,25	0,333333	0,087265
AT-802F FIRE BOSS	4	4	1	0,5	0,5	0,217381
AT-802F	4	4	2	1	0,5	0,285685
Dromader M18	3	3	2	2	1	0,343266
λmax = 5.149.111		CI =0,033149				

Table 6: Global priority weights

Aircraft Type	Performance(0,358)	Price(0,301)	Water capacity(0,066)	Flight hour cost(0,265)	Final priority vector
CL-415	0,173284	0,05132	0.052409	0,066404	0,099110509
CL-215	0,108615	0,106741	0.094704	0,087265	0,101439084
AT-802F FB	0,344746	0,2026	0.199669	0,217381	0,257276371
AT-802F	0,278978	0,255761	0.276015	0,285685	0,273376326
DM18	0,094377	0,383579	0.377203	0,343266	0,268798286

Source: Authors

Based on the performed AHP analysis, the Air Tractor AT-802 fire-fighting aircraft variant was selected according to the stated criteria. This innovative and modern firefighting aircraft matches the performance of twin-engine engines of tankers and helicopters with half the purchase costs. The aircraft is available in amphibious single and two-seater configurations.

2.1. Air Tractor AT 802 F

Air Tractor 802 F (Figure 2-right) is a two-seater aircraft designed to extinguish low vegetation fires and the charging is done on the ground. This aircraft has less initial impact power than the Canadair aircraft and cannot take water on water surfaces. Due to its great mobility and durability, is used often as a reconnaissance aircraft.

Equipped with classic landing gear, the AT-802 can operate on different runway types (asphalt, grass, gravel) or even public roads. This may be ideal for Bosnia and Herzegovina, which has several major airports but also a large number of sports airfields.

Source: Biggs, H. (2008). Fire Boss report - amphibious single-engine air tanker (Issue 81).

Figure 2: AT-802F FIRE BOSS and AT-802F

The costs of maintaining and training crews are relatively small, so the cost-performance ratio is favorable. Thus, it is justified to intervene in extinguishing smaller fires, and the goal is to extinguish all fires, so he can intervene immediately during the reconnaissance if the fire is noticed. The AT 802 F is charged exclusively at the airport or designated airfields. It is necessary to ensure that persons at the airport or airfield are trained to fill the aircraft with water, as there would be not practical for the pilot alone to fill the aircraft with water. Charging takes one to two minutes. After stopping, the pilot signals to the firefighter to approach the aircraft from the left, where a water valve can be seen in the middle at the bottom. After connection, the water is slowly released to a pressure of not more than 6 bar to avoid any damage to the aircraft. When the tank itself is close to full filling, the pressure is reduced, the valve is closed and the pipe is disassembled. During filling operation communication (visual, radio) between ground staff and pilot is crucial. Aircraft propeller area should be clear when starting from the ground. The AT-802 has a capacity of 3,104 liters of water and could be used in combination with highly effective fire-fighting foam (capacity 68-280 liters) and retardant (a substance used to slow or stop the spread of fire or reduce intensity It is fitted with a specially designed computer-controlled firebombing system known as the Air Tractor FRDS [9], which allow to choose how much water/foam/retarder to throw on a forest fire.

2.2. Air Tractor AT 802 A Fire Boss

The Air Tractor 802 A Fire Boss (Figure 2-left) is an amphibious single-seater with a turbo-propeller engine. This aircraft has less striking power than Canadair aircraft, but can take water from different water surfaces and is used as a naval aircraft in extinguishing initial fires and in extinguishing outer borders of wildfires.

The Air Tractor Fire Boss "A" differs from the "F" aircraft in several design solutions, such as floats, so that it can be supplied with water from water (sea) areas.

This aircraft can use a traditionally paved or unpaved runway, but can also collect water by landing on rivers, lakes, water reservoirs, dams, and the open sea. The plane needs less than 1000 meters and 13 meters per second to take 3,104 liters of water. This version is also suitable for Bosnia and Herzegovina, which has properly dimensioned lakes and water reservoirs as well as access to the Adriatic Sea.

The tank is filled hydrodynamically while the aircraft is on a water section of about 800 m. A special system fed the water into the main tank through the inlets. The 3028 l water tank is located in the central part as in the "F" model. Next to it is a 72 l foam tank, and in the floats, there are also foam tanks with a total capacity of 280 l. The foam is mixed during the capture of water, which, like the discharge of water itself, is controlled by a computer system. The water tank is discharged on fire in two seconds, but the water can also be drained gradually. The AT-802 Fire Boss features an efficient Pratt & Whitney Canada 1,700-horsepower PT6A-67F turboprop engine with fuel consumption of just under 300 liters per hour and a maximum take-off weight (MTOW) of 3.5+ hours between refueling and all this at temperatures up to 49C.

Assuming that Fire Boss aircraft take water from a water source 5 minutes away from a forest fire, it is to be expected that in one hour the Fire Boss will release water to the fire at least five times, i.e. the cycle will be 10 minutes. That makes 15,500 liters per hour per aircraft. In other words, two Fire Boss planes with one refueling between the two operations will release over 250,000 liters of water in 7 hours of operation.

2.3. Advantages of Air Tractor aircraft

Since 1992, the AT-802 air tractor has produced over 900 units and is now the standard for firefighting for most European countries prone to fires.

With global climate change, the fire season in the Balkans is getting longer and it can be clearly said that in the near future, the fire season in BiH will begin in May and end in October. When the summer fire season is over, AT-802 can be used to perform forest protection and rehabilitation activities such as aerial insecticides, afforestation, and fertilization, as well as to control damage in the event of oil spills in the Adriatic Sea.

The AT-802 with an extended range variant of 3-4 hours can be used as a search and rescue aircraft (SAR), especially for the two-seater AT-802, which can accommodate an observer and a camera system.

Air Tractor Europe can approve the delivery of newly produced AT-802 aircraft together with trained pilots, engineers, and mechanics and the necessary start-up package of equipment, spare parts, and consumables within 6-12 months after signing the Contract, with efforts to deliver aircraft and set up the system in the shortest possible time.

For budget planning reference, the cost of newly produced fleets for 2022 is a $ 3.6 million single-seat AT- 802A Fire Boss, while the price of a two-seat AT-802A Fire Boss is $ 3.8 million.

Prices for the single-seater AT-802A equipped with a classic rear-wheel-drive configuration are $ 2.6 million while the price of the two-seater AT-802 with classic landing gear is $ 2.8 million.

All prices are without import duties of Bosnia and Herzegovina if any. Namely, in some countries, the Government exempts end users (such as FUCZ) from the obligation to pay import taxes and VAT on goods of interest for national security, as is the case with AT-802 firefighting aircraft.

The cost of training 6 pilots, 1 engineer, and 4 mechanics in our authorized training organization (ATO), (Part145 and 147 organizations), plus delivery of the initial package of aircraft equipment, spare parts, and consumables cost in the range of about $ 500,000 for every 2 aircraft. Each new aircraft comes with a 1 year / 500-hour warranty.

The training of already experienced pilots lasts 4-6 weeks and will be organized in three phases: Phase 1 - SEP (SEA) introduction of pilots to operate amphibious aircraft; Phase 2 - theoretical and simulation training for flying on an AT-802 aircraft and overcoming firefighting; Phase 3 SET (SEA) - practical flight on a two-seater aircraft AT-802 with an instructor (CRI) and final exam with the examiner (CRE).

After the pilots complete their training, Air Tractor Europe will deploy a pilot (with extensive experience in aircraft and AT-802 operations) to make it easier for BiH pilots to gradually master the aircraft, learn the secrets of operating the aircraft and how to use it effectively and safely in firefighting. The main pilot of AirTractor Europe will support BiH pilots for at least one season, and another period if necessary. The recommended minimum requirements for AT-802 pilots are A valid commercial pilot license issued under EASA / JAR-FCL1, a valid medical certificate, at least 200 flight hours and English language proficiency. Former military pilots or pilots with experience in agriculture and sports are also eligible. Any experience in similar operations is always welcome. The minimum requirements for AT-802 engineers/mechanics are: Appropriate education, valid aircraft maintenance license, and appropriate knowledge of English. Previous experience of a candidate in turboprop aircraft maintenance is not required but should be considered an additional advantage. Operational maintenance and upkeep of the AT-802 is very simple and inexpensive when compared to other firefighting aircraft, especially compared to the capabilities, costs of operations, and the complicated and expensive helicopter maintenance system. The direct operating costs (DOC) of the AT-802 are in the range of $ 900 per flight hour and this calculation includes the cost of fuel, lubricants, basic spare parts, and funds for scheduled services.

The life cycle of the AT-802 is not limited to flight hours. The maintenance system is organized into basic inspections, as follows: visual inspection before the flight (10 minutes – pilot/mechanic), weekly inspection (1 hour), 25-hour inspection (mainly visual inspection), 100-hour inspection (usually done overnight), and an annual inspection (20-28 working days at a cost of approximately $ 60,000 for a new aircraft plus the cost of a possible ferry flight when calculating fuel consumption of 300-325 liters of Jet-A1 fuel per flight hour).

The time of inspection may increase/decrease depending on the experience of engineers and mechanics, the availability of spare parts and consumables, the age of the aircraft, and the complexity of the respective work tasks. Air Tractor Europe training of BiH engineers and mechanics will provide them with the knowledge to independently perform all the above maintenance tasks. Training is organized on an all-inclusive basis, and everything is organized by Air Tractor Europe, except for the provision of staff and transport tickets for staff to and from the location where the training will be held. The PT6 engine is inspected every 1,500 hours while the engine is overhauled every 3,000 hours. Generally, the overhaul of the propeller on the fire-fighting AT-802 is performed every 60 months or 3,000 hours, with logistical costs of approximately EUR 25,000 per propeller. AT-802 planes usually fly less than 300 hours a year and the first planned overhaul of the propeller will be done in 2027, while the first planned overhaul of the engine will be done in 2032.

The cost of consumables varies and fire-fighting foam costs 2.5 EUR / liter. It is mixed at a rate of less than 1% of the amount of water with which it is mixed. In terms of fire retardant, it costs 1.5 EUR / kg, and the share of the mixture is 20%.

Air Tractor Europe is able and willing to deliver all forms of logistical support to the future BiH AT-802 unit, including the supply of spare parts and consumables during normal and emergency conditions, technical leasing of personnel, tools, and equipment, performing various maintenance work, including repairs, structural changes, tests, etc.

Air Tractor Europe is able to organize for a period of 5 or 10 years an integrated logistics support system that would fully cover all the needs of aircraft that the Government of the Federation of Bosnia and Herzegovina (FUCZ) will eventually procure, and if needed procurement of spare parts and performing annual inspection tasks.

According to Air Tractor Europe, the FUCZ should have an aviation unit consisting of two sections: the Flight Section and the Technical Section. The manager should be at the head of the unit, and this can be a professional manager or one of the engineers or pilots.

Both departments of the aviation unit should be subordinated to professionals (with proven managerial skills, ideally with previous experience in this field) each Department should have its manager, the so-called Department Manager.

The Flying Department should be headed by one of the pilots, while the Technical Department should be led by one of the engineers. Recommended basic unit structure will allow a simple chain of command and effectiveness in the functioning of the unit, both within the unit and with its supreme authority.

Taking all available information, Air Tractor Europe's recommendations regarding the minimum number of aircraft to be procured by the Government of the Federation of Bosnia and Herzegovina are three (3) Air Tractor AT-802 Fire Boss aircraft, ie two single-seater and one two-seater aircraft, staff training (optimally 6 pilots, 2 engineers, and 6 mechanics), and a start-up logistics package (spare parts, consumables, special aircraft carriers, and external power supply unit for starting the engine). At least 2 aircraft should be provided to be fully operational at all times and permanently available to carry out firefighting and other activities throughout the year.

The above package will cost the Government of the Federation of Bosnia and Herzegovina Herzegovina no more than $ 12.6 million, excluding import costs to Bosnia and Herzegovina.

3. CONCLUSION AND FUTURE RESEARCH

Accurate selection of aircraft for the fire brigade should be one of the basic prerequisites that will maximize the cost-benefit ratio. One of the biggest costs we identified in the paper is the cost of aircraft procurement as well as the cost of operations and maintenance. On the other hand, for a successful and safe air force operation, well-trained and experienced ground forces and logistics is needed that work together to use all methods and tactical actions to make firefighting fast, efficient and complete. In this paper, we have selected the most important criteria related to the financial capabilities of the government and the area in which the aircraft will operate, given that Bosnia is very dangerous in terms of inconvenient terrain. In the future, these results could be compared to analyses that take into account a number of different criteria and adjust them depending on the needs of decision-makers. Also, a good approach would be to make an analysis by using some other multiple-criteria decision-making methods such as Analytic Network Process (ANP), Complex Proportional Assessment (COPRAS), Expressing Reality (ELECTRE), SAW, or TOPSIS(Technique for Order Preference by Similarity to Ideal Solution).

REFERENCES

[1] S. Dožić, and M. Kalić. (2014). An AHP approach to aircraft selection process. Transportation Research Procedia, 3(July), 165–174.

[2] S. M. do Nascimento Maêda, I. P. de Araújo Costa,

[3] M. A. P. de Castro Junior, L. P. Fávero, A. P. de Araújo Costa, J. V. de Pina Corriça, … M. dos Santos. (2021). Multi-criteria analysis applied to aircraft selection by Brazilian Navy. Production, 31(6), 1–13.

[4] K. Kiracı, and E. Akan. (2020). Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets. Journal of Air Transport Management, 89(September), 101924.

[5] C. Ardil, and C. Ardil. (2020). Aircra Selection Process Using Preference Analysis for Reference Ideal Solution (PARIS) Analysis for Reference Ideal Solution (PARIS). International Journal of Aerospace and Mechanical Engineering, 14(3).

[6] K. Nimel Sworna Ross, Ganesh, Kantharaj, Saravana. (2020). Regional aircraft selection integrating fuzzy analytic hierarchy process (FAHP) and efficacy method Sk. Journal of Production Systems & Manufacturing Science, 1(2008), 1–24.

[7] C. Ardil, and N. A. Academy. (2021). Military Fighter Aircraft Selection Using Multiplicative Multiple Criteria Decision Making Analysis Method. International Journal of Mathematical and Computational Sciences, 13(9).

[8] Üsküdar. (2019). Fuzzy AHP - Center of Gravity Method Helicopter Selection and Application, 170–174.

[9] N. Zijadic, E. Simic, and M. Sabic. (2020). Approach Category Upgrade At Sarajevo International Airport. International Journal for Traffic and Transport Engineering, 10(3), 296–308.

[10] H. Biggs. (2008). Fire Boss report amphibious single engine air tanker.

AN OVERVIEW AND ANALYSIS OF THE VESSEL ELECTRICAL NETWORK RELIABILITY AND STABILITY

Gintvilė Šimkoniene
Stasys Donėla
Lithuanian Maritime Academy
I. Kanto str. 7, 92123, Klaipėda, Lithuania
g.simkoniene@lajm.lt, s.donela@lajm.lt

ABSTRACT

The electrical system's reliability is one of the most relevant and essential issues, not only on the land side but also for the design and operation of the vessels. Reliability is one of the critical factors s that ensures the essential human needs, the vessel's operation, and leading work processes. Marine electrical systems are becoming more and more automated. The construction of electrical networks is also becoming more complex. As a result, management and operation become a real challenge for workers.

This research paper analyzes the vessel's electrical network topologies faults in different voltage levels. The research model shows the weak side of a vessel's electrical network and its influence on the electrical network reliability and lifetime of the network component. It is imperative to assess the most sensitive areas of the network. Only by understanding the problems, it is possible to ensure the electrical network's reliability by eliminating the cause of the problem.

Keywords: Electrical network structure, distribution network, reliability, faults statistics

1. INTRODUCTION

Today, in the vessel's electrical network and for all electrical systems, there is an abundance of requirements for the quality of the supply and distribution of electricity would be high quality and the system itself would be modern and reliable. The electrical energy quality [7] means – reliability, security, availability, stability, economy, durability, and non-pollution. High humidity, high temperature, fierce shake, electromagnetic compatibility, and others, which may result in the decrease of their reliability [1]. Sporadic power outages may reflect all system reliability. It is necessary to know the available set of failures and circumstances to assess this.

Reliability indicators assess failures caused by all phenomena. Their evaluation and use depend on the topology of the electrical network, the available data, and the desired results. The primary and additional indicators used to assess the electricity grid's reliability or equipment. However, the main indexes [11] do not always allow the assessment of the functionality of the network and the response to element failures. Therefore, it is necessary to assess the use of additional indicators that can help estimate the magnitude of the accident.

Reliability is described by the leading indicators used to determine the reliability of the distribution network: failure rate, network efficiency, network deterioration, network service life, average disconnection time, average annual disconnection rate, and recovery time. Each fault must be recorded in the system in a separate record. Otherwise, the assessment of the system's reliability may be inaccurate, with the result that the most sensitive parts of the network may be the most dangerous not only to the system itself but also to the crew members on board.

The main interest in this paper is to analyze the disconnections of the vessel network, the main problems of vessel electric power supply: faults failures and the primary phenomenon. Using the Monte Carlo model [3], to evaluate the reliability of to supply of electric energy.

2. PROBLEM STATEMENT

2.1. Factors affecting electric network reliability

A fault is an event that causes the object to become partially or completely incapable of working. Faults and interruptions in the electrical system, network, equipment is highly related to the reliability of the electrical network. The reliability of an electrical network is defined as the suitability, functionality, uninterrupted performance, and stability of a system or equipment that meets all the specified performance specifications over the manufacturer's specified lifetime. Faults are classified into planned and unplanned faults. Unplanned equipment failures cause the biggest most significant damage to electrical systems. Unplanned interruption [5] is defined as accidental caused by short-term or permanent power outages.

There are many factors that affect the vessels power network (see figures 1 and 2): lightning, salinity, temperature changes, overvoltage's, vibration, temperatures, human failures, etc. Those disconnection phenomena's strongly influence outages, disconnections of the network parts, equipment on the vessel's power system. Most of the outages are unexpected disturbances or other interruptions which can lead to the blackout of the whole distribution network, it can damage line connected equipment.

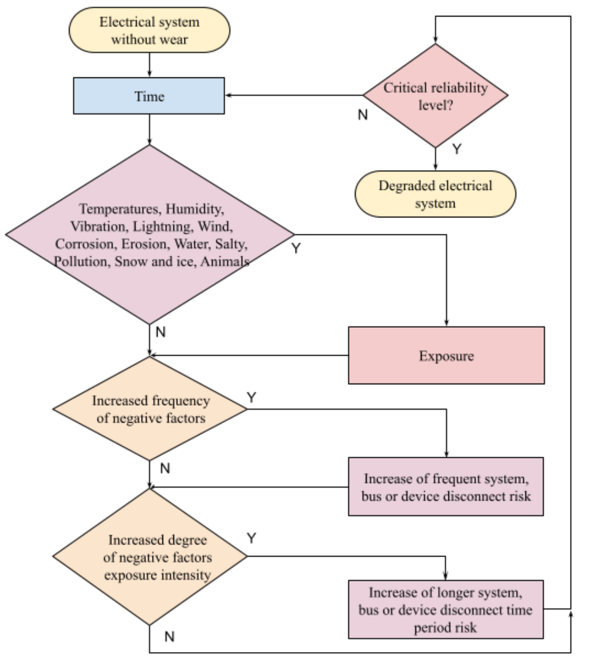


Figure 1: Vessels electric system factors exposure cases

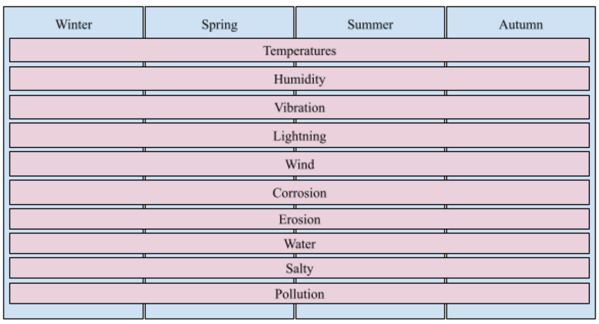


Figure 2: Electric system factors of the vessel

Electrical installations may also be affected at certain times of the year, depending on where the equipment is located (or in the engine room, on deck). The frequency of failures in each part of the system affects the entire system. Still, that area becomes very sensitive to all possible phenomena that can recur, causing major failures or even explosions.

2.2. Fault Frequency

There are various types of equipment in the vessel's electrical systems, of different manufacturers, constructions, etc. The statistics show that the vessel's electric distribution network, Medium Voltage (MV – 440 V and 690 V), is weak. More than 90% of the unexpected outages are due to faults in the vessels' MV networks.

Distribution laws are used to model reliability calculations for various fault flow parameters (working period, normal operation period, period of intense depreciation). The most common probability distribution functions (fault distribution laws) are used to assess and calculate reliability: Normal (Gaussian); Weibull [6]; gamma; exponential; probabilistic; Poisson distribution (rare event distribution); lognormal; Relay. These laws describe a random variable's probability distribution (nature of change).

Normal distribution (Gaussian)

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(t-\mu)^2/\sigma^2} \qquad (1)$$

- Weibull distribution

$$\lambda(t) = \lambda(t)^{a-1} \qquad (2)$$

Describes the change in the intensity of faults, usually depending on the service life. It is possible to model various fault flow cases: working, normal operation, and intensive wear [8].

- Exponential distribution

$$f(t) = \lambda e^{-\lambda t} \qquad (3)$$

The probability of operation based on the intensity of failures is assumed to reduce the reliability of the equipment over time. To describe the operation and recovery time of the equipment to be repaired. For complex repair systems. When $t \geq 0$, it is possible to set the minimum number of objects to be monitored N for an average value t_{avrg} is determined by the relative estimation error δ is determined by the relative estimation error β. This law applies to the description of faults for which the actual law of fault distribution is unknown.

- Poisson distribution

$$P(x) = \frac{e^{-\mu}\mu^{x}}{x!} \qquad (4)$$

To assess the likelihood that it will happen over time *x* faults. Used to rare model events.

- Distribution of the probability distribution function

$$f(t) = \frac{1}{a} e^{-at} \qquad (5)$$

- Gamma distribution

$$R(T_\gamma) = 1 - F(T_\gamma) = 1 - \int_0^{T_\gamma} f(t)dt = \frac{\gamma}{100} \qquad (6)$$

For non-repairable devices. To describe the duration of the repair and the duration of the scheduled shutdown. Here: a – distribution form parameter. μ- the expected number of failures during the period t.

Key indicators to ensure the reliability of repaired equipment:

1. *Probability of restoration $R_t(t)$* – it is a probability at a time interval *(0,t)*, under certain conditions, it is assumed that the device will be restored to the operating position, the time of repair of the element ($T_{pv}(t)$) will be shorter than *(0,r)*: $R(t) =$

$P(Tpv < t)$;

2. The probability of non-correction $Q_t(t)$, over time

(0, t):$Q_t(t) = P(Tpv > t) = 1 - R(t)$.

3. *The intensity of restoration (repair)*$\mu(t)$ – the ratio of the rate of change of the probability of correction to the uncorrected probability at time *t*.

Probability of device recovery to full operability at $\mu =$ $const$:

$$R_t(t) = 1 - e^{-\mu t} \quad (7)$$

Using the exponential method, the reliability of the device and the probability of failure can be assessed. The probability of a failure occurring is that a certain number of failures will occur over a period of time *t, when i=0, 1, 2, …),* calculated using the following formula:

$$Q_i = \frac{\lambda^i t^i}{i!} \cdot e^{-\lambda t} \quad (8)$$

The accuracy of the calculation of the reliability characteristics of the equipment depends on the number of observed objects – on their sample. To strain after an effect electricity grid of good quality, economical and reliable work requires monitoring the network, its operation, lifetime at the same time to evaluation of potential failures to avoid them. Electric energy reliability is concerned with appropriate equipment isolation, rapid response fault removal, and avoiding all of this.

The time component predominates in most of the calculations used, but recovery or other time in the vessel's system is not a major factor in determining system reliability. Highly dependent on the knowledge and ability of the crew working in the electrical engine room to return the system to operation after a failure.

3. MODELING AND DATA ANALYSIS

The reliability of the electricity network is assessed and calculated according to the data collected, when the electricity network element, device, and network was damaged; how many consumers were affected (did not have electricity); how long the fault has been rectified. Reliability is calculated and assessed: the availability of electricity supply and service level to the consumer over a period [9].

From the point of view of reliability, the assessment of the state of the electricity network requires all the information about all and, at the same time, the individual installation due to the calculations and estimates of the performed system modelling. Device modelling is a significant factor that affects the reliability of the entire system. Modelling should be as simple as possible and capable of capturing and assessing all potential risks.

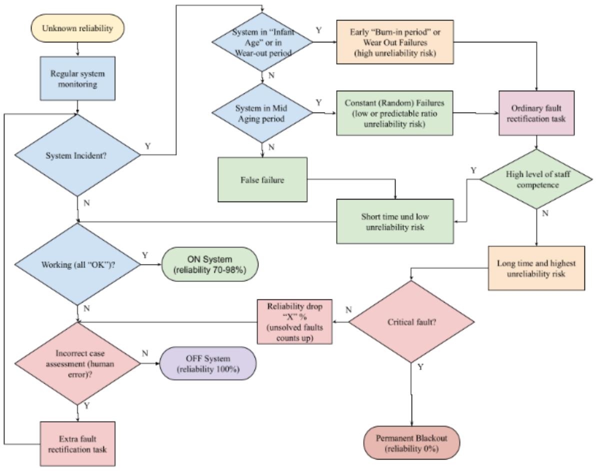


Figure 3: Reliability factors flowchart

The electrical network model developed and used is acceptable and usually operates without interference. The primary purpose of this network model (see Figure 3) is to identify the main factors that have the most significant negative impact on the stability of the electricity network when the electricity network is not in regular operation. The model presents probabilistic phenomena and block parts that describe the operation processes of the electrical system and/or its equipment in the event of failure or non-failure, depending on the service life and ageing phenomena. All the above phenomena and system failures demonstrate the system's ability (percentage) to provide a stable and reliable electricity supply to all vessel's electricity consumers.

It is known that the characteristic of electrical systems is a coincidence. Accidental properties also characterize faults in electrical systems. The Electric 'network's reliability also depends on if network topology 'component's information. All networks can be shown as nodes. The components in the same zone connect to other switches. One of the most popular is the topological matrix, which is based on the Monte Carlo method [2]. Monte Carlo modelling [4] techniques evaluate by simulating the system's actual process and random states. The suitability of the assessment technique and model, the abundance of the indicators to be assessed, the suitability and quality of their input to assess the system in question are the leading and most essential aspects in selecting the most appropriate solutions and the number of models. The Monte Carlo method uses congruent generation to generate random numbers, which creates a continuous distribution of random numbers (0,1). The state modelling method is most used for modelling, and the states of the systems are determined from the states of the system elements obtained during the numerical experiment. If the states of the system elements - from 0 to 1 - are evenly distributed in random quantities. Then a specific value of the random variable X is acquired - random realization. The function of the random variable can then be expressed:

$$X: \Omega \rightarrow S \qquad (9)$$

$$X(\omega) = x \epsilon S \qquad (10)$$

Where: Ω – sample space; S – the state space of the random variable x; $X(\omega)$ – realization; ω – sample element. State spaces $S =$

$\{Free,\ busy,\ broken,\ inactive\}$ is expressed in vectors

$S = (S_1, S_2, \dots S_i, \dots, S_n)$. Where: S_i – the state of the i-th system element.

The state of the system element is described:

$$S_i = \begin{cases} 0\ (Working) \\ 1\ (Not\ working) \end{cases} \qquad (11)$$

For smaller values of evenly distributed size, beyond the element's readiness factor, the element is in a failure state:

$$S_S = \begin{cases} 0, (S_1 = 0) \cup (S_2 = 0) \\ 1, (S_2 = 1) \cap (S_2 = 1) \end{cases} \qquad (12)$$

An evaluation of the state of the system is calculated:

$$R = \frac{n_0}{n} \qquad (13)$$

$$n_0 + n_1 = n \qquad (14)$$

Where: n_0 – number of experiments when the system n_0 times is working; n_1 – a system not working.

The highest efficiency of this method is very low when the probability of failure is low. In theory, the expected simulation values are equal to the average of the modelling results:

$$r = \frac{1}{N} \sum_{i=1}^{N} r_i \qquad (15)$$

Where: r_i- results of the i-th simulation; R – expected values; N – number of simulations.

Many model variations are used to evaluate the reliability of the electrical network. The essential function of the method is to evaluate the current and future states of failures and the entire network [10]. To assess the reliability of the electricity network, it is necessary to have accurate data on the equipment of the electricity system, which usually disrupts the supply of electricity to consumers and is the leading cause of electricity outages and network failures. Assessing the reliability of an electrical system with many reliable elements using the Monte Carlo method requires many system simulations.

For comparative reliability state analysis of the situation, interruption and reliability indicators should be collected, sorted, and systematized in the same or similar principles. These days, there are no accumulated historical data interruptions, and interruptions are unreliable and representative of the data.

4. SIMULATION RESULTS

The vessel's electrical network is of the radial type, which consists of many individual elements. Their efficiency affects special-purpose users (electric motors, ventilation system, etc.) and general-purpose users. Based on statistics obtained by different companies and different types of vessels, it is estimated that 80% and more disconnections in the electricity network occur from 690V, 440V, 220V networks. Above 1000 V in the network, faults occur in about 5%. Based on the data, a time frame of one year, all faults are rated at 100%, and the percentage size is distributed according to the event. The data of failures are converted to percentages and shown in table 1.

Table 1: Faults distribution – based on vessel company real data case

Fault name	All failures
Environmental factors (nature conditions etc.)	12%
The same parameters having devices but created of different companies (internal characteristics are different).	27%
The human factors	33%
The period of installation and capacity of load, lifetime	8%
Load	17%
Force majeure	3%
Total:	100%

Each termination event must be recorded in the system as a separate item, a reference to those primitive (scheduled and unplanned interruptions): in place of the termination system; date and time; termination of the cause and its group (unplanned interference only); termination of the nature of the termination; the number of users affected by the termination; the number of broken connections between transmission and distribution systems; environmental impact. However, reliability is highly dependent on both the employee and the company and data entry, tracking and proper maintenance of electrical equipment. Today, it is known that companies often do not keep such data, which causes the system to be permanently disconnected and faulty. Therefore, to understand the system's reliability with or without the operation of specific equipment, this scientific paper presents a calculation methodology that shows the relation vessel between the operation of electrical equipment. And such a developed methodology also shows the reliability of the system.

In this work, using the vessel's principal scheme (figure 4), an electrical network was created, in which all the main equipment is named as nodes (figure 5).

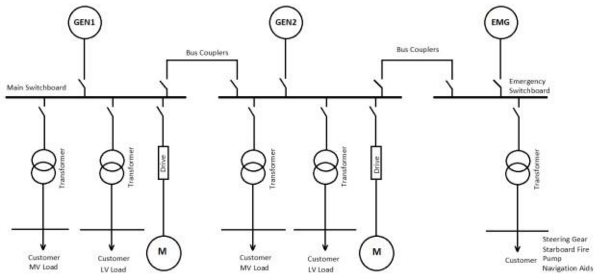


Figure 4: Electrical network of vessel

Using the vessel's principal diagram, constructions were taken for research to assess the importance of disconnecting certain nodes in the electricity network for the whole electricity system.

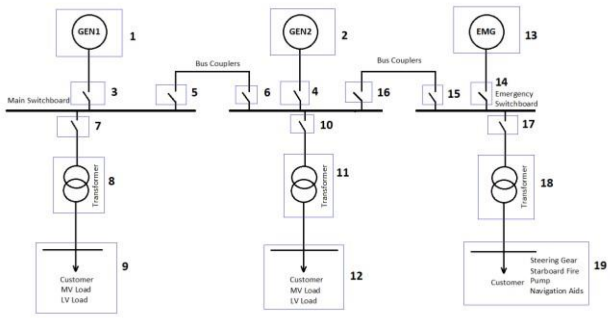


Figure 5: Nodes of electrical network

Using the above calculation methodology, a matrix calculation methodology has been developed, in which the main devices are marked in yellow, the operation of which depends on the reliability of the system or not. Matrices with numbers: 1 with yellow – this element is the main device, and it is working; 1 – element is working when 1 numbering element (yellow colour) is working; 0 – element is not working.

Table 2: Electrical Network connection method

Nodes of Network		Connection method when 1st and 2nd GEN working											
		1	2	3	4	5	6	7	8	9	10	11	12
Connection method	1	1	1	1	1	0	0	1	1	1	1	1	1
	2	1	1	1	1	0	0	1	1	1	1	1	1
	3	1	1	1	1	0	0	1	1	1	1	1	1
	4	1	1	1	1	0	0	1	1	1	1	1	1
	5	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0
	7	1	1	1	1	0	0	1	1	1	1	1	1
	8	1	1	1	1	0	0	1	1	1	1	1	1
	9	1	1	1	1	0	0	1	1	1	1	1	1
	10	1	1	1	1	0	0	1	1	1	1	1	1
	11	1	1	1	1	0	0	1	1	1	1	1	1
	12	1	1	1	1	0	0	1	1	1	1	1	1

Electrical network normally uses 2 or more generators. The normal operation showing in figure 5. Emergency generator using when both generators are not working. The analysis of the states of the electrical network and the calculations of the reliability assessment are presented below.

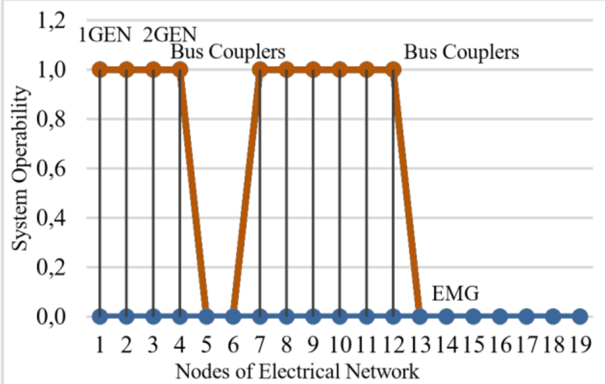


Figure 6: Electrical Network when working 1GEN and 2GEN

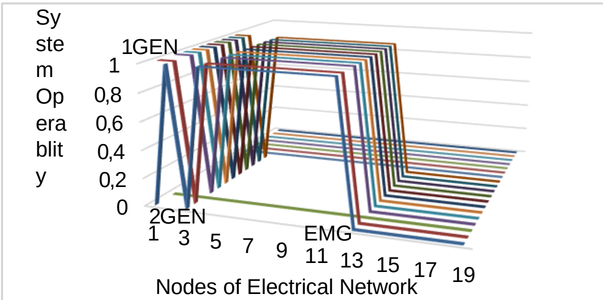


Figure 7: Electrical Network when working 2nd GEN

This scheme shows that the Electrical network can work operationally, but the 2nd GEN must operate at a higher capacity than normal. The diagram shows that the inactivity of 1 GEN only affects element 3. Of course, it is necessary to assess more than just the resilience of electrical equipment to withstand system failures.

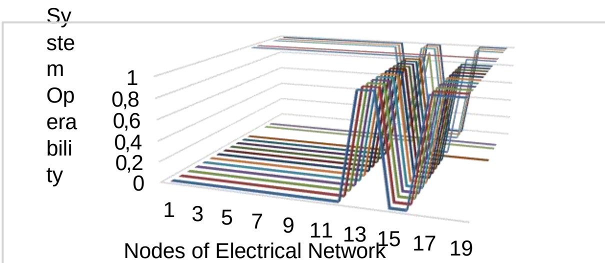


Figure 8: Electrical Network when working EMG, but not working 1GEN and 2 GEN

Figure 8 shows that Electrical Network when working EMG, but not working 1GEN and 2GEN.

Table 3: Electrical network reliability of nodes

Nodes	Electrical network reliability of nodes		
	When working 1GEN and 2GEN	When working 2GEN, but not working 1GEN	When working EMG, but not working 1GEN, 2GEN
1	0.912281	0.614035	0.467836
2	0.912281	0.678363	0.467836
3	0.912281	0.54386	0.467836
4	0.912281	0.736842	0.467836
5	0.912281	0.877193	0.467836
6	0.912281	0.877193	0.467836
7	0.912281	0.467836	0.467836
8	0.912281	0.467836	0.467836
9	0.912281	0.467836	0.467836
10	0.912281	0.877193	0.467836
11	0.912281	0.877193	0.467836
12	0.912281	0.877193	0.204678
13	0	0	0.994152
14	0	0	1
15	0	0	0.105263
16	0	0	0
17	0	0	0.982456
18	0	0	0.982456
19	0	0	0.982456
Reliability evaluation	0.974359	0.934385	0.153894

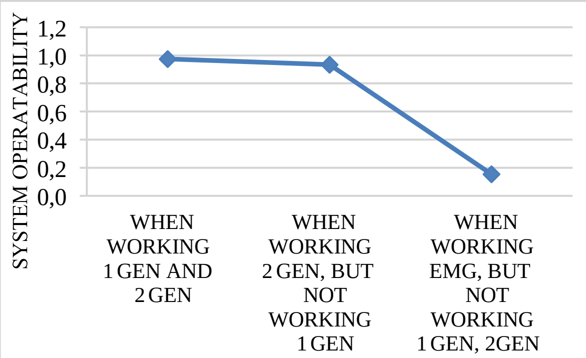


Figure 9: The evaluation of reliability

Results show that reliability strongly depends on how the electric network is constructed. Reliability analysis makes it possible to assess the extent to which a system meets performance criteria, quantify potential failures, and help make a technically or economically viable decision. The obtained results of the reliability analysis allow providing the weakest and most vulnerable zones and locations of the equipment and, at the same time, determine the frequency of failures and the average duration of failures of specific equipment or group of devices. The collection of statistical data may be necessary for employees (ETO or other employees): the most common causes of failures are given; areas with insufficient load distribution; the weakest points of protection measures; which contributes to power outages and failures.

5. CONCLUSION

Most power outages on the vessel can be avoided. Reliability and quality of service can only be achieved by investing in worn-out electrical equipment. To ensure a reliable and secure electricity supply, and electricity efficiency, it is necessary to choose an appropriate program, method or algorithm for the analysis and research of the reliability of the electrical network. Modelling an electrical system or installation as an entire is a very important factor influencing the reliability of the whole system. The simulation should be as simple as possible but at the same time allow for the accurate capture and assessment of all potential risks. Understanding the model and its level of constraints can the results be interpreted correctly without fetishizing them. Reliability indices and their usefulness can show the vessel's electrical network's weaknesses. Reliability indicators shall be selected in such a way as to allow a proper assessment of the state of the network and to ensure that data are collected, aggregated and processed continuously and consistently. Most vessel electrical systems' data and final reliability figures are only approximate values. More sophisticated modelling and a broader study of the reliability of the electricity system will be developed in the future for a more detailed analysis of the electricity grid.

REFERENCES

[1] Hu, B., & Qin, S. (2011). An effective fault detection approach for electrical equipment of propulsion system in a type of vessel based on subjective Bayesian principle. *The Proceedings of 2011 9th International Conference on Reliability, Maintainability and Safety* (pp. 970-974). Guiyang, China: IEEE.

[2] Huijia, L., Hanmei, H., & H, J. (2008). A method of reliability evaluation for complex medium-voltage distribution system based on simplified network model and network-equivalent. *2008 China International Conference on Electricity Distribution* (pp. 1-6). Guangzhou: IEEE.

[3] Yuan, Y., Jingyan, Y., Jianhua, Z., & Xiangning, X. (2005). Reliability analysis of power distribution systems based on hybrid method into account of voltage sags. *2005 International Power Engineering Conference* (pp. 945-949). Singapore: IEEE.

[4] Jamshid, S., & Abrar, M. (2020). Evaluation of Load Point and Customer Point Indices of a Distribution Generation System. *2020 International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)* (pp. 1-5). Moscow, Russia: IEEE.

[5] Kornatka, M. (2017). Distribution of SAIDI and SAIFI indices and the saturation of the MV network with remotely controlled switches. *2017 18th International Scientific Conference on Electric Power Engineering (EPE)* (pp. 1-4). Kouty nad Desnou, Czech Republic: IEEE.

[6] Li, C., Teng, Y., An, L., & Dan, Q. (2019). Imprecise reliability of lifetime data based on three-parameter generalized inverse Weibull distribution. *2019 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia)* (pp. 1667-1670). Chengdu, China: IEEE.

[7] Marnay, C. (2007). Microgrids and Heterogeneous Security, Quality, Reliability, and Availability. *2007 Power Conversion Conference - Nagoya* (pp. 629634). Nagoya, Japan: IEEE.

[8] Sindaravičius, D., & Kavolynas, A. (2019). Study on the reliability of electricity supply of one selected distribution of 10 kv distribution electric networks. *Agroengineering and Energetics, 24*, 132-137.

[9] Sucita, T., Mulyadi, Y., & Tomotius, C. (2018). Reliability Evaluation of Power Distribution System with Reliability Index Assessment (RIA). *International Symposium on Materials and Electrical Engineering (ISMEE) 2017.* Bandung, Indonesia: IOP Publishing.

[10] Xiaochen, Z., Zhaohong, B., & Gengfeng, L. (2011). Reliability Assessment of Distribution Networks with Distributed Generations using Monte Carlo Method. *The Proceedings of International Conference on Smart Grid and Clean Energy Technologies (ICSGCE 2011)* (pp. 278-286). Chengdu, China: Energy Procedia.

[11] Zuliani, P., Lomi, A., & Nurcahyo, E. (2019). Reliability Analysis of Distribution Network Based on Reliabilit Index Assessment Method, A Case Study. *International Journal of Smart Grid and Sustainable Energy Technologies, 1*(1), 24-27.

THE ANALYSIS OF FERRY PASSENGER TRANSPORTATION DEMANDS

Maja Škurić
University of Montenegro, Faculty of Maritime Studies Kotor
Put I Bokeljske brigade 44, 85330 Kotor, Montenegro
mskuric@ucg.ac.me

Tatjana Davidović
Mathematical Institute of the Serbian Academy of Sciences and Arts
Kneza Mihaila 36/III, 11000 Belgrade, Serbia
tanjad@mi.sanu.ac.rs

Vladislav Maraš
Aleksandar Radonjić
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, 11000 Belgrade, Serbia
v.maras@sf.bg.ac.rs, a.radonjic@sf.bg.ac.rs

ABSTRACT

We analyze the variations in the ferry passenger transportation demands for an observed period in the case of the Boka Kotorska Bay (located in Montenegro). The region is well known for this kind of transport offered to satisfy touristic purposes during the summer season. Besides different approaches to increase the operating efficiency of ferry operators, we concentrate on the definition of transport planning and optimization of fleet size engaged for passengers during the considered time-frame. Although reviewing various schemes of ferry transportation, we introduce the mixed-integer linear programming (MILP) model to examine several numerical examples of private ferry operators and the application of a commercial CPLEX solver for solving the ferry fleet optimization problem. After the analysis, we propose the scenario for establishing partnership between small operators that forms a joint ferry operator with an aim to increase the profit of all partners. The research proposes future directions in sustainable ferry service development, including the uncertainty in the transportation demands caused by unexpected circumstances such as the COVID-19 pandemic.

Keywords: size of ferry fleet, route planning, variation in demands, tourists visits

1. INTRODUCTION AND BACKGROUND

When modeling transportation problems and defining the optimal size of the fleet (resources), there is a need to provide adequate transport capacity to meet required transportation demands. Discrepancies between transport capacities and unpredictable transport demands occur when the demands are not known in advance or are exposed to some uncertain aspects due to variations caused by seasonality, the level of transport prices, technical solutions, system failures, etc. For this reason, the stochasticity of particular transport processes has been largely discussed in the scientific literature, while several studies have been reported at the passenger ferry level [1, 9, 14, 15].

In some cases, due to the uncertainty of the transport demands, there are situations when the capacity of the passenger ferry fleet is not sufficient to meet the transport demands in the considered time interval. Inadequate response in terms of providing transport capacity toward transport demands motivates the ferry operator to develop an appropriate strategy for planning capacity and structure of the fleet. Accordingly, the options for purchasing or chartering-in capacity need to be considered. These are decisions about buying or hiring an additional fleet that come to the fore when there is the increase in some parameters such as the demands for transportation, the traffic volume, etc. As mentioned earlier, the decisions are strategic, because they indicate the possibility of defining the structure of the ferry fleet in a long time and reflect the aspect of the uncertainty of parameters [14].

The ship fleet sizing problem has been studied extensively in the previous period. The general strategic problems in shipping facing with the assignment level of the new fleet for the transport tasks have been investigated in [2]. The concept of user equilibrium was formulated as a linear programming model. The ship fleet employment process using mixed-integer linear programming was defined in [10]. The author investigated the transportation demands containing uncertainty described by probability distributions. Moreover, a numerical analysis to solve the container ship employment with the anticipated demand was used. The author tested the stochastic dependence in several numerical examples as shown in [11].

On the other hand, observing routing problems, the methodology for optimal routing in liner shipping service considering the ship fleet sizing was proposed in [3]. A ferry company strategy based on the traffic flow schedule providing the overall service economic benefit was introduced in [16]. A detailed review of the literature regarding the sizing of the fleet of ships used in maritime transport was reported in [12]. In the analysis, they included different optimization problems related to the fleet capacity and required transport demands.

Referring to the ferry fleet optimization, a ferry network design problem integrating three different but complementary aspects: the optimal fleet size, routing, and scheduling for both direct and multi-stop services was presented in [7]. The authors developed a heuristic algorithm that exploits the polynomial-time performance of shortest path algorithms in the case of the Port of Hong Kong. A formulation for ferry service network design with stochastic demands via the notion of service reliability was developed in [9]. The results of the used method led to substantial cost savings compared to deterministic methods under demand uncertainty. The method for the ferry service network design in the Port of Hong Kong, assuming that the demand is a stochastic component was proposed in [1]. The authors formulated the problem as a two-phase stochastic program. A Service Reliability-based gradient solution approach was used.

For providing the economic benefits resulting in making strategic decisions for ferry services sustainability, the feedback on how users value the quality attributes of ferry routes serving long distance traffic was shown in [8]. These contributions are reached through the users' preference survey in the case of two strategic ferry routes. On the other hand, a modified exponential demand function to calculate user and social surplus for 97 ferry services in Norway was used in [6]. The authors concluded that a positive social surplus can be achieved even though the operators need subsides. The transportation systems that include the waiting time for vehicles and passengers to board a ferry were observed. In the paper, the psychological implications of the position in the queue and average waiting time that impact the information between passengers are given in [4].

A recent study on the passenger ferry fleet sizing was reported by Škurić et al. [13]. The authors investigated the optimal allocation of the ferry fleet along routes in the Boka Kotorska Bay (Montenegro) by defining a mixed-integer linear programming (MILP) model for the maximization of ferry operator's profit. The problem was solved with an exact CPLEX solver, while the authors used three MILP-based heuristics in the case of hard numerical examples. In the model formulation, they included the transportation demands on routes for local inhabitants and tourists and the option for using ferries of existing, purchased, and chartered-in fleets. Similar to [13], in this paper, we deal with the touristic routes only and propose the new scenario for establishing a joint ferry operator (a result of the small operators partnership) in the engaged fleet structure to maximize the profit in a two-year time.

The paper is structured as follows. Section 2 explains the details of demands and considered routes in the case of tourists' transportation in the Boka Kotorska Bay (Montenegro) in the years 2018 and 2019. The model formulation to maximize the profit of ferry operators is given in Section 3. Section 4 contains the results and a new scenario for defining the ferry fleet structure to provide increase in the profit for a joint company (operator) consisted of small operator partnerships. Final recommendations are provided in Section 5.

2. PASSENGER FERRY DEMANDS ANALYSIS

Here we analyze the average monthly tourists' demands in 2018 and 2019 achieved at four routes in the Boka Kotorska Bay.

The considered routes are [14]:

- Route 1: Perast – Our Lady of the Rocks – Perast.
- Route 2: Kotor – Herceg Novi – Our Lady of the Rocks – Perast – Kotor.
- Route 3: Kotor – Our Lady of the Rocks – Perast – Kotor.
- Route 4: Cruise cycling along the Bay.

Each route was operated by different small private operators. The observed period for each route is from March to November, even though there were no demands for transportation of tourists at Routes 2 and 4 in March and November. As there was no traffic in January, February, and December, we did not consider the whole year period. The average monthly tourist demands for Route 1 are presented in Figure 1. As it can be noticed, a bigger average throughput was achieved in 2019 (67 tourists compared to 59 in 2018 [14]), especially in May, June, and July. One ferry of 55 passenger capacity (f1) realized the whole transport. Sometimes in the summer season, the ferry made two or three calls to the ports [14].

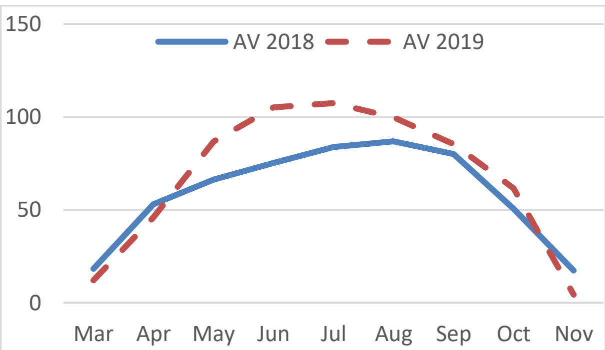


Figure 1: Average monthly passenger demands for Route 1 [14]

Looking at Route 2, the average monthly tourists' demands are shown in Figure 2. The transportation was realized by one ferry of 55 passenger capacity (f2). This route generally characterizes only one ferry's departure from and arrival to Kotor daily. The average passenger throughput in 2018 was 19, while in 2019 was 23 [14].

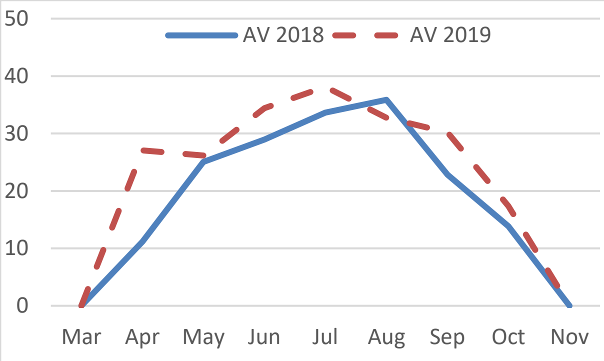


Figure 2: Average monthly passenger demands for Route 2 [14]

The average monthly passenger demands for Route 3 are given in Figure 3. This short route was served with the ferry of 55 passenger capacity operating once or twice a day (f3). Obviously, from the statistics, there was a similar average passenger throughput in 2018 (of 24 tourists per day) and 2019 (of 26 tourists per day) [14].

A ferry of 400 passenger capacity (f4) was engaged for tourists' transportation along Route 4 (see Figure 4). This route is familiar for the whole bay cruise cycling from April to October. The average daily transport demand with two stops in 2018 was 90 tourists, while the statistics increased in 2019 and amounted to 111. There was a higher increase from June to September where the ferry operated twice or three times in a day than occasionally but without total capacity used [14].

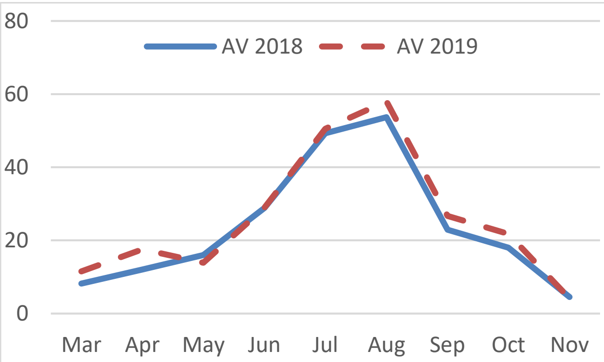


Figure 3: Average monthly passenger demands for Route 3 [14]

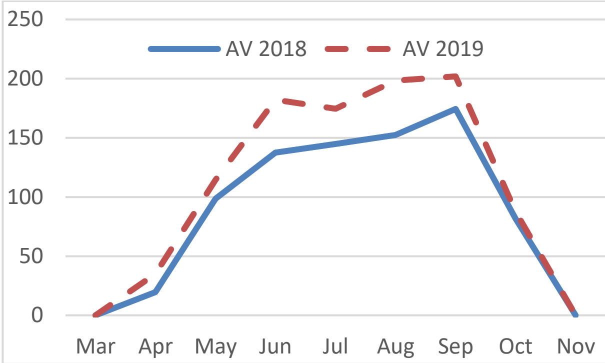


Figure 4: Average monthly passenger demands for Route 4 [14]

The data presented in the section are used for testing the mathematical model developed for maximization of the operator's profit in the case of changing the fleet structure.

3. MODEL DECRIPTION

MILP problems involve maximizing or minimizing a linear function with the existence of the appropriate constraints that apply to some of the variables in the model. The MILP problem can generally be presented as [5]:

$$\min \sum_{j=1}^{n} c_j x_j \tag{1}$$

s.t.

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad \forall i \in M = \{1,2,\dots,m\}$$

$$x_j \in \{0,1\}, \quad \forall j \in \mathcal{B}$$

$$x_j \geq 0, \quad \forall j \in \mathcal{G}$$

$$x_j \geq 0, \quad \forall j \in \mathcal{C}$$

where the set $\boldsymbol{N} = \{\boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{n}\}$ is divided into three subsets $\boldsymbol{\mathcal{B}}$, $\boldsymbol{\mathcal{G}}$, and $\boldsymbol{\mathcal{C}}$ corresponding to binary, integer and continuous variables, respectively.

In our case, the objective, eq. (2), is to maximize the profit (P) of the ferry operator. The profit is calculated as the difference between the revenues and the costs. The components of the objective function are grouped as follows:

$$P = EFT + PF + CF - ICP - ICC - PCL - PCT \tag{2}$$

with

EFT – the income and cost difference of tourists transportation with the ferries of existing fleet in $;

PF – the income and cost difference of tourists transportation with the ferries of purchased fleet in $;

CF – the income and cost difference of tourists transportation with the ferries of chartered-in fleet in $;

ICP – costs on idle time of purchased ferry in $;

ICC – costs on idle time of chartered-in ferry in $;

PCL – costs on unused seats on board purchased ferry in $;

PCT – costs on unused seats on board chartered-in ferry in $.

Tourists can be transported by all types of ferries in the fleet (existing, purchased and hired). For details on model formulation, parameters, and constraints, see [13, 14]. The generated numerical examples are simplified here since the touristic routes are only considered in the analysis. However, the analysis provided in the next Section contains the comparison of two outputs: the generated profit and the number of unused seats on board ferries. The CPLEX MIP exact solver version 12.6 was used to solve the numerical examples.

4. RESULTS

From the statistics presented in Section 2, we identify that the level of utilization of the ferries' transport capacity is:

- 2018: 56% (f1), 38% (f2), 30% (f3), and 25% (f4).
- 2019: 56% (f1), 50% (f2), 35% (f3) and 30% (f4).

The total profit of the operators for observed 9-month-period of both 2018 and 2019, respectively, is presented in Tables 1 and 2. The real profit of four ferries is given in the second column of Tables 1 and 2.

Based on the low capacity utilization of each ferry and policy to service one route only, we analyze the possibility for available ferries to be assigned to all four routes. The result of the modeled profit, calculated by eq. (2) is presented in the third column of Tables 1 and 2. Unlike real examples (of assigned ferry f1 to Route 1, ferry f2 to Route 2, ferry f3 to Route 3, and ferry f4 to Route 4), in Tables 1 and 2 the allocation of available ferries in the fourth column are given.

Table 1: Real and profit generated by CPLEX solver for transportation demands in 2018 [14]

	Real profit ($)	Modeled profit ($)	Engaged ferry (CPLEX)
March	1652	2448.5	f1, f2, f3
April	22953	24332	f1, f2, f3
May	70552	102428	f1, f2, f3, f4
June	88796	120954	f1, f2, f3, f4
July	102229	119136	f1, f2, f3, f4
August	107688	158107	f1, f2, f3, f4
September	102562	114028	f1, f2, f3, f4
October	54839	70746	f1, f2, f3
November	3693	3716.5	f1, f2, f3
Total	554964	715896	f1, f2, f3, f4

Table 2: Real and profit generated by CPLEX solver for transportation demands in 2019 [14]

	Real profit ($)	Modeled profit ($)	Engaged ferry (CPLEX)
March	7139	10954	f1, f2, f3
April	35006	45859	f1, f2, f3, f4
May	80868	94537	f1, f2, f3, f4
June	115047	150253	f1, f2, f3, f4
July	122971	148619	f1, f2, f3, f4
August	131619	175911	f1, f2, f3, f4
September	119108	150787	f1, f2, f3, f4
October	59662	78113	f1, f2, f3, f4
November	1652	5515	f1
Total	673072	860548	f1, f2, f3, f4

The total profit both in 2018 and 2019 would increase from 1228036 $ to 1576444 $. In 2018, ferry f4 realized a smaller number of voyages with respect to other ferries, while the majority of transport demands for Route 4 was realized by ferries f1, f2, and f3. However, according to the results provided by CPLEX solver, ferry f4 was engaged only from May to September. A similar situation happened in 2019, and results indicate that ferry f4 was engaged more than in 2018 due to the increased demands from April to October. In all cases of the monthly examples in 2018 and 2019, the CPLEX solver got the optimal solutions easily within the short CPU time [14]. As can be seen from the presented results, pure rearrangement of ferries leads to the increase in the operators' profit. However, we went even further in our analysis proposing the modification of the ferry fleet for the additional profit increase. The obtained results are described in the remainder of this section.

4.1. New fleet scenario analysis

If we assume that the private operators establish a joint company for the ferry transport in the bay along four routes starting with the four ferries given in Sections 2 and 4 (f1, f2, f3, and f4), the joint operator can consider different strategy and purchase or charter-in additional ferries to maximize the total profit. For example, if we assume that there are available ferries to be purchased at the market [14]:

- ferry f5 with the capacity of 12 passengers;
- ferry f6 with 24 passengers;
- ferry f7 available to transport 55 passengers;
- ferry f8 available to transport 70 passengers;
- ferry f9 with 150 passengers;
- ferry f10 with the capacity of 200 passengers.

On the other hand, at the market there are available ferries to be chartered-in [14]:

- ferry f11 with the capacity of 12 passengers;
- ferry f12 with 24 passengers;
- ferry f13 available to transport 55 passengers;
- ferry f14 available to transport 70 passengers;
- ferry f15 with 150 passengers;

- ferry f16 with the capacity of 200 passengers.

Applying the MILP model, the results of the new scenario in the profit maximization and number of unused seats on board ferries obtained by the CPLEX solver are given in Tables 3 and 4.

Table 3: Results of new scenario for 2018 [14]

	New profit ($)	Unused seats	Fleet structure
March	6548	643	f1, f2, f3, f11
April	30484.5	702	f1, f2, f3, f12
May	112266	1091	f1, f2, f3, f11, f12
June	113276	813	f1, f2, f3, f11, f12
July	191286.5	1473	f1, f2, f3, f5, f11, f12
August	197635	1456	f1, f2, f3, f4, f5, f11, f12
September	107635	1092	f1, f2, f3, f4, f11, f12
October	99004.5	1263	f1, f2, f3, f11, f12
November	9878	460	f1, f2, f3, f11
Total	868013.5	8993	f1, f2, f3, f4, f5, f11, f12

As it can be seen, the achieved profit for the analyzed two seasons (2018 and 2019) would increase to 1635385.5 $ compared with 1228036 $ in the real-life case realized by only 4 ferries, f1, f2, f3, and f4. In the new scenario, the fleet would include ferries f1, f2, f3, f4, f5, f11, and f12. The joint operator would purchase ferry f5 and charter-in ferries f11 and f12. The total number of unused seats is 15216, as the required total number of transported tourists is 116051. The results from Tables 3 and 4 are also the consequence of the more intensive engagement of smaller ferries in comparison with the bigger ones, while the later are used more for the increased daily transport demands. In 2018, the results indicate that operator should purchase ferry f5. In that case, for 2019 the operator will provide 94500 $ less for the investment in the fleet (purchased and chartered-in) in comparison to 2018 because of the ferry f5 added to the existing fleet. Besides, the operator maximized the total profit. Most of the operating, voyage, maintaining and staying at the berth costs of an unallocated ferry would be lower if the operator's fleet consists of ferries with a smaller transport capacity. However, this will be the subject of some other investigations.

Table 4: Results of new scenario for 2019 [14]

	New profit ($)	Unused seats	Fleet structure
March	10261	336	f1, f3, f5, f11
April	35540	688	f1, f2, f3, f5, f11
May	87687.5	684	f1, f2, f3, f5, f11, f12
June	128372	755	f1, f2, f3, f4, f5, f11, f12
July	149834	732	f1, f2, f3, f4, f5, f11, f12
August	144841	828	f1, f2, f3, f4, f5, f11, f12
September	128670.5	1181	f1, f2, f3, f4, f5, f11, f12
October	79910	687	f1, f2, f3, f5, f11, f12
November	2256	332	f5, f11
Total	767372	6223	f1, f2, f3, f4, f5, f11, f12

As it can be seen, the total profit of a new scenario for 2019 is less than one in the case of having the fleet of ferries f1-f4. Therefore, a deeper analysis of a longer period should be taken into account. Also, for a detailed survey of the financial profitability, it is necessary to take into account the uncertainty in the level of transportation demands on an annual basis, mitigate the negative consequences and preparedness for an economic crisis, such as the one caused by the COVID-19 pandemic.

5. CONCLUSION

In this paper we presented the analysis of the ferry passenger transportation demands for a two-year time in the case of the Boka Kotorska Bay. The statistics indicate that the region was visited by more than 116 thousand tourists that sought the ferry transportation services on four different routes. We first provide the increase of operators' profit by employing the MILP model that suggested larger involvement of smaller ferries along Route 4. Next, we proposed a new scenario for creating a joint ferry company (operator) to deal with the possibility to purchase and/or charter-in additional ferries to achieve the increased income.

The results showed that the maximization of the total profit is a reality (increased from 1228036 $ to 1635385.5 $) covering the costs of a new ferry purchased and two ferries chartered-in. However, in the case of uncertain transportation demands and without the appropriate policy for economically sustainable ferry service development in a long term, the financial business of the operator may be treated as uncertain and record losses. To avoid it, special attention in the further investigation may be directed to the stochasticity of the transportation demands for the ferry services in the observed region.

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REFERENCES

[1] An, K., & Lo, H.K. (2014). Ferry service network design with stochastic demand under use equilibrium flows. Transportation Research Part B, 66, 70-89.

[2] Bakkehaug, R., Eidem, E.S., Fagerholt, K., & Hvattum, L.M. (2014). A stochastic programming formulation for strategic fleet renewal in shipping. Transportation Research Part E, 72, 60-76.

[3] Fagerholt, K. (1999). Optimal fleet design in a ship routing problem. International Transactions in Operational Research, 6, 453-464.

[4] Findley, D.J, Anderson, T.J., Bert, S.A., Nye, T., & Letchworth, W. (2018). Evaluation of wait times and queue lengths at ferry terminals. Research in Transportation Economics, https://doi.org/10.1016/j.retrec.2018.06.009.

[5] Hansen, P., Mladenović, N., Brimberg, J., & Moreno Pérez, J.A. (2018). Variable Neighborhood Search. Handbook of Metaheuristics, International Series in Operations Research & Management Science 272, Chapter 3, 57-97.

[6] Jorgensen, F., Mathisen, T.A., & Larsen, B. (2011). Evaluating transport user benefits and social surplus in a transport market - The case of the Norwegian ferries. Transport Policy, 18(1), 76-84.

[7] Lai, M.F., & Lo, H.K. (2004). Ferry service network design: optimal fleet size, routing, and scheduling. Transportation Research Part A, 38, 305-328.

[8] Laird, J. J. (2012). Valuing the quality of strategic ferry services to remote communities. Research in Transportation Business & Management, 4, 97–103.

[9] Lo, H.K, An, K., & Lin, W-H. (2013). Ferry service network design under demand uncertainty. Transportation Research Part E, 59, 48-70.

[10] Ng, MW. (2014). Distribution-free vessel deployment for liner shipping. European Journal of Operational Research, 238(3), 858–862.

[11] Ng, MW. (2015). Container vessel fleet deployment for liner shipping with stochastic dependencies in shipping demand. Transportation Research Part B, 74, 79-87.

[12] Pantuso, G., Fagerholt, K., & Hvattum, L. M. (2014). A survey on maritime fleet size and mix problems. European Journal of Operational Research, 235, 341–349.

[13] Škurić, M., Maraš, V., Davidović, T., & Radonjić, A. (2021). Optimal allocating and sizing of passenger ferry fleet in maritime transport. Research in Transportation Economics, 90, 100868:1-16, doi: 10.1016/j.retrec.2020.100868.

[14] Škurić, M. (2022). Ship fleet sizing for local and regional passenger ferry transport. University of Belgrade, The Faculty of Transport and Traffic Engineering. PhD thesis.

[15] Wang, C., Corbett, J.J., & Firestone, J. (2008). Modeling energy use and emissions from north American shipping: application of ship traffic, energy and environment model. Environmental Science & Technology, 42(1), 193–199.

[16] Yan, S., Chen, C-H., Chen, H-Y., & Lou, T-C. (2007). Optimal scheduling models for ferry companies under alliances. Journal of Marine Science and Technology, 15(1), 53-66.

WOMEN LOGISTICIANS ON THE MAGIC MOUNTAIN PATH – THROUGH DIFFICULTIES TO SUBLIMITY (AD AUGÚSTA PER ANGÚSTA)

(PLENARY SESSION PAPER)

Snežana Tadić, D. Sc.
University of Belgrade, Faculty of Transport and Traffic Engineering, Logistics Department
Vojvode Stepe 305, Belgrade, Serbia
s.tadic@sf.bg.ac.rs

ABSTRACT

Logistics is an area of scientific and applied research in which women are also present as scientists, professors, engineers, sector and operations managers, operators in the field of order-picking, warehousing, etc. They are present in all phases of analysis, planning and management of logistics processes and systems. Logistics is an extremely complex area, and a career in logistics can be equated with a magic mountain path. The path is magic because the area is characterized by numerous challenges, problems, dynamic stochastic changes of requirements, processes, systems, participants and their attributes. A woman with her knowledge, skills and virtues, in an environment that is often harsh, must overcome all obstacles along the way. This paper describes the basic components of a magic mountain path, a career in logistics. In order to overcome the path and conquer the peaks, women need institutional support, but also awakening on a personal level, i.e. individual training. The paper describes both areas of support: the principles and goals of the gathering in the Association of Women in Logistics (AWL), and the Concept of Three Women's Gold Nuggets (3WGN). In addition, a part of the results of the research of the Association of Women in Logistics in Serbia is presented.

Keywords: Women logisticians, mountain path, components, institutionalization, individual training, Association of Women in Logistics (AWL), concept 3WGN (Three Women's Gold Nuggets)

1. INTRODUCTION

Logistics includes all systems and processes that enable the realization of material and non-material flows (Zečević & Tadić, 2011). The flow is a set of processes of movement and stillness, while the flows of goods, materials and cargo are the basis for the functioning of any socio-economic system (Zečević, 2006). Every company or individual initiates a large number of flows in order to perform their activities, i.e. to meet their requirements and needs, Flows have different characteristics in terms of type of goods or cargo, assortment, appearance, quantity, law of origin, time of realization, frequency, location of origin and destination, specific requirements, etc. The requirements are changeable, and the realization is in a dynamic-stochastic environment.

The carrier of the realization of flows is the logistics chain, and the logistics systems are the carriers of the realization of the logistics chain. The logistics chain is a complex system of processes and activities of ordering, packaging, transport, transshipment, storage, formation of cargo units, sorting, control, order-picking, consolidation, preparation of supporting documentation, etc. The order and number of activities in the chain are strongly influenced by the variability of the attributes that describe them: space, time, quality, costs, level of service, patience interval, technology, carrier, tied-up capital, etc. (Zečević, 2006). On the other hand, the logistics chain goes through different systems and includes a large number of participants (production, trade, service, transport, freight forwarding, logistics companies), with their own, individual goals and interests, which are most often in conflict. Each link in the chain has components of logistics philosophy, technique and technology, planning, management, optimization and informatics. Chain participants and logistics systems through which the chain passes, operate in an environment that is constantly changing, so the working conditions, characteristics, goals and interests of participants and systems are changing. Variable categories and characteristics of flows, logistics chains, process and activity attributes, logistics systems, goals and interests of participants, in a dynamically stochastic environment, indicate the degree of complexity of planning and management. This complexity of logistics requires different knowledge and skills, personality traits, and evokes feelings of beauty and sublimity (Tadić, 2020).

On the other hand, there are many qualities that can be treated as sublime and beautiful, and many of them often characterize women thus bringing them closer to logistics (Tadić, 2020). However, on the path to success, to leadership positions, women encounter numerous barriers. It is not just about systemic problems, bias in the employment and promotion system and life priorities. Women, especially in this area, are limited both traditionally and culturally, so they need more self-confidence to lead (Tadić, 2021).

The career of women in logistics is like a mountain path, full of challenges, obstacles, hindering factors. The characteristics of the path, i.e. the complexity of logistics requirements and systems, women with their knowledge, skills and virtues and the changing environment and circumstances, are the basic components of the magical path of women's success in logistics (Figure 1). On this path, women logisticians have to fight both on an *institutional* and an *individual*, personal level. The aim of this paper is to explain the importance of the institution, but also the awakening of the individual in women. In order to eliminate problems, better use of potential and increase leadership, the Association of Women in Logistics (AWL) has been registered in Serbia. By gathering and uniting in AWL, the cooperation of women logisticians is institutionalized. The association should initiate and coordinate various initiatives, but the essence is in the person who is in the institution. A woman has to fight on her own, to develop on a personal level, find something strong and awake the "wild woman" in herself. The link between the institutional and individual levels of the struggle for women's leadership in logistics is strong and mutual. The association should initiate and help the awakening of the individual, the search for women's gold nuggets, and the strength of the individual sets in motion the initiatives of the association. The expected results are changes in the system, easier overcoming of the magic mountain path, i.e. the path to success, and raising the leadership of women in logistics.

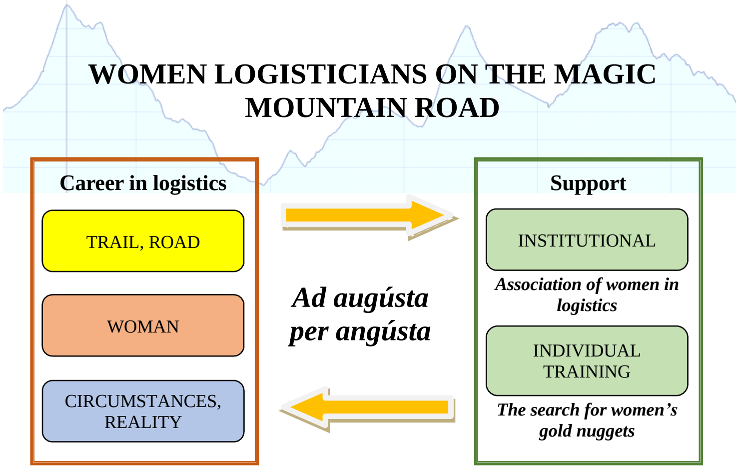


Figure 1: Women on the magic path in logistics

The paper is organized as follows. After the introduction, the second chapter will describe the components of a successful career in logistics, that magic mountain path. The third chapter will explain the role of the institution and individual development in overcoming it, for the success of women in logistics. The principles and goals of the AWL and the elements of the Concept of Three Women's Gold Nuggets (3WGN) are presented. The fourth chapter will present and analyze the results of research on the position of women in logistics, primarily in Serbia. In the end, instead of the classic conclusion, a true story is given about the strength, perseverance, joy and wealth of women logisticians on a harsh mountain path.

2. COMPONENTS OF THE MAGIC MOUNTAIN PATH

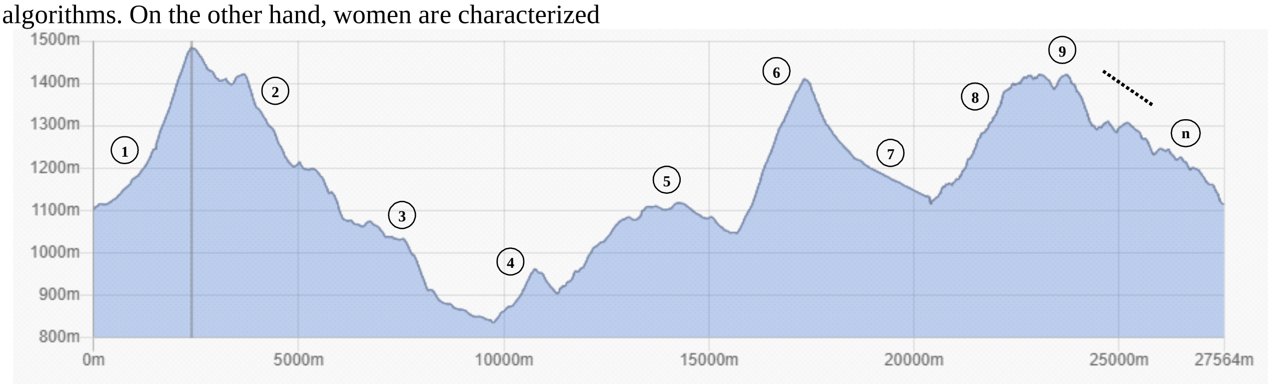
Logistics is an extremely complex area, and when we introduce a conductor into the beauty of a complex structure, that is, methods, algorithms, optimization techniques, we get the sublimity in the beautiful. On the other hand, when we introduce harmony, i.e. the concept or the strategy of logistics, into chaos, i.e. the space of exceptional complexity of logistics flows we get a feeling of beauty in the sublimity (Tadić, 2020). A career in the field of the beautiful and sublimity can be seen as a magical mountain path, full of obstacles and challenges, opportunities and feelings, which require different knowledge, skills and virtues. The magic mountain path of a woman's career in logistics consists of three basic components (Figure 2): characteristics of the trail, i.e. the path, characteristics of the woman and reality, i.e. the circumstances (conditions, environment, facts).

2.1. Characteristics of the path, i.e. trail

Mountain paths are extremely complex. They consist of ups and downs, stone and dirt surfaces, cliffs and abysses, mountain flowers and thorns, forest, karsts and endless clearing, beautiful landscapes and harsh conditions of nature, music and silence of nature and wilderness, many obstacles - fallen trees, fast rivers and wild streams, etc. Logistics is also an extremely complex area. It is characterized by changing requirements, stochastic and non-stationary phenomena, extreme non-homogeneity of units of movement in terms of type of goods, cargo, appearance, quantity, law of origin, time of realization, spatial dispersion of origin and destination locations, variable structure of logistics chains, chaotic processes, many different systems, participants with conflicting goals, cultural differences, etc. In logistics, as well as on the mountain path, challenges are overcome, problems are solved, experiences are gained, new goals are set and expectations are shifted. It's magical! Complexity, challenge, problem, strength of personality, those are the things that make the mountain path and the career in logistics magical.

2.2. Characteristics of a woman

Mastering a mountain trail, but also making a career in logistics, requires certain knowledge, skills and personality virtues. Women have different knowledge and skills, they are often better students, they finish their studies faster, they master different methods, techniques, algorithms. On the other hand, women are characterized by the virtues needed to solve complex requirements, problems, processes and systems in logistics, but also challenges and obstacles on the mountain path. Intuition, perseverance, responsibility, empathy, sensitivity, enthusiasm, integrity, creativity, truthfulness, imagination, thoughtfulness, wisdom, curiosity, patience, harmony, etc. are virtues that attract women and logistics. Without some of these virtues, the mountain path is abandoned and it remains invincible.



PATH, TRAIL

Logistics
- Chaotic requirements and processes
- Large number of participants
- Stochastic and non-stationary phenomena
- Various systems and technologies
- Conflict goals
- Structural and cultural differences
- Spatial dispersion
- Inhomogeneity of units of motion
- Variable flow characteristics
- Etc.

Mountain
- Ups and downs
- Stone and dirt
- Abyss and cliffs
- Forest and clearings
- Mountain flowers and thorns
- Beautiful lanscapes and harsh conditions
- Fast rivers and wild streams
- Obstacles, fallen trees
- Music and silence of nature and wilderness
- Etc.

WOMAN
- Knowledge
- Skills
- Persistence
- Creativity
- Responsibility
- Intuition
- Curiosity
- Patience
- Harmony
- Etc.

CIRCUMSTANCES, REALITY

Logistics
- Crises and wars
- Pandemics and climate change
- Liberalization and regulation
- Market fluctuations
- Globalization
- Regionalization
- Personalization
- Demographic change
- Artificial intelligence
- Etc.

Mountain
- Rain and snow
- Wind and ice
- Hail and storm
- Sun and clouds
- Thunder and lightning strikes
- Landslides and avalanches
- Mud and water
- Humidity and heat
- Etc.

Figure 2: Complexity and beauty of the magic mountain path in logistics

2.3. Reality and circumstances

Logistics chains, processes and activities are realized in a stochastically dynamic environment. Changes are present in all social and economic segments. There are financial crises, pandemics, wars, climate change, processes of globalization and regionalization, liberalization and strict regulation, demographic changes and changes in consumer behavior, development of new technologies and artificial intelligence, etc. Conditions and reality change logistics requirements and business conditions, structures of logistics chains, attributes of logistics processes, transport routes, logistics strategies, etc. On the other hand, planning and managing logistics systems and processes in changing environmental conditions is a special challenge. The challenges posed by the conditions of the environment enhance the magic of the mountain path. On this path rain and snow, wind and ice, hail, sun, thunder and storm, landslides and avalanches, humidity and heat, mud and water, etc. take turns. These changes require additional attention, concentration, wisdom, enthusiasm, patience and perseverance, change, adjustment of speed, rhythm, steps and body position to the conditions of the path and the environment. Those who do not have enough virtues and knowledge to adapt to the changing conditions of the environment give up on the magic mountain road.

3. CONQUERING THE MAGIC MOUNTAIN PATH IN LOGISTICS

Although women are generally more intuitive, more subtle, more detailed, more analytical, more communicative, better at connecting people and mediating, there are numerous obstacles to their success (Tadić, 2021). Traditionally and culturally, a woman is limited, more questionable, more self-critical, less prone to risk, often has less ambition and is more insecure. There is a fear of the unknown, a fear of responsibility. The reasons are numerous, often a consequence of the environment, but also one's own expectations. In order to increase the leadership of women in logistics, institutional support (association of women) is needed, but also changes, i.e. improvements at the individual level.

3.1. Association of Women in Logistics

Women who have succeeded in the field of logistics are in contact, help and cooperate with each other, but also with successful women from the other fields. They easily recognize each other, exchange experiences, create successful business opportunities and give advice (Tadić, 2021). However, in order to formally gather, unite and engage in activities to raise women's leadership in the field of logistics, the Association of Women in Logistics has been registered in Serbia. The association was also warmly received by colleagues from the area, so the intention is to expand to the level of the region.

The idea of founding AWL arose from a partial understanding of the situation and problems of women's leadership in Serbia, world trends, but the energy was triggered by a spark that smolders in deeds from the distant past (Figure 3). The association should include everyone who can contribute to its development - logistics women, as well as successful women from other fields, but also men, experts in the field, who will encourage and motivate women on the path to success. The goal is to eliminate problems, obstacles to the success of women in the field.

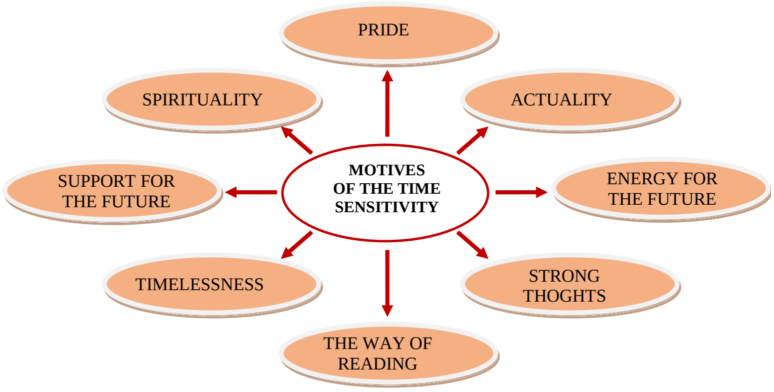


Figure 3: A spark from the past as a motive for the Association of Women in Logistics

The piece on the nobility and sublimity of the female sex (Agrippa, 1529), written five centuries ago and dedicated to the ruler of the Netherlands in that time, Margarita of Austria, to support her successful future rule, gave motives for founding the Association. The piece promotes the sublimity and superiority of women, at a time when some undesirable forces in the environment ruled, such as witch hunts.

In accordance with the saying "The end is always the first in intention and the last in execution", the goals of the AWL are visible in the ideas of its formation. The potentials of women's leadership in logistics exist and are visible, but they need to be strengthened and brought closer to all women, logistics engineers, employees in different companies, in different jobs and decision-making levels. Through various activities and initiatives, the Association will work on removing obstacles to the advancement of women in logistics, improving their knowledge and skills, self-confidence, but also promoting success. The basic principles of the Association are: promotion of logistics, promotion of diversity, continuous improvement, network development, strengthening the base, strengthening the goals and promoting male allies, and the ultimate goal is to present women's leadership as beautiful and sublime and its setting as a business priority of companies and society as a whole (Tadic, 2021). The association should give a description, profiles and maps of the magic mountain road, but in order to master it, a woman i

n logistics must find strength in herself.

3.2. The search for women's gold nuggets

Training, i.e. advancement of a woman can be reported in two interactively connected spheres - ***external and internal***. In the external sphere, women are improving in the field of their core business, logistics, and complementary areas (IT technologies, business management, operational research, etc.). The inner sphere predominantly belongs to the woman herself. It is a space where specific values and knowledge are located. A woman can find in herself the valuables she possesses and which are often in the shadow of ordinary, everyday, burdensome and existential obligations. The first step in the search for these values is awareness of their presence and the possibility of getting out of the shadows. *Every woman has her own specific valuables in the shadows*. Her sphere is as specific as her personality, so valuables differ in number, size and quality. They are very rarely identical, they are changeable in space, time, appearance, circumstances, but they are always present in a woman's personality. Their number in the collection is insignificant, but three valuables stand out in the observation of this paper. These values are associatively called in this paper the Three Women's Gold Nuggets (3WGN), which consists of: the gold nugget of ***truth***, the gold nugget of ***movement***, and the gold nugget of ***nature***. Every woman can go in search of these values, to begin to discover what may be hiding in the shadows (Figure 4).

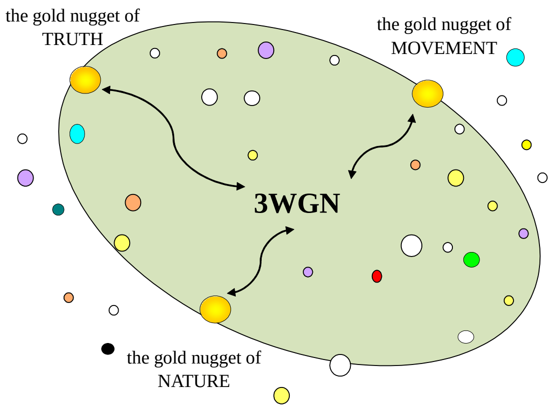


Figure 4: Search for Three Women's Gold Nuggets (3WGN)

The gold nugget of TRUTH. A woman must be aware of one truth: *she is an individual*, who combinatorially possesses many characteristics of the beautiful and the sublime. As an individual, she chooses and decides on all possibilities in life. She inherited something, and she acquires something and forms the image of her personality of her own choice, as a work of art in the mosaic of life. She chooses stones in various colors and shades and arranges them with pleasure, in accordance with reality, circumstances and regardless of difficulties. As in random processes in time and space, the mosaic changes, the female individual is the creative artist of her life, she creates a new image, combines and mixes colors, chooses and changes elements in her own creativity. The truth is that she has to do it when she stays with herself, for a moment she is left alone, in the peace of her property, when she individually, instinctively becomes a creator. These moments of individuality can be the strongest parts of her life. A woman's individuality goes with her, both when she is alone and when she is in a group, she never leaves her and gives her the opportunity to choose equilibrium, when and how much she is needed. Sometimes, periodically or rarely, her individuality can, more or less, be overshadowed. It is natural for individuality to be changeably visible, and in accordance with the circumstances and the will of the woman. The most important thing is to be aware of her presence, possibilities and her performance. The poet Cristian Morgenstern states in his works: *He who travels to the truth, travels alone.* A woman can go in search of a higher degree of visibility of her own individuality.

The gold nugget of MOVEMENT. Are there differences in the movements of women and men? It would be natural to say that there are no differences. Statistically, in some areas and in some sense, there are deviations. Differences are present in the business environment. Movements can be different - physical, spiritual, business, etc. They can be divided by levels, described in the coordinate spatial system, measured in space and time by a series of qualitative and quantitative performances. Logistics is woven from the processes of movement and flows in nano, micro, meta, macro, mega, as well as in immeasurable spaces. In describing reality, Johann Wolfgang Goethe observed that most people move left and right, and that a smaller part of the population moves upwards in a spiritual sense. He was not the only one who noticed that the population concentrates on moving on one level of thought and knowledge and that it rarely decides to move to a higher level. Every move up does not mean that after a certain time, the person will not be in the phase of descent. The ups and downs change periodically throughout life. Despite the, perhaps greater, natural strength of men, it often happens that women in certain sections of life or business, have a better sense of balance of energy consumption. This is the gold nugget of a woman who finds it in herself and proudly adapts and uses it. When the greatest ascents are in front of a woman, she will count up to ten in herself before a man, and patiently repeat it several times, as many times as necessary, with calm perseverance and natural sensitivity for the equilibrium of life's effort. Movement is the basis of life. Individual training is not just moving left and right in one plane, but moving up and down, and this is a woman's personal challenge. Skyrunning is not a simple movement, it is running on a road measured in tens of kilometers, on which the seasons, storms, fog, ice and snow, winds and sun, rivers and mud change alternately. Life is skyrunning, and in that race a woman can successfully prepare and adapt for challenges in logistics.

The gold nugget of NATURE. By observing phenomena in nature, humans acquire vast knowledge and use it. Nature has its values and sometimes hides them, and sometimes it awakens and stimulates humans to understand the processes and systems of existence. The application of models and methodologies in OR (Operation Research) techniques, which are based on the behavior of a colony of insects, ants, bees, is well known. Much more than that is the various influences of nature on humans and the benefits that humans derive for the needs of existence. Here we point out another aspect of the benefits that a woman, in personal development, can individually take from the nature. Standing in front of a landscape in nature and awakening a part of nature in you, is a magical experience. Standing on top of a mountain that is in ice and snow, while the wind mercilessly howls and hits ice flakes on the face, awakens something wild in a woman, something that makes her survive. That awakening of nature in a woman is a wonderful picture of life. Magically realistic and abstract images are awakened in her soul, strong thoughts of power, talents and wisdom are initiated, art and music are initiated. Instincts, knowledge, intuition, wildness and the need for existence are awakened (Figure 5).

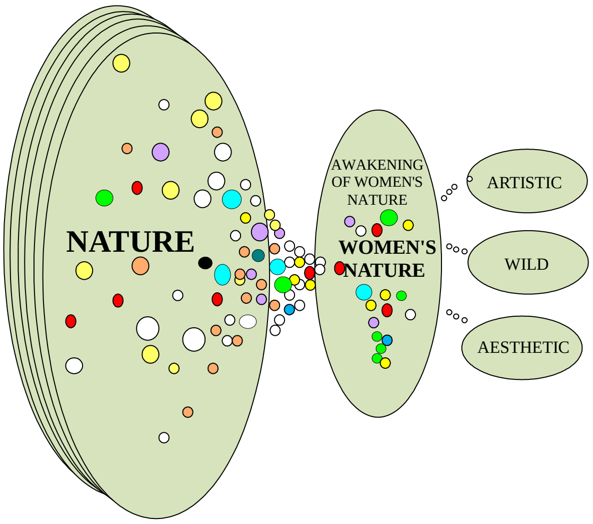


Figure 5: From nature to nature

Nature is the gold nugget in the waking logistics woman, who gets the necessary power to feel comfortable in the space of complex logistics systems and processes. A woman in logistics strives to develop the ability to develop and improve individually, to be ready to overcome all the ups and downs in work and life, to extract all wisdom, power and knowledge from her own nature and to associatively resemble to a woman running with a wolf (Estes, 1992). There are many life stories that the author of this paper heard from her fellow women logisticians. In very complex business and life situations, women instinctively mobilized incredible inner natural strength to overcome imposed, encountering problems. Strength is present in every woman, according to her nature. Composer Ludwig van Beethoven on the connection between nature and man states: *Only in nature can man learn wisdom*. There are various ways and examples of awakening that power. Part of that power is also found in the hidden part of the woman, in the part that is sometimes called the *wild woman* (Estes, 1992). Going to the magical landscapes of nature (skyrunning - one of a million ways) is a good example of tuning that "*inner piano*" - a woman versus nature in the role of piano tuner of her inner musicality of nature.

4. RESEARCH IN SERBIA

The treatment of women in logistics is changing, but they are still an underutilized resource. Research shows that companies with women leaders are more successful, but there are few companies that define progress in the field of women's leadership as one of the business priorities. Although more and more companies are developing, promoting and sponsoring women in logistics, changes are slow and more visible at lower hierarchical levels of decision-making. Research in developed countries shows that women make up a third of supervisors at the first level of decision-making and only 11% of logistics and supply chain managers (AWESOME, 2019). The situation in Serbia is better from the aspect of education and participation of logistics women at lower hierarchical levels of decision-making, but it is significantly worse at higher leadership positions (Tadić, 2020). Research shows that the situation in the region is somewhat better, but it is more a consequence of adopted laws, standards and rules, than a real improvement in the field of women's leadership (Tadić, 2021).

The greatest number of logistics engineers in Serbia is employed in companies of logistics providers, freight forwarders and transport service providers (40%), in logistics centers (20%) and trade and distribution companies (20%). Women logisticians are least represented in manufacturing companies (about 15%), and most in public institutions, state and city administrations (60%) (Tadić, 2020). Recent AWL research shows that the participation of logistics women in the public sector has been declining in the last few years, which shows their readiness to step out of the comfort zone and fight for a position in the harsh business world.

Research shows that half of the women respondents, women logisticians, and over 60% of men respondents, men logisticians, do not know whether the company in which they work follows the gender structure of employees. It was expected that women would be more interested in the topic of gender equality, as well as in monitoring the gender structure, which was not shown by the research. This may mean that the gender structure is not monitored enough or that employees are not sufficiently informed about its monitoring, the topic of gender equality and its importance.

The greatest number of women (47%) and men (41%) estimate that the participation of women in the total number of full-time employees is between 30 and 40%, and as many as a quarter of men believe that women make up the majority of employees in their companies. However, the representation of women in the logistics sector is significantly lower compared to the company as a whole. As many as 55% of female and 47% of male respondents estimate that logistics women make up less than 30% of employees. Here, too, the estimates of men are more favorable, given that over 30% of respondents think that women make up over 40% of employees in the logistics sector in their companies (Figure 6).

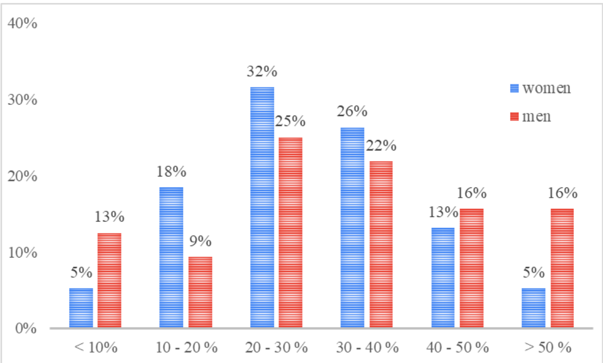


Figure 6: Estimation of women's participation in the number of employees in the logistics sector of companies

A comparative analysis of the responses of women and men respondents on women's participation by hierarchical levels of decision-making shows that men assessments are more favorable. This indicates a tendency for women and men to perceive or want to present women's participation differently, especially at higher hierarchical levels of decision-making. Women are most represented at the middle levels of decision-making, probably because the first level is often more physically demanding. The participation of women at the highest levels of decision-making is extremely small, although significantly higher according to men.

About half of the respondents in both groups do not know, and 8% of women and 16% of men respondents stated that their company does not have plans and goals for achieving gender equality and greater participation of women at higher levels of decision-making. It is interesting that some men respondents, as a reason for not having gender equality plans, stated that it already exists and argued that women work in most positions at the highest levels of decision-making. Two dilemmas arise here: Is there objectivity in perceiving the real situation, given that the assessment of gender equality is given by a male respondent? Is a high position in the company's decision-making hierarchy sufficient confirmation of gender equality?

There is a significant difference between the men and women groups of respondents in the perception of companies' progress in terms of gender equality (Figure 7). Namely, there are a significantly higher percentage of men respondents who think that the changes are noticeable. This indicates that changes that may seem significant to men may be considered less important and insufficient by women.

The assessment of women's participation in logistics at higher levels of decision-making in five years shows the optimism of women who in 44% of cases believe that their participation will be equal to or greater than the participation of men. In the long run, only 25% of men think this, which may mean that some men think that women should have a more significant, but not greater share than them in logistics. In addition, some male respondents believe that women's participation at higher hierarchical levels is largely a matter of women's choice, as they choose jobs with less responsibility.

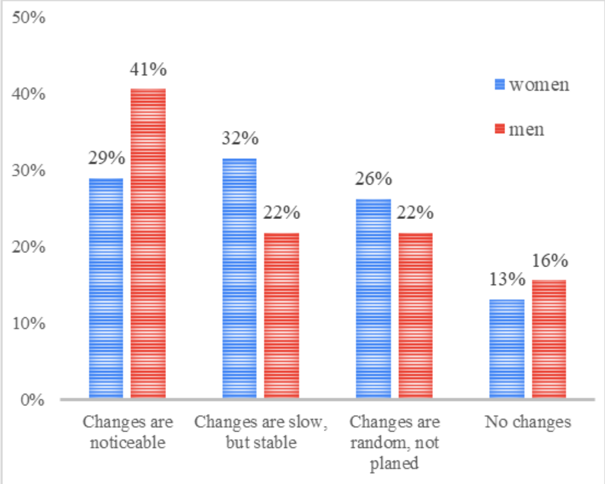


Figure 7: Assessment of the company's progress in achieving gender equality

About 40% of women and 53% of men respondents stated that there are initiatives in their companies for employment, development, retention and/or advancement of women. First of all, they list initiatives related to personal development (courses, trainings and in-service training, language courses, etc.), communication with management and the human resources department, evaluation processes, parenting support, etc. As an initiative aimed only at women in the company, competitions such as "best woman", and similar, stand out. As many as 40% of women and 60% of men are not aware that in their companies there are initiatives that provide incentives, i.e. relax the family woman in terms of time and care and thus contribute to her advancement in the company. However, about 30% of respondents in both groups stated that they exist in the forms of: flexible working hours, days off, the possibility of working from home, gifts for children, discounts for kindergartens, etc.

One third of women and almost half of men respondents think that women are more demanding as managers, while some of them point out that this is a reflection of their greater analyticalness and thoroughness in relation to men. About 20% of female respondents stated that women at higher levels of decision-making have more understanding towards employees, especially women, and they explain this with empathy and interest in the problems of subordinates. About 40% of respondents in both groups believe that there is no difference between men and women at higher levels of decision-making. The answers indicate that equal conditions, opportunities and treatment of the sexes enabled women to reach positions at higher hierarchical levels with knowledge, skills and virtues, regardless of gender and the characteristics associated with it. On the other hand, some female respondents point out that women at higher levels of decision-making identify with men in a sense of adopting some traditionally "masculine" traits (rigor, sharpness, demandingness, etc.). From this interpretation, it can be concluded that in some companies, equality between women and men has not been achieved, but rather the identification with them.

The majority of women (over 60%) and the overwhelming majority of men (over 90%) claim that there is no pay discrimination against women in their company. It could be said that the difference in percentages exists because among men there is a belief that women are not discriminated against in terms of salary and position in which they can work, but they are a real product of their work and abilities. From this it can be concluded that pay discrimination does not exist, but that the path to higher positions in the company is more difficult for women, because it is sometimes conditioned by the belief that they are less capable than men. On the other hand, some women respondents who stated that there is pay discrimination, point out that it is more pronounced in smaller than in larger companies and that part of the responsibility for such a situation lies with women themselves, because they do not fight enough for their rights.

About a quarter of the respondents from both groups think that the opinion of men is mostly or sometimes more valued in their company. A similar number of respondents from both groups believe that the ideas and contributions of women in the company are devalued. In addition, 35% of women and 17% of men respondents believe that women's emotions are not desirable in companies. Some women believe that this is one of the main reasons for the slow progress. Women's emotions are sometimes considered a weakness, although, according to women, they are their most valuable tool. On the other hand, some women emphasize that there is a responsibility of women for this perception of their emotions, because they often point out that they are the cause of mistakes they make in work.

These results show that there are certain problems, but also that women in logistics are aware that their position and career depends mostly on themselves. Awareness is raised about the importance of their association, but also of individual awakening and improvement. We perceive the differences in the perceptions of men and women regarding gender equality and treatment, i.e. women's opportunities, as a provocation to work on fitness, in order to overcome the magic mountain road.

5. CONCLUSION

Here is one true story for the end, instead of the classic conclusion. After I achieved success and passed the finish line of a skyrunning race, which took place in harsh natural and climatic conditions, I was approached by an acquaintance, a man. He asked me if this race was decided by the male part of my personality, and if I overtook and passed many, seemingly more physically fit men, who gave up on the harsh ice climbs, because the female part of the personality prevailed. In doing so, he alluded to the theories of well-known psychoanalysts. I understood his funny question and answered that this race was decided by *me and my part of nature with a logistical philosophy*. In the blizzard, on a dangerous, icy, harsh mountain trail where I saw out of the corner of my eye men who stumble, trip and give up, I counted to ten, then repeated the count, without looking away from the part of the trail right in front of me and without focusing on those which were well in front, near the top, or on the abyss below and around me. I was feminine disciplined and responsible. A young lady, also a logistician, my former student, also finished the race. And she reached the finish line before many men. We met by chance on a magical mountain road and were proud of each other. We were happy, and we were not even close to winning the race. The joy was as if we were champions, us two logisticians!

Only a woman logistician on a magical mountain road can see the real self. No one can see well what she is going through. And no one can describe the trail, the mountain path, the way she sees it. It is her personal mirror on two sides. One side is she and the other side is the trail. Each section of the life path has its own starting and finishing gate. At the starting gate, a woman is full of hope, passion and desire to succeed. She trembles, she doubts, she jumps with excitement, she is getting ready to leave. She has to resist those emotions. She embarks on a path full of uncertainty, stochastic, ups and downs, obstacles, setbacks, problems, time consciously and unconsciously unwinds, labyrinths of life threaten to lead her to the wrong side, orientation and excitement do not give up, she uses all her virtues, takes from the environment everything it is useful to overcome the path, she turns ugly into useful and beautiful, acquires wisdom, raises her self-confidence. At the finish gate is pride, confirmation of values and struggles, courage, joy, laughter and music. That's wealth! "A woman stands like a gate, at the exit, as well as at the entrance of this world," said Nobel laureate Ivo Andrić.

REFERENCES

[1] Zečević, S., & Tadić, S. (2011). Logistics. Bar: Faculty of Business Management (in Serbian).

[2] Zečević, S. (2006). Logistics centres and freight villages. Belgrade: University of Belgrade, Faculty of Transport and Traffic Engineering (in Serbian).

[3] Tadić, S. (2020). Women in logistics - beautiful and sublime. Tehnika, 75(3), 389-394.

[4] Tadić, S. (2021). A step further - women's association in logistics. Tehnika, 76(6), 825-831.

[5] Estes, K. P. (1992). Women who run with the wolves. Ballantine books, New York, US.

[6] Agripa, H. K. (1529). De Nobilitate et Praecellentia Foeminei sexsus, ad Margaretam Augustam Austriaco & Burgundionum Principem.

[7] AWESOME, Gartner (2019). Women in Supply Chain Research. Available at: https://www.awesomeleaders.org/wp-content/uploads/2019/05/AWESOME-2019GartnerReport_CSCMP.pdf

LOCATING VAL SERVICES IN THE LOGISTICS NETWORK

Snežana Tadić, D.Sc.
Mladen Krstić, D.Sc.
Miloš Veljović, M.Sc.
Slobodan Zečević, D.Sc.
University of Belgrade, Faculty of Transport and Traffic Engineering, Logistics Department
Vojvode Stepe 305, Belgrade, Serbia
s.tadic@sf.bg.ac.rs

ABSTRACT

With the development of logistics, the offer of companies has been expanded from basic to numerous additional services that add value to the products - VAL services (packaging, labeling, assembly, customization of products to customer needs, etc.). These services have become an instrument for achieving profitability and competitiveness of companies. Although locating VAL services in the logistics network is one of the key decisions of logistics providers, not enough attention has been paid to this problem in the literature. In this paper, the factors influencing the location of VAL services in the logistics network are analyzed. In addition, a model based on fuzzy systems has been defined, which, gives the degree of centralization of VAL services in the logistics network based on the assessment of the impact of various factors. The basic goal and contribution of the paper has been achieved in this way.

Keywords: VAL services, locating, logistics network, fuzzy systems

1. INTRODUCTION

VAL (Value Added Logistics) services are logistics services that add value to the product, such as: packaging, repackaging, labeling, assembly, procurement, distribution, reverse logistics, quality control, order picking, cross docking, localization and customization of products to customer needs, pricing, information and financial services, customs clearance, etc. (Lai, 2004; Hoek, 2001; Bowersok et al., 2010; Chen & Notteboom, 2012; 2014). These services are the main instrument for revenue generation, but also the competitive advantages of companies (Mentzer et al., 1997). The development of VAL services represents a natural advancement of logistics compared to the time when company services were reduced to transport and storage, and represents the predominant strategy in the current management of global supply chains (Chen & Notteboom, 2014; Li, 2011; Jaiaram & Tan, 2010).

VAL services can be performed in different places in the supply chain: at the manufacturer, retailer or logistics provider. They are very often performed in logistics centers. One of the key decisions of logistics providers is locating VAL services in the logistics network. This decision depends on many factors (type of distribution system, location of logistics centers, type of products, demand characteristics, etc.). On the other hand, it affects the supply chain configuration, costs, profitability, service level, product quality, efficiency of response to customer requirements, their satisfaction, etc.

Despite its importance, not enough attention has been paid to this topic by researchers. Chen and Notteboom (2012) analyzed the determinants/factors influencing the allocation of VAL services to logistics centers within the supply chain and assessed the impact of locating VAL services on supply chain configuration and costs. The authors dealt with the same issue in the next research (Chen & Notteboom, 2014) with additional reference to the role of logistics characteristics of products and the nature of VAL services in making decisions about the location of VAL services. The literature is particularly scarce in terms of models for locating VAL services in the logistics network. In addition, there are almost no examples in the literature of the application of the fuzzy system for solving location problems. They are mostly solved by applying simulation techniques (e.g. Wang et al., 2021; Ghasemi & Khalili-Damghani, 2021), by defining classical (e.g. Krstić et al., 2019; Tadić et al., 2019b) or heuristic (e.g. Tadić et al., 2021) mathematical programming optimization models , or by applying multicriteria decision-making methods, either in their conventional form (e.g. Pamučar et al., 2021) or in the environment of intuitive and interval sets such as fuzzy (e.g. Zečević et al., 2017; Tadić et al., 2013; Tadić et al., 2012) or gray (e.g. Tadić et al., 2020).

This paper analyzes the factors influencing the location of VAL services in the logistics network. It also defines a model based on fuzzy systems, which based on the assessment of the impact of various factors gives the degree of centralization of VAL services in the logistics network, which is the main goal and contribution of the paper. Also, this creates a basis for future research and application of fuzzy systems and other tools, models and software in this area. Finally, the value of the degree of centralization obtained by applying the model provides a significant support and recommendation to companies in the decision-making process on locating new or selecting existing logistics centers where VAL services could be performed, as well as for making other decisions.

The paper is organized as follows. After the introduction, the second section analyzes the factors influencing the location of VAL services in the logistics network. The third section defines a model for determining the degree of centralization of VAL services in the logistics network, based on fuzzy systems. The fourth section presents examples of the application of the defined model in the MATLAB software. In the end, the conclusion and directions of future research are given.

2. FACTORS INFLUENCING THE LOCATING OF VAL SERVICES IN THE LOGISTICS NETWORK

Some of the main factors influencing the location of VAL services, i.e. the degree of their (de)centralization in the logistics network are (Chen & Notteboom, 2012): customer response time, economies of scale and delivery frequency, demand stability and predictability, product life cycle and margin, share of transport costs in total costs, flexibility and specificity of certain products or packaging for individual markets. Each of these factors and how it affects the location of VAL services will be described below.

Customer response time (F1) is the time between the moment the customer orders products or services and the time they are delivered to them. It significantly affects customer satisfaction (Chen & Cox, 2012). Response time can range from a few minutes to several years, depending on a number of factors: type of products, ordering system, competition, work efficiency, cooperation and communication between the company's sectors and the integration of their activities, etc. (Sabur & Simatupang, 2015), but also the communication and integration of all participants in the supply chain and application of information technology (Chiang et al., 2014; Agarwal et al., 2007). The shorter customer response time, the closer the VAL service location should be to the customer (Chen & Notteboom, 2012).

Economies of scale and delivery frequency (F2) also significantly affect the degree of centralization of VAL services. Economies of scale imply a reduction in unit production costs due to an increase in its volume (Besanko et al., 2009). Therefore, manufacturers strive to perform a larger volume of production in one production plant. This contributes to the centralization of both production and VAL services. Economies of scale and delivery frequency are inversely proportional, i.e. increasing one decreases the other (Chen & Notteboom, 2012). Therefore, the high frequency of deliveries is favored by the decentralization of production and VAL services, in order to reduce distances to customers, and thus response time and transport costs. Delivery frequency is expected to increase as manufacturers and retailers seek to reap additional economic benefits associated with low inventory levels and precisely timed delivery. As a result, there will be a conflict between the goals of economies of scale and high-frequency deliveries (Notteboom & Rodrigue, 2009). In a logistics network of companies that have a small economies of scale and a high frequency of delivery, VAL services should be located as close as possible to customers (Chen & Notteboom, 2012).

According to Fisher (1997), the ***stability and predictability of demand*** (F3) predominantly depends on the type of products. This author divides products into functional and innovative, highlighting numerous differences in demand for them (in terms of product life cycle, margins, product diversity, average inventory rates, time required for custom production, etc.). Functional products include products that people buy in a wide range of retail outlets, such as grocery stores and gas stations. These products meet basic needs, which do not change significantly over time, so demand is stable and predictable. On the other hand, in order to give customers an additional reason to buy products, many innovative products are created, especially in the field of fashion and technology. The demand for these products is not easily predictable precisely because of their innovative nature. The lower the stability and predictability of demand, the closer the location of VAL services will be to customers (Chen & Notteboom, 2012), so that the company will be able to respond to customer requests in a timely manner.

The share of transport costs in total costs (F4) depends on distances within supply chains and energy costs (Chen & Notteboom, 2012), as well as supply strategies (Notteboom and Rodrigue, 2009). The higher the share of transport costs in total costs, the smaller the distance of the location of the realization of VAL services from the customers (Chen & Notteboom, 2012).

The product life cycle (F5) and ***product margin*** (F6) depend on the type of products. Functional products usually have a long life cycle, while life cycle of innovative products are generally shorter (usually only a few months), because companies that produce copies of products distort the competitive advantage of original products, so companies are forced to introduce further innovations very quickly (Fisher, 1997). VAL services for products with a short life cycle should be implemented as close as possible to customers. The characteristics of functional products and the demand for them lead to the development of competition and thus to low margins. On the other hand, innovative concepts contribute to increasing product margins. VAL services for high margin products should be implemented as close as possible to the customers (Chen & Notteboom, 2012).

Flexibility (F7), i.e. the ability to respond to changes in the market is also one of the factors that significantly affect the location of VAL services in the logistics network. The customer requests are more numerous and diverse, and their expectations about the speed and quality of response to requests are increasing (Tadić et al., 2013b; 2015). Of particular importance in this context is mass customization, i.e. production according to individual needs, wishes and requirements of the customers. To ensure flexibility, VAL services need to be located as close as possible to the customers (Chen & Notteboom, 2012).

Finally, the location of VAL services is influenced by ***market-specific product and packaging requirements*** (F8). The appearance, characteristics and specificity of products and packaging depend on the individual requirements of customers, but also on numerous collectivist factors and characteristics of demand, ethnic, cultural, linguistic, confessional characteristics of the market, region, country or local area. In parallel with the process of globalization that is still ongoing, the opposite processes are taking place, encouraging regional, national and local landmarks and contents, which are caused by various factors (geopolitical factors, the COVID19 pandemic, etc.). These processes further encourage the development of market-specific product and packaging requirements. In this context, the services of packaging, declaration, labeling, etc. are especially important. Greater specificity of products and packaging related to a particular market most often encourages companies to locate the realization of VAL services closer to the customers (Chen & Notteboom, 2012).

In addition to the above, there are a number of other factors that can influence the locating VAL services in the logistics network, such as (McCann, 1993; Chen & Noteboom, 2014; Rivera et al., 2016a; 2016b): type of VAL services, value added to the product, inventory holding policy, costs depending on the geographical area in the supply chain (storage costs, labor costs, etc.), level of technology of participants in the supply chain, availability of logistics clusters that provide additional opportunities and benefits for the implementation of VAL services, etc. Consideration and quantification of the influence of these factors on the location of VAL services are somewhat more complex compared to the previously described factors. Therefore, these factors will not be included in the model defined in this paper, but will be the subject of future research and expansion of this model.

3. MODEL FOR DETERMINING THE DEGREE OF CENTRALIZATION OF VAL SERVICES IN THE LOGISTICS NETWORK

This section will define a model for determining the degree of centralization of VAL services in the logistics network, based on fuzzy systems (FS) (Figure 1). To make it easier to define the inference machine, several fuzzy systems with two input variables will be defined. Namely, defining fuzzy systems with more input variables would increase the number of inference rules and make it more difficult to define them. The input variables for the first tier of fuzzy systems will be the factors defined in the previous section, taken from research conducted by Chen and Notteboom (2012). F1 and F2 will be inputs for fuzzy system FS1.1. There is a close connection between these two factors, bearing in mind that the high frequency of deliveries usually corresponds to a short customer response time. F3 and F4 are inputs for fuzzy system FS1.2, so the output value of this fuzzy system represents the joint influence of these two factors on the degree of centralization of VAL services. F5 and F6 are inputs for fuzzy system F2.1. These factors are grouped keeping in mind that both directly depend on the type of goods, which was explained in the previous section. F7 and F8 are the inputs for the FS2.2 fuzzy system. These factors are related because they relate to the adaptation of products to requirements, in the first case individual, and in the second collective. The outputs from these fuzzy systems are the inputs for the fuzzy systems FS1 and FS2 at the second tier. Finally, the outputs of the FS1 and FS2 fuzzy systems are the inputs for the fuzzy system FS at the third tier. The output of this fuzzy system is the degree of centralization of VAL services in the logistics network.

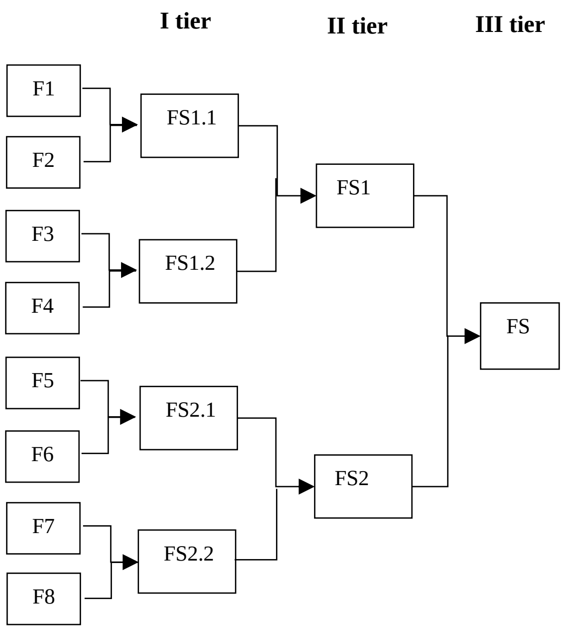


Figure 1: Model for determining the degree of centralization of VAL services

The parameters of the membership functions of the input and output variables are identical in all fuzzy systems. The user of the defined model defines the input values, i.e. the evaluations of each factor. The fuzzy sets, to which the input and output values of the fuzzy systems can belong to a certain degree, are triangular fuzzy numbers (0,0,4), (1,5,9) and (6,10,10). Triangular fuzzy numbers have been applied following the example of some previous research (Li et al., 2013; Tadić et al., 2019a; Krstić et al., 2021). Of course, fuzzy numbers in the form of a trapezoidal or Gaussian curve could also be used, but this would lead to a significant increase in the complexity of the problem. The impact of the application of such fuzzy numbers on the solution may be the subject of future research.

For input variables, fuzzy set (0,0,4) represents values that indicate small degree of centralization (e.g. short customer response time), fuzzy set (1,5,9) represents values that indicate medium degree of centralization (e.g. moderate demand stability and predictability), while the fuzzy set (6,10,10) represents values that indicate high degree of centralization (e.g. low flexibility). Considering the output variable of FS at the third tier, the fuzzy set (0,0,4) represents a small degree of centralization, i.e. a small distance of VAL services from the customers, the fuzzy set (1,5,9) represents the medium degree of centralization, while the fuzzy set (6,10,10) represents a high degree of centralization.

Thus, variables can take the values from the interval [0.10]. The higher value of input variables results in a greater degree of centralization as an output from the FS, i.e. moving further away the VAL services location from the end users. Table 1 shows two extreme cases. In the first case, all factors are rated with 0, which indicates a negative impact on centralization, so VAL services should be located in places in the logistics network that are very close to the customers. With the increase of the evaluation values for each of the factors, the degree of centralization increases. Therefore, in the second extreme case, when all evaluations are equal to 10, it the degree of centralization is very large. This means that complete centralization of VAL services is possible. It is important to emphasize that numerical evaluations represent the intensity of the influence of factors on the degree of centralization and that, in this context, they do not have to match with linguistic evaluations. More precisely, in the case of factors that are directly proportional to the degree of centralization (e.g. demand stability and predictability) there will be a match (short response time - low numerical evaluation - low degree of centralization), while in the case of inversely proportional factors (e.g. share of transport costs) there will be no match (large share of transport costs - low numerical evaluation - low degree of centralization).

Also, the rules of inference are identical in all fuzzy systems. The method of defining inference rules is shown in Table 2 on the example of the FS1.2. The interpretation of the rule will be explained on the example of rule 7. If the demand stability and predictability is high and the share of transport costs in total costs is large, then the impact of factors F3 and F4 on increasing the degree of centralization is medium.

Table 1: Influence of factor evaluations on the degree of centralization of VAL services

Fact.	***Evaluation 0***	***Degree of centr.***	***Evaluation 10***	***Degree of centr.***
F1	very short customer response time	Very low	very long response time very little market specificity	Very high
F2	very small economies of scale and high delivery frequency		very large economies of scale and high frequency of delivery	
F3	very low demand stability and predictability		very high demand stability and predictability	
F4	very large share of transport costs		very small share of transport costs	
F5	very short product life cycle		very long life cycle	
F6	very high product margin		very low product margin	
F7	very high flexibility		very little flexibility	
F8	very high specificity related to the market		very high specificity related to the market	

Table 2: Inference rules in fuzzy system FS1.2

Rule	F3 - demand stability and predictability	F4 - share of transport costs in total costs	Influence of factors F3 and F4 on increasing the degree of centralization
1	Low (0,0,4)	Large (0,0,4)	Small (0,0,4)
2	Low (0,0,4)	Medium (1,5,9)	Small (0,0,4)
3	Low (0,0,4)	Small (6,10,10)	Medium (1,5,9)
4	Medium (1,5,9)	Large (0,0,4)	Small (0,0,4)
5	Medium (1,5,9)	Medium (1,5,9)	Medium (1,5,9)
6	Medium (1,5,9)	Small (6,10,10)	Large (6,10,10)
7	High (6,10,10)	Large (0,0,4)	Medium (1,5,9)
8	High (6,10,10)	Medium (1,5,9)	Large (6,10,10)
9	High (6,10,10)	Small (6,10,10)	Large (6,10,10)

4. EXAMPLES OF THE DEFINED MODEL APPLICATION

The defined model is tested on the examples of hypothetical companies, which have an identical logistics network in Europe, consisting of 1 European logistics center (LC) in Germany, 1 national and several regional LC in 13 European countries (Figure 2). Company 1 sells food products, and Company 2 sells computer equipment. Table 3 gives evaluations for all factors.

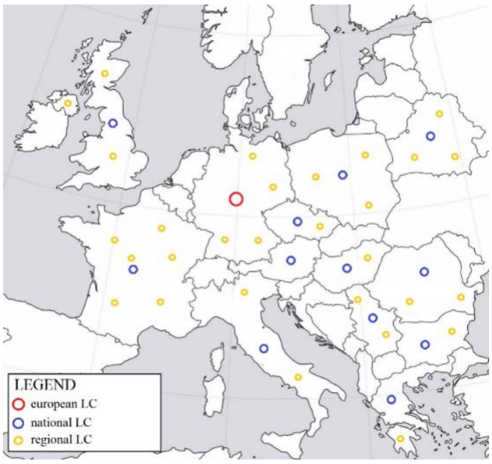


Figure 2: Logistics network of Companies 1 and 2

Table 3: Evaluations of factors influencing the centralization of VAL services of hypothetical companies

Company 1		
Fact.	***Linguistic evaluation***	***Num. evaluation***
F1	short customer response time	1
F2	small economies of scale and high delivery frequency	1
F3	medium demand stability and predictability	6
F4	medium share of transport costs	5
F5	long product life cycle	7
F6	low product margin	7
F7	medium flexibility	4
F8	high specificity related to the market	2

Company 2		
Fact.	***Linguistic evaluation***	***Num. evaluation***
F1	long customer response time	8
F2	large economies of scale and high delivery frequency	9
F3	medium demand stability and predictability	4
F4	large share of transport costs	7
F5	medium product life cycle	5
F6	medium product margin	4
F7	low flexibility	9
F8	low specificity related to the market	9

As described in Section 2, factor evaluations are predominantly influenced by the type of products, but also by the other factors. Companies trade in different products, so the evaluations of factors also differ, especially in terms of customer response time, economies of scale and delivery frequency, flexibility and specificity related to the market. Given the characteristics of the products and demand, food products require faster and more frequent deliveries. Also, product characteristics often change and adapt to individual and market needs (new flavors, aromas, quantities, etc.). On the other hand, computer equipment is a non-food commodity, which usually does not require high speed and delivery frequency, and its characteristics are often standardized and identical in relation to different markets. It is assumed that there are differences from the aspect of other factors, but that in the case of these companies they are less important. It is certain that these differences will also affect the differences in the degree of centralization of VAL services.

The fuzzy logic tool of the MATLAB programming language was used to obtain the solution. Defuzzification of output values in the fuzzy system FS was performed by the centroid method. The approximate value of the degree of centralization of VAL services in the case of Company 1 is 4, while in the case of Company 2 is 6. Therefore, in the first case it is justified to locate VAL services in all national LCs, while in the second case VAL services should be located only in some national LCs (Figure 3). In case the degree of centralization is lower than 4, VAL services could be located in some or all regional centers. On the other hand, if a higher degree of centralization of 6 was obtained, it would be justified to implement them in a smaller number of national and (or) in the European LC.

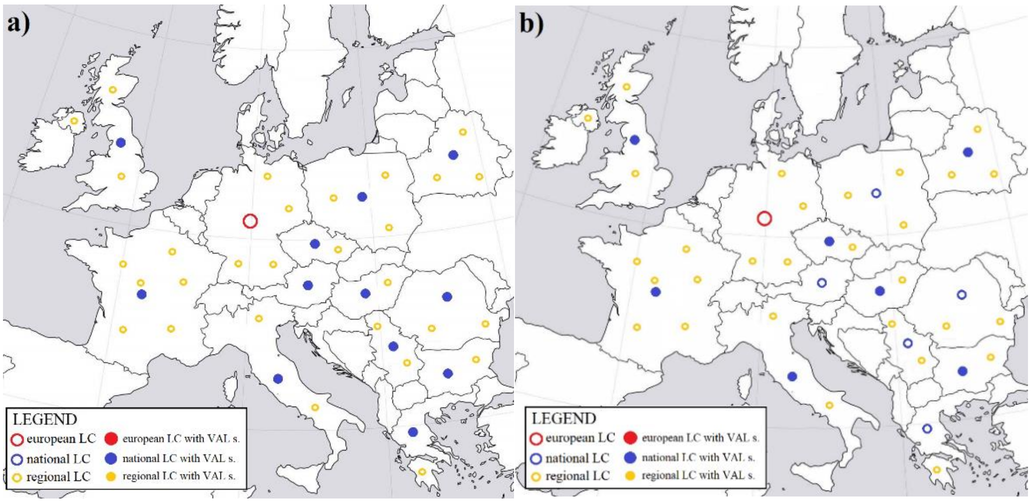


Figure 3: Logistics networks of Company 1 (a) and Company 2 (b) with locations of VAL services

5. CONCLUSION

Locating VAL services is a very important decision, which depends on many factors such as: customer response time, economies of scale and delivery frequency, demand stability and predictability, product life cycle and margin, share of transport costs in total costs, flexibility and specificity of certain products or packaging for individual markets, etc. Based on these factors, the required degree of (de)centralization of VAL services in the logistics network can be evaluated.

This paper analyzed the factors influencing the decision-making on the locations where VAL services are performed in the logistics network. A model based on the fuzzy systems has also been defined, which gives the degree of centralization of VAL services in the logistics network based on the defined factor evaluations, i.e. input values. This achieved the basic goal and contribution of the paper. In this or an upgraded form, the model can be a support to companies in making strategic and tactical decisions regarding the location of VAL services.

The paper provides opportunities for numerous changes, extensions and future research. In some future research, a model can be defined in which, instead of triangular, fuzzy numbers in the form of a trapezoidal or Gaussian curve would be applied. Also, other factors influencing the decision to locate should be analyzed (type of VAL services, value added to the product, inventory policy, costs depending on geographical area, level of technology, availability of logistics clusters, etc.) and join them to input variables in defined model. It is also necessary to analyze whether there is a difference in the weights/importance of these factors, especially from the aspect of different stakeholders (retailers, logistics providers, customers). In this context, it is possible to upgrade the defined model, i.e. combine it with some multi-criteria decision-making methods.

REFERENCES

[1] Agarwal, A., Shankar, R., & Tiwari, M. K. (2007). Modeling agility of supply chain. Industrial Marketing Management, 36(4), 443–457.

[2] Besanko, D., Dranove, D., Shanley, M., & Schaefer, S. (2009). Economics of strategy. John Wiley & Sons.

[3] Bowersox, D.J., Closs, D.J., & Cooper, M.B. (2010). Supply Chain Logistics Management, 3rd ed., The McGraw-Hill/Irwin Series Operations and Decision Sciences

[4] Chen, J.C., & Cox, R.A. (2012). Value stream management for lean office: a case study. American Journal of Industrial and Business Management, 2(2), 17−29.

[5] Chen, L., & Notteboom, T. (2012). Determinants for assigning value-added logistics services to logistics centers within a supply chain configuration. Journal of International Logistics and Trade, 10(1), 3-41.

[6] Chen, L., & Notteboom, T. (2014). A cost perspective on the location of value-added logistics services in supply chains. International Journal of Logistics Systems and Management, 18(1), 24-48.

[7] Chiang, A. H., Chen, W. H., & Wu, S. (2014). Does high supply chain integration enhance customer response speed? The Service Industries Journal, 35(1-2), 24–43.

[8] Fisher, M.L. (1997). What is the right supply chain for your product. Harvard Business Review. March-April 1997, reprint No. 97205.

[9] Ghasemi, P., & Khalili-Damghani, K. (2021). A robust simulation-optimization approach for pre-disaster multi-period location–allocation–inventory planning. Mathematics and computers in simulation, 179, 69-95.

[10] Hoek, R.I. (2001). The contribution of performance measurement to the expansion of third party logistics alliances in the supply chain. International Journal of Operations & Production Management, 21(1/2), 15–29.

[11] Jánošíková, Ľ., Jankovič, P., Kvet, M., & Zajacová, F. (2021). Coverage versus response time objectives in ambulance location. International Journal of Health Geographics, 20(1), 1-16.

[12] Jayaram, J. & Tan, K-C. (2010). Supply chain integration with third-party logistics providers, International Journal of Production Economics, 125, 262–271.

[13] Krstić, M., Kovač, M., & Tadić, S. (2019). Dry port location selection: Case study for the Adriatic ports. XLVI International Symposium of Operational Research, SYM-OP-IS (pp. 303-308), Kladovo, Serbia

[14] Krstić, M., Tadić, S., Kovač, M., Roso, V., & Zečević, S. (2021). A Novel Hybrid MCDM Model for the Evaluation of Sustainable Last Mile Solutions. Mathematical Problems in Engineering, 2021.

[15] Lai, K-H. (2004). Service capability and performance of logistics service providers, Transportation Research Part E, 40(5), 385–399.

[16] Li, L. (2011). Assessing the relational benefits of logistics services perceived by manufacturers in supply chain, International Journal of Production Economics, 132(1), 58–67.

[17] Li, Y. Z., Hu, H., & Huang, D. Z. (2013). Developing an effective fuzzy logic model for managing risks in marine oil transport. International Journal of Shipping and Transport Logistics, 5(4-5), 485-499.

[18] McCann, P. (1993). The logistics-cost location-production problem. Journal of Regional Science, 33(4), 503–516.

[19] Mentzer, J.T., Rutner, S.M., & Matsuno, K. (1997). Application of the means-end value hierarchy model to understanding logistics services value, International Journal of Physical Distribution & Logistics Management, 27 (9/10), 630–643.

[20] Notteboom, T., & Rodrigue, J.P. (2009). The future of containerization: perspectives from maritime and inland freight distribution. GeoJournal, 74, 7-22.

[21] Pamučar, D., Žižović, M., Biswas, S., & Božanić, D. (2021). A new logarithm methodology of additive weights (LMAW) for multi-criteria decision-making: Application in logistics. Facta Universitatis, Series: Mechanical Engineering, 19(3), 361 – 380.

[22] Rivera, L., Gligor, D., & Sheffi, Y. (2016a). The benefits of logistics clustering. International Journal of Physical Distribution & Logistics Management 46(3), 242-268.

[23] Rivera, L., Sheffi, Y., & Knoppen, D. (2016b). Logistics clusters: The impact of further agglomeration, training and firm size on collaboration and value added services. International Journal of Production Economics, 179, 285-294.

[24] Sabur, V. F., & Simatupang, T. M. (2015). Improvement of customer response time using Lean Office. International Journal of Services and Operations Management, 20(1), 59-85.

[25] Tadić, S. R., Zečević, S. M., & Krstić, M. D. (2013a). Locating city logistics terminal using fuzzy AHP analysis: Case of Belgrade. Tehnika, 68(4), 707-716.

[26] Tadić, S., Krstić, M., & Brnjac, N. (2019a). Selection of efficient types of inland intermodal terminals. Journal of Transport Geography, 78, 170-180.

[27] Tadić, S., Krstić, M., & Kovač, M. (2019b). Location of dry port terminals: Case study for the territory of Republic of Serbia. 5th scientific conference with international participation “Politehnika”, (pp. 558-563). Belgrade, Serbia

[28] Tadić, S., Krstić, M., & Kovač, M. (2021). Implementation of the dry port concept in central and Southeastern Europe logistics network. World Review of Intermodal Transportation Research, 10(2), 131-151.

[29] Tadić, S., Krstić, M., Roso, V., & Brnjac, N. (2020). Dry port terminal location selection by applying the hybrid grey MCDM model. Sustainability, 12(17), 6983.

[30] Tadić, S., Zečević, S., & Krstić, M. (2012). City logistics terminal location selection using combined fuzzy AHP and fuzzy TOPSIS analysis. 1st International conference on traffic and transport engineering, ICTTE (pp. 345-358). Belgrade, Serbia

[31] Tadić, S., Zečević, S., & Krstić, M. (2015). City logistics – status and trends. International journal for traffic and transport engineering, 5(3), 319-343.

[32] Tadić, S., Zečević, S., & Petrović-Vujačić, J. (2013b). Globalni trendovi i razvoj logistike. Ekonomski vidici, 18(4), 519-532.

[33] Wang, H., Zeng, W., & Cao, R. (2021). Simulation of the urban jobs–housing location selection and spatial relationship using a multi-agent approach. ISPRS International Journal of Geo-Information, 10(1), 16.

[34] Zečević, S., Tadić, S., & Krstić, M. (2017). Intermodal transport terminal location selection using a novel hybrid MCDM model. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 25(6), 853-876.

PENAL PROVISIONS IN THE NAVIGATION LAW OF THE REPUBLIC OF SERBIA

Nataša Tomić-Petrović, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, Belgrade, Serbia
natasa@sf.bg.ac.rs

ABSTRACT

Within the general purpose of criminal sanctions - suppression of acts that violate or endanger values protected by criminal law - the purpose of punishment in the field of navigation is also: 1) preventing the perpetrator from committing crimes and influencing him not to commit crimes in the future; 2) influencing others not to commit crimes; 3) expressing social condemnation for a criminal offense, strengthening morals and strengthening the obligation to respect the law; 4) achieving fairness and proportionality between the committed act and the gravity of the criminal sanction. The purpose of prescribing, imposing and applying misdemeanor sanctions is that citizens respect the legal system and that in the future no misdemeanors are committed for which a natural person, entrepreneur, legal entity and responsible person in a legal entity can be held liable.

Chapter 26. of the Criminal Code of the Republic of Serbia deals with criminal offenses against public transport, where we will consider criminal offenses in particular: Endangering public traffic (Article 289), Endangering the safety of air or maritime traffic or a fixed platform (Article 292), Hijacking of aircraft, ships and other means of transport (Article 293) and Piracy (Article 294). Law on Maritime Navigation (2011), Law on Navigation and Ports on Inland Waters (2010) and Law on Trade Shipping (2015) of the Republic of Serbia also provide for penal provisions that will be elaborated in the paper. The aim of the author is to offer guidelines in order to continue our struggle for safer navigation.

Keywords: penal, law, sanction, criminal act, misdemeanor

1. INTRODUCTION

History is a constant searching of past times, wrote F. Brodel. As early as 1350, Emperor Dušan had a fleet of four galleys that the Venetians allowed him to buy in Venice "as a sign of special friendship". And on September 20th, 1439, the Serbian ruler issued a Charter on the paying back the debts and a Charter on the abolition of customs in Trebinje. The Charter also stated that property from a wrecked Venetian ship cannot be seized. This item was introduced because of the despot Jovan Komnin Assen, the brother of Empress Jelena, who appropriated the trophy from one such Venetian ship. Emperor Dusan was also ready to send 1,120 perpers in the name of compensation. [2]

Once upon a time, there was a belief that the navigation of ships must be interrupted at the exit from the Mediterranean Sea to the then unknown sea, today's Atlantic Ocean. It is estimated that a total of three million sunken ships lie at the bottom of all large water surfaces on the Earth today. We remember the tragic story of the Russian submarine "Kursk" which sank in the Barents Sea /at a depth of only 108 meters/ with 118 crew members and two nuclear reactors, which were taken out soon after the tragedy. Three more Russian nuclear submarines lie in the same waters.[1]

Today, we are witnessing growing challenges on the maritime front. International and interstate waterways are determined by the Government. Today the focus is on preventing air and water pollution caused by transport. Taken in consideration that almost three-quarters of the Earth's surface is covered by oceans, it is interesting to recall December 2009 when the world's largest transatlantic passenger ship, the Sea Oasis[2], a 360-meter-long and 47-meter-wide ecological ship built in Finland, using wastewater treatment system and saving energy started sailing.

In this paper we shall analize criminal legislation in the area of navigation in the Republic of Serbia and offer guidelines in order to continue our struggle for safer navigation.

2. THE CRIMINAL CODE OF THE REPUBLIC OF SERBIA

In accordance with the Criminal Code of the Republic of Serbia[3], the criminal legislation of the Republic of Serbia applies to anyone who commits a crime on its territory, but also to anyone who commits a crime on a domestic ship, regardless of where the ship is at the time

[1] The first US nuclear submarine, the Nautilus, was "christened" in January 1954, while the first Soviet K-3 nuclear submarine sailed in 1958.

[2] The floating giant belongs to the fleet of the American company "Royal Caribian".

[3] "Official Gazette of the Republic of Serbia", no. 85/05, 88/05, 107/05, 72/09, 111/09, 121/12, 104/13, 108/14, 94/16, 35/19.

of the crime. If criminal proceedings have been initiated or completed in a foreign country in the above cases, criminal prosecution in Serbia will be undertaken only with the approval of the Republic Public Prosecutor. The criminal prosecution of an alien in these cases may, subject to reciprocity, be ceded to a foreign state.[4]

Chapter 26. of the Criminal Code deals with criminal offenses against public transport, where we will consider criminal offenses: Endangering public traffic (article 289), Endangering the safety of air or maritime traffic or fixed platform (article 292), Hijacking of aircraft, ship and other means of transport (article 293) and Piracy (article 294). [see: 4]

The criminal offense of "Endangering Public Traffic" (article 289. of the Criminal Code) commits a participant in traffic on roads who does not comply with traffic regulations and thus endangers public traffic to endanger the life or body of people or property on a larger scale, so as a result light assault and battery occurs or causes property damage exceeding the amount of two hundred thousand dinars, and will be punished by imprisonment for a term not exceeding three years. Whoever does not comply with traffic regulations and thus endangers railway, ship, tram, trolleybus, bus or cableway traffic in such a way as to endanger the life or body of people or large property, will be punished by imprisonment for six months to five years. If the said acts were committed by negligence, the perpetrator will be punished by a fine or imprisonment for a term not exceeding one year.

The criminal offense "Endangering the safety of air or maritime traffic or fixed platform" (article 292. of the Criminal Code) is committed by violence against a person in an aircraft, ship or fixed platform located in the continental shelf, or their cargo, by installation or entry into the aircraft, on a ship or stationary platform of an explosive or other dangerous device or substance or by destroying or damaging or obstructing the navigation device or causing other damage to an aircraft, ship or stationary platform endangering the safety of air traffic or shipping or the security of a stationary platform and will be punished by imprisonment for two to ten years. If this act resulted in severe assault and battery to a person or large-scale damage, the perpetrator will be punished by imprisonment for a term between two and twelve years, and if one or more persons have died as a result of this offense, the perpetrator will be punished by imprisonment for five to fifteen years. Whoever threatens to commit the said act, shall be punished by imprisonment for a term between six months and five years.

The criminal offense of "Hijacking of Aircraft, Ship and Other Means of Transport" (article 293. of the Criminal Code) is committed by whoever, by force or threat of use of force, takes control of an aircraft in flight or a ship during navigation or other public mean of transport while driving or over a stationary platform in the continental shelf and will be punished by imprisonment for a term between two and ten years. If this act resulted in severe assault and battery to a person or large-scale damage, the perpetrator will be punished by imprisonment for two to twelve years, and if this act resulted in the death of one or more persons, the perpetrator will be punished by imprisonment from five to fifteen years.

Criminal Code of the Republic of Serbia in article 294. predicts **the criminal offense "Piracy".** A crew member or passenger of a ship who, on the high seas or in a place not under the authority of any State, commits violence or robbery against persons on another ship, detains, seizes, damages or destroys another ship or property on it or causes large-scale damage, shall be punished by imprisonment for a term between two and twelve years, and if one or more persons have died as a result of this offense, the perpetrator shall be punished by imprisonment for a term between five and fifteen years.

In March 2021, Denmark, followed by Spain, Portugal, Italy, Great Britain and the United States, decided to start deploying their warships along the Gulf of Guinea and at the same time strengthen maritime security cooperation with coastal countries in the region. At the end of November of the same year, the navy of the Kingdom of Denmark issued an official announcement about an armed incident in the international waters of the Gulf of Guinea[5]. An international initiative is needed to fight piracy. Since the beginning of the 21st century, China has also participated in 39 joint anti-piracy naval maneuvers with West African countries.

This year the migrant crisis became more and more uncontrolled, but has developed in Europe since 2014. and represents the influx of migrants from Asia and Africa, and now Ukraine. [see: 3]

It should also be mentioned that the Criminal Code of the Republic of Serbia predicts in article 391. **the criminal offense of "Terrorism"** committed by anyone with the intent to seriously intimidate the population, or to force Serbia, a foreign state or an international organization to do or not do something, or to seriously endanger or violate the basic constitutional, political, economic or social structures of Serbia, foreign state or international organization, among other things: - performs hijacking of aircraft, ship or other means of public transport or transport of goods.

[4] See: article 6. of the Criminal Code of the Republic of Serbia, "Official Gazette of the Republic of Serbia", no. 85/05, 88/05, 107/05, 72/09, 111/09, 121/12, 104/13, 108/14, 94/16, 35/19.

[5] The Gulf of Guinea is a maritime region of the Atlantic with a 6,000 kilometers long coastline shared by 20 countries between Angola and Senegal. At the beginning of the century, pirate attacks began to take place along the coast of Somalia, in East Africa, first on foreign fishing boats in poaching, and then on tankers. Today, that maritime region is the zone of the most frequent and brutal pirate attacks and kidnappings in the world, according to the International Maritime Agency within the UN. During 2020, 99% of all pirate attacks and kidnappings took place in the Gulf of Guinea.

Whoever threatens to commit this criminal offense, will be punished by imprisonment for a term between six months and five years. If the death of one or more persons occurred during the execution of the said act or great destruction was caused, the perpetrator will be punished by imprisonment for a term not less than ten years.

Article 426. of the Criminal Code of the Republic of Serbia regulates **the criminal offense "Leaving a damaged ship and aircraft prematurely"** committed by the commander of a warship who leaves a damaged ship during war or armed conflict before performing his duty under the ship service regulations who will be punished by imprisonment for two to ten years. A crew member of a warship who leaves a damaged ship during war or armed conflict before the ship's commander has issued an order to leave, or a crew member of a military aircraft who leaves a damaged military aircraft during war or armed conflict before performing his duty under the regulations on flying and using aircraft will be punished by imprisonment for one to eight years.

3. THE LAWS ON NAVIGATION IN THE REPUBLIC OF SERBIA

The **Law on Maritime Navigation** (2011)[6] (part eleven), the **Law on** Navigation and Ports on Inland Waters (2010)7 (part eight) and the Law on Trade Shipping8 (2015) (part eleven) of the Republic of Serbia also provide for penal provisions that will be elaborated in more detail in the paper.

3.1. The Law on Maritime navigation

The Law on Maritime Navigation[9] of the Republic of Serbia deals in particular with the suppression of illegal actions against the safety of maritime navigation. In the sense of the suppression of unlawful Acts against the Maritime Navigation Safety, it is prohibited to the commander and another member of the crew, passenger or other person on a domestic ship to: 1) by force or threat or any other form of intimidation seize or take over the control over a ship; 2) perform an act of violence against a person on board the ship if that act is likely to endanger the safe navigation of the ship; 3) destroy or cause larger damage to the vessel ship or its cargo, which can jeopardize the safety of the vessel; 4) place or allow placing on the domestic ship, by any means, device or substance which is likely to destroy the ship, or cause damage to the ship or load; 5) destroy or seriously damage maritime navigation installations or seriously interfere with their operation, if such action may endanger the navigation safety; 6) transmit false information, thereby endangering the safe navigation of the ship; 7) threaten in order to compel a physical or juristic person to do or abstain from doing any act, if that threat is likely to endanger the safe navigation of the ship. (article 172)

It is forbidden for the captain, other member of the ship's crew, passenger or other person on the domestic ship to: commit an act, which by its nature is intended to intimidate the population, or to force a government or international organization to perform, or refrain from performing any action in connection with the discharge of explosives, radioactive material or biological-chemical-nuclear weapons from that domestic ship, discharges oil, liquefied natural gases, or other hazardous or harmful thing in an quantity or concentration that causes or is likely to cause death or serious injury of people or pollution of marine environment. (article 173) It is forbidden for the captain and another member of the crew on a domestic ship to transport on board: 1) explosive or radioactive material and biological-chemical-nuclear weapons, knowing that they are intended for committing a crime that will cause death or serious injury of people or environmental pollution, intimidation of population, or forcing a government or international organization to perform or refrain from performing any action; 2) original material, special fission material, equipment, material specially designed or prepared for the processing, use or production of special fission material knowing that it is intended for use in nuclear explosive activities, or any other nuclear activity without protective measures; 3) equipment, materials or software or similar technology that significantly contribute to the design, production or delivery of biological-chemical-nuclear weapons, with the intention of using them for that purpose. (article 174)

The captain of a domestic ship may not transport a person on board if he has information that that person has committed an act from articles 172-174. of the Law on maritime navigation, and cannot help that person to avoid prosecution. (article 175) The captain of a domestic ship may extradite to the authorities of another member state of the International Convention on the Suppression of Unlawful Acts against the Safety of Maritime Navigation a person on board a domestic ship for who has reason to believe that has committed acts from articles 172-175. of this law. The captain of the domestic ship on which this person is on board shall inform the competent authorities of the State to which he intends to surrender that person of his intention and of the reasons before entering the territorial sea of that State, if possible. (see: article 176) Convention on the Suppression of Unlawful Acts against the Safety of Maritime Navigation is adopted in our country in March 2004 with the adoption of the Decree promulgating the Law on Ratification of the Convention on the Suppression of Unlawful Acts against the Safety of

[6] Official Gazette of the Republic of Serbia", no. 87/2011, 104/13, 18/15, 113/17, 83/18.
[7] Official Gazette of the Republic of Serbia", no. 73/2010, 121/2012.
[8] Official Gazette of the Republic of Serbia", no. 96/15, 113/17.

[9] "Official Gazette of the Republic of Serbia", no. 87/11, 104/13, 18/15, 113/17, 83/18.

Maritime Navigation.[10] [5] By this act the state parties have confirmed their wish to monitor rules and standards related to the prevention and control of unlawful acts against ships and persons on board ships, in order, to update them if necessary.[1]

Article 194. of the Law on Maritime Navigation regulates the "**Criminal offense of Marine Pollution**" committed by the captain or crew member of a domestic ship who intentionally, recklessly or negligently pollutes the marine environment, in a manner that affects changes in water quality, in zones from article 163. of this law, and who will be punished by imprisonment for a term not exceeding three years. A legal entity is liable for this criminal offense if the criminal offense was committed in its favor by a natural person who occupies a leading position within the legal entity in terms of authorization to represent the legal entity, decision-making on behalf of the legal entity or control within the legal entity. The liability of that legal entity does not exclude the criminal liability of a natural person who, as the perpetrator, instigator or accomplice, participated in the execution of the criminal offense referred to in paragraph 1 of this article.

Article 195. of the Law on Maritime Navigation provides for a fine of 150,000 to 2,000,000 dinars for an economic offense that a company or other legal entity will be punished with, also if they do not apply and maintain the Safety Management System. For the stated action, the responsible person in the legal entity or another legal entity will also be fined from 10,000 to 100,000 dinars for the economic crime.

According to article 196. of the Law on Maritime Navigation a fine of 50,000 to 2,000,000 dinars for a misdemeanor will be imposed on, company or other legal entity also: - if a larger number of passengers than defined went on board a passenger ship; - if it embarks and distributes cargo on board contrary to the provisions of article 29 of this Law; - if it puts into navigation or keeps in navigation a ship or other vessel without any of the prescribed ship documents and books or the ship documents or books are kept contrary to the provisions of this Law; - if the prescribed minimum number of crew members with the prescribed titles and authorizations on competence is not embarked on the ship or other vessel. For this violation, the responsible person, the captain of the ship or the person who replaces him, will be fined from 30,000 to 150,000 dinars.

Article 197. of the Law on Maritime Navigation provides for a fine of 100,000 to 1,000,000 dinars that will be imposed for a misdemeanor, to company or other legal entity also: - if there is no international certificate on the prevention of pollution during the transport of harmful liquid items in bulk; - if there is no ship oil pollution emergency plan (SOPEP) and an international certificate on the prevention of oil pollution; - if there is no international certificate for the prevention of air pollution (IAPP certificate), international certificate for the prevention of air pollution from engine emissions (NOx - EIAPP certificate) and IMO certificate of type approval for each incinerator. For these actions, the responsible person in the company or other legal entity will also be fined from 10,000 to 100,000 dinars for the misdemeanor.

According to article 198. of the Law on Maritime Navigation a fine of 30,000 to 150,000 dinars will be imposed on the responsible person - the captain of the ship or the person who replaces him also: - if he does not personally manage the ship when required by the safety of the ship and if he does not operate the ship when the ship enters the port or leaves from it, as in all other cases, when required by the safety of the ship and navigation; - if during the voyage of the ship does not take the measures to the crew member, passenger or other person on the ship, who committed the crime, necessary to prevent or mitigate the harmful consequences of that crime and the perpetrator is called to account.

Article 199. of the Law on Maritime Navigation provides for a fine of 10,000 to 100,000 dinars that will be imposed on a natural person - a member of the ship's crew: 1) who has acquired the authorization of qualification, i.e. special qualification of a member of the ship's crew by fraud or on the basis of falsified documents; 2) who, by violating his duty, does not act according to the rules of navigation and thus endangers traffic safety or damages the ship or cargo on it, or endangers the safety of passengers on board or other crew members or the environment from pollution by dangerous and harmful items (oil, waste fuels and their mixtures, waste water and other waste materials, as well as radioactive or similar waste) from the ship (article 85).

According to article 200. of the Law on Maritime Navigation a fine of 20,000 to 150,000 dinars will be imposed on the responsible person - the captain of the ship or the person who replaces him: 1) if, contrary to the provisions of this Law, he transports passengers by a ship not intended for passengers; 2) if does not maintain machines, devices and equipment in good condition on board or if it does not take care of the safety of ship's devices for embarking and disembarking of passengers, dangerous and other cargo, and for proper embarkation, accommodation and disembarkation of passengers.

Article 201. of the Law on Maritime Navigation provides for a fine of 10,000 to 150,000 dinars that will be imposed on the responsible person - the captain or the person who replaces him also: - if he fails to submit a report on the criminal offense committed on board to the diplomatic or consular mission of the Republic of

[10] "Official Gazette of SCG - International treaties", no. 2/04, "Official Gazette of RS - International treaties", no. 1/10.

Serbia in the country in whose port it sails into after the committed criminal offense, or if the perpetrators of the criminal offense are not treated according to the instructions of that diplomatic or consular mission.

According to articles 202. and 203. of the Law on Maritime Navigation a fine of 10,000 to 100,000 dinars will be imposed on a natural person for a misdemeanor: if the boat and yacht are operated by a person who does not have the appropriate document, as well as at least the prescribed number of crew members professionally trained to operate the boat and yacht. In addition to the penalty for violations from art. 196, 198 and 199 of this Law, the captain and other member of the ship's and other vessels crew may, as a protective measure, be prohibited from performing certain activities on any ship for a period of one year.

Article 204. of the Law on Maritime Navigation proclaims that the misdemeanor procedure in the first instance, for the misdemeanors from the Law on Maritime Navigation, is conducted and the decision on the misdemeanor is made by the Commission for Misdemeanors in Navigation.

3.2. The Law on Navigation and Ports on Inland Waters

Penal provisions for economic offenses and misdemeanors are also prescribed by the Law on Navigation and Ports on Inland Waters[11]**.**

According to the article 265. of the Law on Navigation and Ports on Inland Waters a fine of 100,000 to 3,000,000 dinars will be imposed on a company or other legal entity for an economic offense also: - if it breaks or damages the air or underwater telecommunication cable, or the high voltage cable, the underwater power supply, oil, gas or water pipeline installed on the waterway and thereby disrupting telecommunication connections, the supply of electricity, oil, gas or water; - if, by order of the Harbor Master's Office, a damaged, stranded or sunken vessel, or an object lost from the vessel that interferes with or endangers the safety of navigation, is not removed from the waterway; - if it releases, spills or discharges from the vessel into inland waters harmful objects or substances that may cause pollution or create an obstacle or danger to navigation. For these actions, the responsible person in the company or other legal entity will be fined from 30,000 to 200,000 dinars.

Article 266. of the Law on Navigation and Ports on Inland Waters provides for a fine of 50,000 to 2,000,000 dinars that will be imposed on a company or other legal entity for an economic offense also: - if it fails to record data that are important for the safety of navigation; - if it does not maintain the port, i.e. the pier and the temporary reloading point in a condition that ensures the safe reception of vessels and the performance of port activities in accordance with their purpose. For these actions, the responsible person in the company or other legal entity will also be fined from 20,000 to 150,000 dinars for the economic offense.

According to the article 267. of the Law on Navigation and Ports on Inland Waters a fine of 150,000 to 2,000,000 dinars will be imposed for a misdemeanor, on company or other legal entity also: - if it does not regulate and maintain navigability and does not set up navigation safety facilities in a way to ensure safe navigation in accordance with determined waterway category; - if it discharges, spills or dumps into inland waters harmful objects or substances, parts of cargo or waste from cargo that may cause water pollution or create an obstacle or danger to navigation, as well as if it burns garbage on board (by article 276. a fine of 10,000 to 100,000 dinars will be imposed on a member of the vessel's crew for this misdemeanor); - if, by order of the Minister responsible for internal affairs, it does not engage in the search and rescue of endangered persons and objects on waterways; - if the ship is sailing outside a certain navigation zone or contrary to a certain purpose or if the ship takes a voyage for which the ship has not been declared capable contrary to the data from the ship's certificate; - if it puts into navigation or keeps in navigation a ship and another vessel without any of the ship's documents and books, prescribed by this Law; - if it performs activities in the port that endanger the safety of people, vessels, pollutes the environment or performs other activities that are contrary to the provisions of order in the port; For these actions, the responsible person in the company or other legal entity will also be fined from 20,000 to 150,000 dinars for the misdemeanor.

Article 268. of the Law on Navigation and Ports on Inland Waters provides for a fine of 100,000 to 2,000,000 dinars that will be imposed on an authorized legal entity for technical maintenance of state waterways, i.e. an authorized legal entity for technical maintenance of state waterways on the territory of the Autonomous Province also: - if it does not regulate and does not maintain navigability and does not set up navigation safety facilities in a way to ensure safe navigation in accordance with the established category of waterway. For these actions, the responsible person in the authorized legal entity for technical maintenance of state waterways, i.e. the authorized legal entity for technical maintenance of state waterways in the territory of the autonomous province, will be fined from 5,000 to 150,000 dinars.

According to the article 269. of the Law on Navigation and Ports on Inland Waters a fine of 100,000 to 2,000,000 for the misdemeanor will be imposed on a legal entity - port operator if: - it performs port activity outside the port area; - if it performs port activity without the approval of the Agency. For these actions, the responsible person in the legal entity will also be fined for the misdemeanor from 5,000 to 150,000 dinars.

[11] "Official Gazette of the Republic of Serbia", no. *73/2010, 121/2012.*

Article 270. of the Law on Navigation and Ports on Inland Waters provides for a fine of 30,000 to 150,000 dinars that will be imposed on the captain of a foreign merchant ship, i.e. a vessel or a person who replaces him, also: - if the foreign vessel is sailing on state waterways without approval; - if, when entering the waterways of the Republic of Serbia, it fails to inform the Harbor Master's Office of the quantity, manner of storage and type of dangerous cargo it carries, as well as of the port or pier of disembarkation; - if it discharges, spills or dumps into inland waters harmful objects or substances, parts of cargo or cargo waste that may cause pollution of inland waters or create an obstacle or danger to navigation, as well as if it burns garbage on board; - if they do not act in accordance with the orders issued by the Harbor Master's Office; - if he does not keep the vessel at the place of the navigation accident until the end of the investigation, if he does not remove the vessel whose position endangers safety and does not inform the competent Harbor Master's Office about the navigation accident.

Article 271. of the Law on Navigation and Ports on Inland Waters provides for a fine of 20,000 to 150,000 dinars for the misdemeanor that will be imposed on the captain of the ship or the person who replaces him also: - if during the voyage of the ship does not take measures toward the crew member, passenger or other person on the ship or ship in towing or pushing, who committed the crime, necessary to prevent or mitigate the harmful consequences of that crime and call the perpetrator to account; - if he does not undertake the rescue of the ship with which the ship he commands collided or which does not remove such a ship from the waterway, if there is a danger that it will sink; - if it does not undertake the rescue of the ship requesting assistance on inland waters, if the ship it commands is nearby.

According to the article 273. of the Law on Navigation and Ports on Inland Waters a fine of 10,000 to 100,000 dinars will be imposed for the misdemeanor on a member of the crew of a ship and another vessel who, in violation of his duty prescribed by this Law, fails to act in accordance with the rules of navigation and thereby endanger the safety of navigation or damages the ship or other vessel or cargo on it, or endangers the safety of passengers and persons on board, or another vessel or other crew members or the environment from pollution by dangerous and harmful substances from the ship or other vessel.

Article 275. of the Law on Navigation and Ports on Inland Waters provides for a fine of 10,000 to 150,000 dinars that will be imposed on the captain of the ship or the person who replaces him also: - if he fails to submit a report to the diplomatic mission or the consular mission of the Republic of Serbia in the country in whose first port, i.e. pier after the crime, the ship sails into, or if the perpetrators are not treated according to the instructions of the diplomatic or consular mission of the Republic of Serbia.

Article 277. of the Law on Navigation and Ports on Inland Waters provides for a fine of 5,000 to 80,000 dinars that will be imposed on a natural person for a misdemeanor also: - if he operates a boat, floating body or floating object without appropriate professional training; and - if it does not inform the competent Harbor Master's Office about the navigation accident.

According to the article 278. of the Law on Navigation and Ports on Inland Waters in addition to the penalty for misdemeanors under article 271, item 2), 8), 10), 12) and 13) of this Law, to the captain and other crew members of ship and other vessels may, as a protective measure, be prohibited, as a protective measure, exercising all or some authorizations for performing certain duties on any ship or other vessel for a period of two years. The protective measures referred to in paragraph 1. of this article will be imposed by the Misdemeanor Court.

Article 279. of the Law on Navigation and Ports on Inland Waters provides for the misdemeanor procedure in the first instance, for the misdemeanors from this law, conducted and the decision on the misdemeanor made by the Commission for misdemeanors in navigation in the ministry appointed by the minister. The Commission is obliged to keep records of misdemeanors and passed measures in misdemeanor proceedings. The misdemeanor procedure in the second instance is conducted by the Misdemeanor Court.

3.3. The Law on Trade Shipping

The Law on Trade Shipping[12] of the Republic of Serbia as a property law also contains part (11) on penal provisions.

According to the article 789. of the Law on Trade Shipping a fine of 50,000 to 500,000 dinars will be imposed on a company or other legal entity for an economic offense if it transports persons under six years of age without an escort, persons suffering from infectious diseases, persons intoxicated, explosive, highly flammable, toxic, radioactive, corrosive and infectious substances, organic peroxides, as well as other objects which due to their characteristics may be harmful and dangerous to human safety or health or may cause other damage. For these actions, the responsible person in the legal entity or another legal entity will also be fined for economic offense with a fine of 10,000 to 100,000 dinars.

Article 790. of the Law on Trade Shipping provides for fines of 50,000 to 2,000,000 dinars for a company or other legal entity that will be fined for a misdemeanor: - if it performs the activity of a carrier of inland navigation contrary to the conditions referred to in article 19. of this Law; - if it performs the activity of a maritime company or business manager of a maritime

[12] “Official Gazette of the Republic of Serbia”, no. 96/15, 113/17.

company without the approval of the Ministry. A fine of 5,000 to 150,000 dinars will be imposed on a natural person who commits these offenses, and a fine of 10,000 to 500,000 dinars will be imposed on an entrepreneur who commits this offense.

According to the article 791. of the Law on Trade Shipping a fine of 5,000 to 150,000 dinars will be imposed on the responsible person - the captain of the ship or the person who replaces him: 1) if he performs cabotage with a foreign ship, i.e. cabotage towing and pushing without the approval of the Ministry; 2) if he does not communicate to the ship with which the ship he commands collided, even though he could, the name of the last port from which he sailed and the name of the port to which he is sailing.

The Law on Trade Shipping[13] of the Republic of Serbia represents modern tendencies in the regulation of property relations in navigation law.

4. CONCLUSION

With aim to approach criminal legal provisions in navigation of the Serbian law and offer guidelines for our struggle for safer navigation this paper is written.

Within the general purpose of criminal sanctions - suppression of acts that violate or endanger values protected by criminal law - the purpose of punishment in the field of navigation is also: 1) preventing the perpetrator from committing crimes and influencing him not to commit crimes in the future; 2) influencing others not to commit crimes; 3) expressing social condemnation for a criminal offense, strengthening morals and strengthening the obligation to respect the law; 4) achieving fairness and proportionality between the committed act and the gravity of the criminal sanction. The purpose of prescribing, imposing and applying misdemeanor sanctions is that citizens respect the legal system and that in the future no misdemeanors are committed for which a natural person, entrepreneur, legal entity and responsible person in a legal entity can be held liable.

In addition to education, punitive measures are also very important for the realization of safe navigation. Despite the numerous efforts of researchers around the world, having in mind the importance of the rivers and sea and resources that they offer, accidents and endangering of safety in water traffic happen and we should be aware of their serious consequences.

REFERENCES

[1] Law on International Legal Assistance in Criminal Matters, (2009). foreword by M. Majić, first edition of the Official Gazette, Belgrade *(In Serbian)*

[2] Mirčeta L, (2016). Dušan Silni, biography of the first Serbian Emperor, sixth edition, Belgrade, Laguna. *(In Serbian)*

[3] Petrović D, Bukvić R, (2022). Europe and the Migrant Issue 2014-2021. Eliva Press.

[4] Tomić-Petrović N. (2019). Traffic and transport law: practicum. Belgrade: University of Belgrade.

[5] Tomić-Petrović N. (2020). The role of the navigation safety system in Serbia. The 19th International Conference on Transport Science. ICTS 2020. (pp. 353-357). Portorož, Slovenia.

[13] "Official Gazette of the Republic of Serbia", no. 96/15, 113/17.

HOW CHILDREN EXPERIENCE THE SPEED OF A VEHICLE?

Aleksandar Trifunović, Ph.D.
Dalibor Pešić, Ph.D.
Maja Petrović, Ph.D.
Svetlana Čičević, Ph.D.
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, Belgrade, Serbia
a.trifunovic@sf.bg.ac.rs, d.pesic@sf.bg.ac.rs, majapet@sf.bg.ac.rs, s.cicevic@sf.bg.ac.rs

ABSTRACT

Children in the lower grades of primary school between the ages of 6 and 9, although they rarely participate in traffic on their own, represent a vulnerable population. Children have many "restrictions" for independent safe participation in traffic. Among other things, children have trouble estimating the speed (and in some situations the direction) of the vehicle. For the purposes of this experiment, the respondents were shown two videos of a moving vehicle from a real environment on the screen at the same time. The vehicle was moving at speeds of 30 km/h, 50 km/h, and 80 km/h. Respondents were tasked with estimating which vehicle was moving faster or which vehicles were moving at the same speeds. 26 respondents participated in the experiment. The results showed that there are differences between the estimated vehicle speeds.

Keywords: traffic safety, children, perception of speed, vulnerable population

1. INTRODUCTION

The behaviour of children in traffic is often unpredictable and depends on various factors, which can be a consequence of behaviour at home or at school. Children of younger school age (from 6 to 10 years of age) are in the phase of developing skills and abilities for safe participation in traffic. Their role as independent participants in traffic is limited to cyclists and pedestrians, who belong to the group of the most endangered participants in traffic. For this reason, in most countries, various studies are being conducted with the aim of reducing the number of children killed in traffic. Studies examining children’s behaviour in traffic have been conducted in experimental field conditions (Johansson & Leden, 2007; Riaz et al., 2022; Zeedyk & Kelly, 2003), some conducted in simulated traffic conditions (Meir et al., 2015; Morrongiello & Corbett, 2015; Tapiro et al., 2016; Aleksandar Trifunović et al., 2014), some are based on the analysis of videos of children's behaviour in traffic (Fu & Zou, 2016; Johansson et al., 2011), while some are based on children's self-assessment of behaviour (Koekemoer et al., 2017). In developed countries, great attention is paid to traffic education, education and perception testing, as well as the orientation of children in space (Gitelman et al., 2019; Meir et al., 2015), that is, examining the skills and abilities that are necessary for the safe behaviour of children in traffic.

As children get older and get closer to adolescence, their abilities begin to be more similar to those of adults, but the development of skills needed for independent safe behaviour in traffic varies by age and individual (Gitelman et al., 2019). Even some children over the age of 14 do not have developed abilities and skills to behave safely in traffic (Plumert & Kearney, 2014; Schwebel et al., 2012). Children in traffic may behave unsafely due to lack of knowledge, or due to peer pressure (Schwebel et al., 2012). Male children are more prone to risky behaviours in traffic, compared to female children (Gitelman et al., 2019; Granié, 2009). More often children behave unsafely in traffic because they use a mobile phone, which distracts them from attention, perception, and concentration (Stavrinos et al., 2009; Tapiro et al., 2016). Also, one of the important limiting factors influencing children's behaviour in traffic, in addition to knowledge, is experience (Plumert & Kearney, 2014; Schwebel et al., 2012). The modest life and traffic experience that children have is another characteristic that places younger children in the most vulnerable group of traffic participants.

Research shows that younger children (6 years of age) and adolescents are a particularly vulnerable group of road users due to limited physical, mental, and cognitive abilities (Meir et al., 2015; Schwebel et al., 2012; A. Trifunović et al., 2017; World Health Organisation, 2020). Lack of physical maturation, but also cognitive and psychological maturity, limits their ability to assess risk and creates the potential for children to behave unsafely in traffic. In particular, younger children (up to 13 years of age) have difficulty estimating the speed, direction, and distance of moving vehicles, which overall leads to an increased risk in situations where children need to cross the street (MacGregor et al., 1999; Morrongiello & Corbett, 2015).

A study conducted by Pešić et al. (2019) examined the estimate passenger car speed with and without daytime running lights. A similar study was conducted by Čičević et al. (2017), who examined vehicle speed estimates, depending on the type of media on which they are presented. Our study includes estimated passenger car speed of the most endangered category of traffic participants, children aged 6 to 9.

For these reasons, an experimental study was conducted, which aims to examine how children estimate different test a passenger speeds of vehicles in traffic.

2. METHODOLOGY

Children aged 6 to 9 participated in the study. The experiment involved 26 participants. For the purposes of this experiment, a video of a moving passenger vehicle was made. The selected test speeds are 30 km/h, 50 km/h, and 80 km/h. These speeds were chosen because, according to the "Law on Road Traffic Safety", from 2021, the speed of vehicles in the school zone, in the settlement, is limited to 30 km/h, and outside the settlement to 50 km/h (in time from 7.00 to 21.00, unless otherwise determined by the traffic sign). The permitted speed of vehicles outside the settlement is 80 km/h (*Law on Road Traffic Safety*, 2020; Pešić et al., 2019).

2.1. Experiment description

For the purposes of this experiment, the subjects were shown two videos of a vehicle from a real environment on the screen at the same time. The vehicle was moving at speeds of 30 km/h, 50 km/h and 80 km/h, in the direction of the respondent. The distance covered by the vehicle exceeded 200 m (Pešić et al., 2019). The subjects viewed the traffic scenarios in a two-lane undivided road, during the daytime on a sunny day. The present study focused on the trajectory characteristics of free flow driving with no roadside interference. Driving environment included usual traffic signalization and vegetation, there were no additional objects added in the traffic scenes in order to avoid the impact on participants' expectations about the movement of the visual targets, and to prevent distraction. The task of the respondents in the experiment was to estimate the passenger car speed in all combinations of conditions listed above. The respondents stated their judgment orally, while an assistant in the experiment, entered the spoken values into the appropriate field in on-line questionnaire (Pešić et al., 2019). The questionnaire also contained demographic questions about gender, age, area of residence (urban, rural).

2.2. Selection of passenger car for experiment

The passenger car used for the experiment was Peugeot 308, the hatchback version with five doors. Vehicle dimensions are: length 4253 mm, width 2043 mm and height of 1457 mm. The color of the vehicle is factory bright-golden yellow (jaune lacerta met, color code - 582A). The facts from the literature suggest that it is easier to spot the vehicle if there is a higher contrast between the vehicle color and the environment. In general, brighter colored vehicles have a higher contrast with environment, so it is therefore easier to perceive (Allen & Clark, 2021; Kępa & Żagan, 2018; Tofflemire & Whitehead, 1997).

2.3. Video recording of moving vehicles

The video material was recorded with a high-resolution camera (the name of the camera - Canon Camcorder HFR 806), with a brightness of about 8,000 lux in sunny weather. The angle taken by the camera with the recorded vehicle is 0 ° (conditions taken from the literature: Peña-García et al., 2014). Respondents were 160 cm away from the video screen so that the approximate field of view angle was 32 ° x 18 ° (conditions taken from the literature: Cavallo and Pinto, 2012). The video screen used in the experiment is Electric 270, measuring 260 x 195 cm. The video was broadcast on the entire screen, using a BanQ 1080p projector (1920 x 1080), with a contrast of 10000: 1 and 107 trillion colors.

2.4. Experiment procedure

Respondents were shown the same vehicle on the left and right sides of the screen (Figure 1). The images show the combinations of vehicle speeds presented in Table 1.

Table 1: Combinations of vehicle test speeds displayed to respondents

Same test speed	Different test speeds
30 km/h - 30 km/h	30 km/h - 50 km/h
50 km/h - 50 km/h	30 km/h - 80 km/h
80 km/h - 80 km/h	50 km/h - 80 km/h

During the experiment, videos of moving vehicles were displayed in random order. In a situation where the left and right vehicles are moving at different speeds, there are two options, with one option showing higher speeds on the right and lower speeds on the left side of screen, and vice versa. Randomly, for each respondent, higher vehicle speeds were on the left and right, respectively, so that the side on which the higher or lower speed is, would not affect the result of his estimation of test speeds.

Figure 1: Example of a vehicle shown to the respondents in the video

2.5. Collecting and processing data

Collecting and processing data Statistical analysis was carried out in the statistical software package IBM SPSS Statistics v. 22. Normality of distribution was tested by inspection of histograms and the Kolmogorov-Smirnov test. Since the data for all measured variables distribution were do not normally distributed, we used nonparametric methods. To assess the significance of differences the Cochran's Q test and Hi-square test were used. The null hypothesis (H_0) was: There is no statistically significant difference, with the alternative hypothesis (H_a) being: There is significant statistical significance between two conditions. The threshold for statistical significance (a) was set to 5%. Consequently, if probability (p) is smaller or equal to 0.05, H_0 is rejected, and Ha is accepted. On the contrary, if p > 0.05, H_0 is not rejected.

3. RESULTS

Respondents have a higher percentage of correct answers for comparing the same speeds (30 km/h - 30 km/h, 50 km/h - 50 km/h, 80 km/h - 80 km/h) than for comparing different speeds (30 km/h - 50 km/h, 30 km/h - 80 km/h, 50 km/h - 80 km/h). It can be concluded that respondents have a higher percentage of correct answers when estimating lower test speeds (Figure 1). That there are statistically significant differences between the estimates of test speeds is confirmed by the results of the Cochran's Q test (p=0.007).

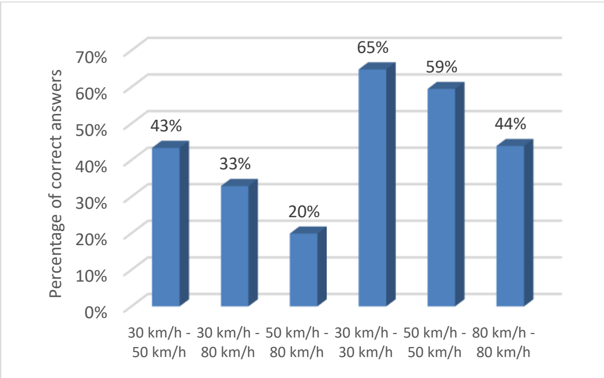


Figure 2: Percentage of correct answers for test speeds

3.1. Rural vs. Urban Areas

Respondents from urban areas have a higher percentage of correct answers for estimates of test speeds, when the same test speeds are observed (30 km/h - 30 km/h, 50 km/h - 50 km/h, 80 km/h - 80 km/h)(Figure 2). There are statistically significant differences according to the area of residence of the respondents, for estimating the speed of the vehicle, for all three same mutually compared speeds: 30 km/h - 30 km/h (χ^2 = 2.457; p = 0.048), 50 km/h - 50 km/h (χ^2 = 6.646; p = 0.024) and 80 km/h - 80 km/h (χ^2 = 7.475; p = 0.014).

On the other hand, there are statistically significant differences according to the area of respondents' residence, for estimating the speed of vehicles at different test speeds, and only for speeds of 50 km/h - 80 km/h (χ^2 = 3.408; p = 0.039). Respondents from urban areas have a higher percentage of correct answers than children from rural areas, for the stated pair of vehicle speeds.

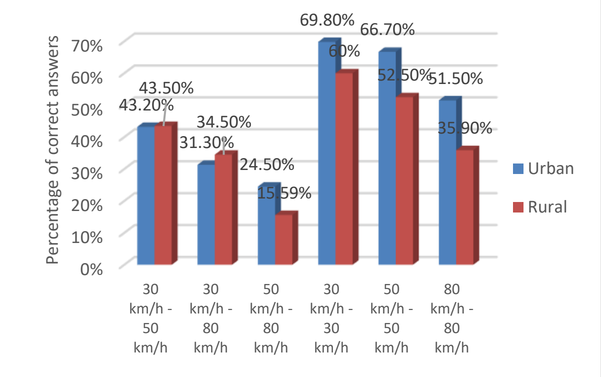


Figure 3: Percentage of correct answers for test speeds - Rural vs. Urban Areas

3.2. Age Differences

According to the results shown in Figure 3, it can be concluded that the percentage of correct answers increases, with the increasing age of respondents. The results of the Chi-square test show significant statistical differences between the age of the children and the estimated speed of the vehicle, for test speeds of 30 km/h - 80 km/h (χ^2 = 6.754; p = 0.025), as well as for speeds 50 km/h - 80 km/h (χ^2 = 9.758; p = 0.009). In both cases of estimating different vehicle speeds, older children have a higher percentage of correct answers.

When it comes to comparing the same test speeds, the results of the Hi-square test show statistically significant differences between the ages of children, for test speeds: 30 km/h - 30 km/h (χ^2 = 27.457; p <0.001), 50 km/h - 50 km/h (χ^2 = 21.247; p <0.001) and 80 km/h - 80 km / h (χ^2 = 24.754; p <0.001). When comparing the estimates of the same vehicle speeds that the respondents estimated, for all the above examples, older children have a higher percentage of correct answers.

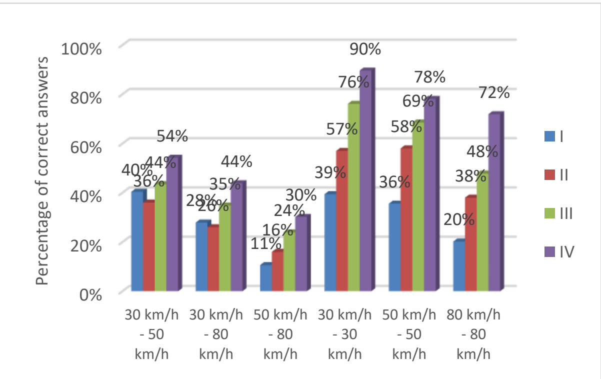


Figure 4: Percentage of correct answers for test speeds – Age differences

4. DISCUSSION

Children need to have developed numerous abilities and skills that enable them to safely participate independently in traffic, and which are related to the perception of objects in space. When time is added to these components, as well as the movement of objects in a certain space - over time, on the one hand, while on the other hand we have the movement of children in the same space and time, a complex situation is created and the question arises how to safely movement of children and vehicles in the same space and at the same time. A good estimation of the direction and speed of vehicles by children is necessary for independent safe participation in traffic (Aleksandar Trifunović, 2020).

According to the results of the research, for the estimate of vehicle speed, there are statistically significant differences according to the area of respondent's residence for vehicle speeds compared (50 km/h - 80 km/h). The stated speeds of vehicle movement are more accurately estimated by the respondents from the urban areas. The consequence of such results may be the experience that children from urban areas have in a real traffic environment. Children from rural areas encounter a smaller number of vehicles, usually one vehicle in one lane per direction, while children from urban areas encounter a large number of vehicles and streets with more than one lane per direction (Cicevic et al., 2013; Aleksandar Trifunović, 2020; Aleksandar Trifunović et al., 2017).

On the other hand, the importance of experience for estimating vehicle speed shows the existence of differences between children's ages and estimating different vehicle speeds, for vehicle test speeds of 30 km/h - 80 km/h and 50 km/h - 80 km/h. From the obtained results it can be concluded that older children have a higher percentage of correct answers for higher vehicle test speeds (30 km/h - 80 km/h), (50 km/h - 80 km/h), while for the lowest vehicle speeds 30 km/h - 50 km/h) there is no difference between the ages of the children. This result shows that with complex tasks and with the estimation of higher vehicle test speeds, smaller children have difficulties, which indicates that younger children are not ready for independent safe participation in traffic. Similar results can be found in studies that point out that younger children (up to 13 years of age) have difficulty estimating the speed, direction, and distance of moving vehicles, which all lead to increased risk in situations where a child has to cross the street (MacGregor et al., 1999; Morrongiello et al., 2016, 2019; Morrongiello & Barton, 2009; Morrongiello & Corbett, 2015).

5. CONCLUSION

Based on the data collected and analysed, the conclusions of this research are as follows:

- The highest percentage of correct answers children record for the lowest test speed (30 km/h);
- Children have the lowest percentage of correct answers when estimating the highest test speed (80 km/h);
- With increasing test speed, the percentage of correct answers for speed estimation decreases;
- Respondents have a higher percentage of correct answers when estimating the same speeds (30 km/h - 30 km/h, 50 km/h - 50 km/h, 80 km/h - 80 km/h), as opposed to when estimating different speeds (30 km/h - 50 km/h, 30 km/h - 80 km/h, 50 km/h - 80 km/h);
- There are significant statistical differences between the areas of respondent's residence;
- Respondents from urban areas have a higher percentage of correct speed estimation answers, as opposed to respondents from rural areas;
- There are significant statistical differences between the ages of the respondents;
- Older respondents estimate their test speed more accurately, unlike younger ones.

The results presented in the study can be used to test children, as they estimate the speed of a passenger vehicle. In this way, parents, guardians, teachers, and other entities dealing with children can have feedback on how children estimate different speeds in traffic. On the other hand, the results can be used to educate children about speed estimation. During testing, children gain speed estimate experience, which is very important for the development of their skills, knowledge, and ability to estimate the speed of vehicles.

Future research

However, since this issue is affected by many factors, future research should include different test speed ranges, different vehicle categories, and colours, different route lengths (e.g., 100 m, 300 m, and 500 m), different road weather conditions, as well as different children's age groups.

REFERENCES

[1] Allen, M. J., & Clark, J. R. (2021). Automobile Running Lights —a Research Report*. *Https://Doi.Org/10.1111/j.1444-0938.1964.Tb01721.X*, *47*(12), 329–345. https://doi.org/10.1111/J.1444-0938.1964.TB01721.X

[2] Cicevic, S. J., Trifunovic, A. V., Nesic, M. M., & Samcovic, A. (2013). Perception and attitudes towards digital billboards. *2013 11th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services, TELSIKS 2013*, *2*. https://doi.org/10.1109/TELSKS.2013.6704454

[3] Čičević, S., Dragović, M., Žunjić, A., Trifunović, A., Mitrović, S., Nešić, M. (2017). Road Design Elements Evaluation before and after Reconstruction (Chapter 8). Ergonomic Design and Assessment of Products and System (editor Aleksandar Žunjić), NOVA Science publishers. pp. 141-193, New York, USA. ISBN 978-1-53611-796-7

[4] Fu, L., & Zou, N. (2016). The influence of pedestrian countdown signals on children's crossing behavior at school intersections. *Accident; Analysis and Prevention*, *94*, 73–79. https://doi.org/10.1016/J.AAP.2016.05.017

[5] Gitelman, V., Levi, S., Carmel, R., Korchatov, A., & Hakkert, S. (2019). Exploring patterns of child pedestrian behaviors at urban intersections. *Accident; Analysis and Prevention*, *122*, 36–47. https://doi.org/10.1016/J.AAP.2018.09.031

[6] Granié, M. A. (2009). Effects of gender, sex-stereotype conformity, age and internalization on risk-taking among adolescent pedestrians. *Safety Science*, *47*(9), 1277–1283. https://doi.org/10.1016/J.SSCI.2009.03.010

[7] Johansson, C., & Leden, L. (2007). Short-term effects of countermeasures for improved safety and mobility at marked pedestrian crosswalks in Borås, Sweden. *Accident; Analysis and Prevention*, *39*(3), 500–509. https://doi.org/10.1016/J.AAP.2006.08.017

[8] Johansson, C., Rosander, P., & Leden, L. (2011). Distance between speed humps and pedestrian crossings: Does it matter? *Accident Analysis and Prevention*, *43*(5), 1846–1851. https://doi.org/10.1016/J.AAP.2011.04.020

[9] Kępa, P., & Żagan, W. (2018). The effects of using passing beams during the day in real traffic conditions: *Https://Doi.Org/10.1177/1477153518816123*, *51*(7), 1108–1117. https://doi.org/10.1177/1477153518816123

[10] Koekemoer, K., Van Gesselleen, M., Van Niekerk, A., Govender, R., & Van As, A. B. (2017). Child pedestrian safety knowledge, behaviour and road injury in Cape Town, South Africa. *Accident; Analysis and Prevention*, *99*(Pt A), 202–209. https://doi.org/10.1016/J.AAP.2016.11.020

[11] *Law on Road Traffic Safety*. (2020). Official Gazette of the Republic of Serbia 128/2020.

[12] MacGregor, C., Smiley, A., & Dunk, W. (1999). Identifying Gaps in Child Pedestrian Safety: Comparing What Children Do with What Parents Teach: *Https://Doi.Org/10.3141/1674-05*, *1674*, 32–40. https://doi.org/10.3141/1674-05

[13] Meir, A., Oron-Gilad, T., & Parmet, Y. (2015). Are child-pedestrians able to identify hazardous traffic situations? Measuring their abilities in a virtual reality environment. *Safety Science*, *80*, 33–40. https://doi.org/10.1016/J.SSCI.2015.07.007

[14] Morrongiello, B. A., & Barton, B. K. (2009). Child pedestrian safety: parental supervision, modeling behaviors, and beliefs about child pedestrian competence. *Accident; Analysis and Prevention*, *41*(5), 1040–1046. https://doi.org/10.1016/J.AAP.2009.06.017

[15] Morrongiello, B. A., & Corbett, M. (2015). Using a virtual environment to study child pedestrian behaviours: a comparison of parents' expectations and children's street crossing behaviour. *Injury Prevention : Journal of the International Society for Child and Adolescent Injury Prevention*, *21*(5), 291–295. https://doi.org/10.1136/INJURYPREV-2014-041508

[16] Morrongiello, B. A., Corbett, M., Milanovic, M., & Beer, J. (2016). Using a Virtual Environment to Examine How Children Cross Streets: Advancing Our Understanding of How Injury Risk Arises. *Journal of Pediatric Psychology*, *41*(2), 265. https://doi.org/10.1093/JPEPSY/JSV078

[17] Morrongiello, B. A., Seasons, M., McAuley, K., & Koutsoulianos, S. (2019). Child pedestrian behaviors: Influence of peer social norms and correspondence between self-reports and crossing behaviors. *Journal of Safety Research*, *68*, 197–201. https://doi.org/10.1016/J.JSR.2018.12.014

[18] Pešić, D., Trifunović, A., Ivković, I., Čičević, S., & Žunjić, A. (2019). Evaluation of the effects of daytime running lights for passenger cars. *Transportation Research Part F: Traffic Psychology and Behaviour*, *66*. https://doi.org/10.1016/j.trf.2019.09.008

[19] Plumert, J. M., & Kearney, J. K. (2014). How Do Children Perceive and Act on Dynamic Affordances in Crossing Traffic-Filled Roads? *Child Development Perspectives*, *8*(4), 207–212. https://doi.org/10.1111/CDEP.12089

[20] Riaz, M. S., Cuenen, A., Polders, E., Akram, M. B., Houda, M., Janssens, D., & Azab, M. (2022). Child Pedestrian Safety: Study of Street-Crossing Behaviour of Primary School Children with Adult Supervision. *Sustainability 2022, Vol. 14, Page 1503*, *14*(3), 1503. https://doi.org/10.3390/SU14031503

[21] Schwebel, D. C., Davis, A. L., & O'Neal, E. E. (2012). Child Pedestrian Injury: A Review of Behavioral Risks and Preventive Strategies. *American Journal of Lifestyle Medicine*, *6*(4), 292. https://doi.org/10.1177/0885066611404876

[22] Stavrinos, D., Byington, K. W., & Schwebel, D. C. (2009). Effect of cell phone distraction on pediatric pedestrian injury risk. *Pediatrics*, *123*(2). https://doi.org/10.1542/PEDS.2008-1382

[23] Tapiro, H., Oron-Gilad, T., & Parmet, Y. (2016). Cell phone conversations and child pedestrian's crossing behavior; a simulator study. *Safety Science*, *89*, 36–44. https://doi.org/10.1016/J.SSCI.2016.05.013

[24] Tofflemire, T. C., & Whitehead, P. C. (1997). An evaluation of the impact of daytime running lights on traffic safety in Canada. *Journal of Safety Research*, *28*(4), 257–272. https://doi.org/10.1016/S0022-4375(97)00011-X

[25] Trifunović, A., Pešić, D., Čičević, S., & Antić, B. (2017). The importance of spatial orientation and knowledge of traffic signs for children's traffic safety. *Accident Analysis and Prevention, 102*. https://doi.org/10.1016/j.aap.2017.02.019

[26] Trifunović, Aleksandar. (2020). *Application of a Gemetric Modeler for Determining Child's Ready for Self-Safety Participation in Traffic*. University of Belgrade - Faculty of Transport and Traffic Engineering.

[27] Trifunović, Aleksandar, Pešić, D., Čičević, S., & Antić, B. (2017). The importance of spatial orientation and knowledge of traffic signs for children's traffic safety. *Accident Analysis and Prevention, 102*, 81–92. https://doi.org/10.1016/J.AAP.2017.02.019

[28] Trifunović, Aleksandar, Vujanić, M., Dalibor, P., Čičević, S., & Čubranić-Dobrodolac, M. (2014). *The importance of color perception and motor skills of preschool children from the aspect of traffic safety*. 473–478.

[29] World Health Organisation. (2020). *Road traffic injuries*. World Health Organisation. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

[30] Zeedyk, M. S., & Kelly, L. (2003). Behavioural observations of adult-child pairs at pedestrian crossings. *Accident; Analysis and Prevention*, *35*(5), 771–776. https://doi.org/10.1016/S0001-4575(02)00086-6

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UPDATE ON RISK ASSESSMENT FOR CRUDE OIL TANKER FLEET

Peter Vidmar, Ph.D.
Marko Perkovič, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot Pomorščakov 4, 6320 Portorož, Slovenia
Peter.Vidmar@fpp.uni-lj.si, Marko.Perkovic@fpp.uni-lj.si

ABSTRACT

The paper presents the general state of risk management for the crude oil tanker fleet as identified by EMSA and other international maritime organizations. Based on previous statistics on the size of the fleet, accident reports, the amount of oil spilled at sea and the economic value of crude oil transportation, the risk acceptance criteria are assessed. Formal safety assessment is also used for systematic risk assessment, where potential hazards are analysed using structured methods (HAZID and HAZOP) and presented in event trees. The article addresses three risks: PLL (potential loss of life), PLC (potential loss of restraint), and PLP (potential loss of property). A general approach is presented and discussed, focusing on the evolution of risk acceptance over the last decades and the evaluation of F-N risk curves for different tanker sizes.

1. INTRODUCTION

Maritime safety is governed by maritime safety policy instruments that aim to keep the level of risk within an acceptable range. In the case of accidents that mainly affect people, the criteria are related to the potential loss of life and are represented by individual and societal risks. Oil tanker transportation directly affects crew safety, which is limited to 20 to 30 members, depending on the size of the vessel. EMSA reports that the number of fatalities among cargo ship crew varies between 30 and 50 (over the last five years). Oil tankers have the lowest percent compared to other ship types [1]. The direct impact of tanker accidents on civilians is limited and analysed mainly for port areas close to cities and straits passing populated areas [1]. This implies a specific risk assessment that usually considers local ship traffic statistics. Small ports or new terminals do apply here, because the representative data are not available, and so qualitative approaches (like PAWSA) or a comparative method with data from a similar region or terminal is used. A comprehensive approach is proposed by IMO in the Formal Safety Assessment for Crude Oil Tankers [MEPC 58/INF.2] and further developed by [A. Papanikolaou] in the SAFEDOR project and his team publications [2], [3].

Oil tanker transport risk is particularly sensitive from the environmental aspect, related to the loss of containment, particularly in coastal areas. The reason could be mainly expressed from the economical view. First there is the cost of cleaning a polluted coastline; second, much more comprehensive, is the loss of revenue from other economic sectors (tourism, mariculture, quality of coastal living, value of land and parcels…). Based on past oil spills and consequent shoreline clean up procedures, Etkin [6] and Ugurlu [28] evaluated cleaning costs for different clean-up factors - e.g., geographic location, type of shoreline, labour costs, equipment costs, disposal costs, materials costs (absorbents or chemicals) and logistical costs. The correlation of clean-up costs is nearly linear related to spill size. Etkin [7] model based on total tonnes spilled and shoreline length oiled gives $y = 87.59x + 9.469$ where *x* length of shoreline oiled (km) and *y* the overall clean-up cost per tonne. The topic of the potential loss of containment is also the most publicly evident, drawing the most public concern.

The third risk assessment concerns the economics of oil transportation itself. This refers to the risk of loss of property, including the value of the vessel and cargo, but also the cost of penalties, compensation, and other direct and indirect costs. Various insurances reduce the economic risk for the shipping company (such as ship insurance, insurance of cargo during transport, insurance of war risks and risks of environmental damage such as oil pollution). For a single accident event, the economic value may vary depending on the value of the vessel, the cargo, the location of the accident, but most importantly, the extent of the accident. An MSC Formal safety assessment [8] assumes that for severe collision damage the ship damage cost is 5% of the ship's value. Damage costs are not information in the public domains, which is why an average value was used.

All tree risks are calculated from the same interrelation of data. The tanker world fleet review is obtained from the German ISL (Institute of Shipping Economics and Logistics) statistical publication [13] from 2007 to 2016. Fleet statistics and causalities up to 2007 are already analysed in the MSC FSA report [8] and used to extend the statistical period to the year 1980 and evaluate a more representative result.

1.1. Tanker fleet review

The increasing industrialization in a developing world has been the primary influence driving the demand for global crude oil. Overall non-OECD demand has increased at a rate of 3.6% per annum, with the Asia/Pacific region's oil demand growing at roughly 2.7%. Developed nations have diminishing oil demand with a negative -0.4% per annum growth rate. The decline in OECD oil demand is not enough to offset the rising demand from the developing world. The net result is an increasing supply/demand imbalance that is visible on global scale [14], [15].

The graph indicates that global oil production has increased by about 10% over the last 15 years, while oil consumption has increased by about 12% in the same period.

The statistics of the world tanker fleet only now makes sense. First the reduction of small tanker like Handysize, almost constant rate of Handymax and Panamax ships and the growth of larger tankers especially VLCC.

The forecast of the oil tanker fleet change indicates the growth of the fleet [13]. The difference of oil tankers new-building's and fleet reduction is 166 ships added to the world fleet in 2011, 71 ships in 2015 and at the end of 2022 about 60 new ships will expand the fleet [16]. Based on the fleet growth and oil production prognosis the fleet utilisation factor is calculated. It has mainly been constant in the last decade, but never exceeded 90%. At the global level, this spare capacity cushions changes in oil production and demand, mainly because additional transportation capacity is delayed by two to three years, requiring the construction of new vessels. The trend for oil tankers is to increase transport capacity with larger Aframax-class vessels and larger. Despite its critics, oil tanker shipping generally has an excellent safety record; however, serious losses can and do occur. A number of accidents, despite their large scale, caused little or no 'visible' environmental damage because the oil spilled offshore and no coastline was affected. For this reason, many accidents are not known. More well-known shipping accidents, such as the Prestige, the Exxon Valdez, or the Hebei Spirit, are known because the oil heavily polluted the nearby coastline.

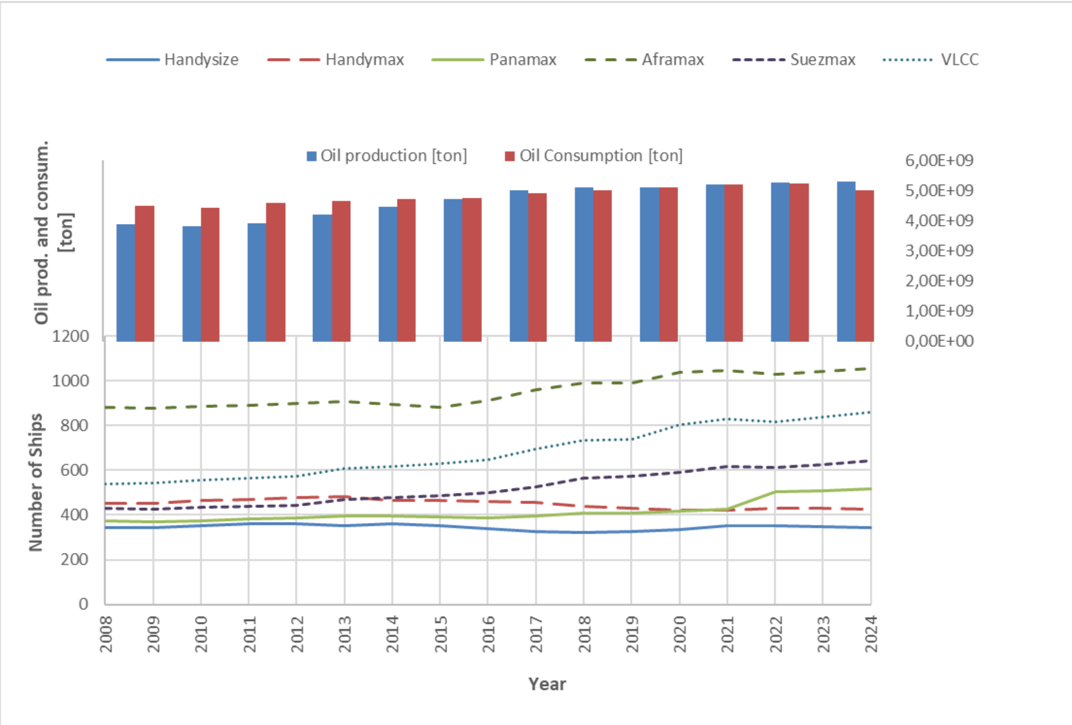


Figure 1: Relation of oil production/consumption and tanker fleet utilization

1.2. Focus on risk assessments

Authorities are struggling with the need to adapt to the expanding tanker trade, which includes the need to allow larger vessels. Safety analysis is necessary to understand the suitability of certain risk control options (ROCs). In this way, investments in safety are not only justified, but also effective. While the international shipping community has long been concerned with maritime safety, tanker safety has become more prominent in recent decades. Tankers must also comply with International Maritime Organisation (IMO) safety standards enforced by the International Convention for the Prevention of Pollution from Ships (MARPOL). One of the most important risk control options added to MARPOL in 1992 was the amendment requiring double-hull construction for tankers with deadweight capacities of 5000 dwt and above. The accident of the tanker Erika off the coast of France in December 1999 encouraged IMO members to adopt a revised timetable for the phasing out of single-hull tankers, which came into force in April 2005.

The Formal Safety Assessment (FSA) for crude oil tankers is a tool for risk evaluation developed by IMO, more precisely the SAFEDOR project consortium [3] to enhance the safety of ships, crews, and the environment. The FSA uses five steps: hazard identification (HAZID), risk assessment, risk control options, cost benefit assessment and decision-making recommendations. Its goal is a systematic approach to safety in all aspects regarding particular vessels.

2. RISK EVALUATION CRITERIA

Risk acceptance was included in the assessment of methods and tools because it can be a decision criterion for organisations (e.g., in the finance and insurance sector, critical infrastructure protection, shipping sector). Another reason for explicitly mentioning risk acceptance is the need to focus management attention on this issue. Risk criteria should reflect the organisation's values, policies, and objectives; be based on the external and internal context; take into account the views of stakeholders; and be derived from standards, laws, guidelines, and other requirements [19]. Looking at the IMO FSA policies for crude oil tankers, one can understand the reasons for risk acceptance based on cost-benefit calculations. However, depending on the country and company policy on risk acceptance levels, risk treatment could and should be an ongoing challenge, regardless of the results of risk assessment or cost-benefit balance [12]. For crude oil tankers, risk criteria are based on three primary risks: potential loss of life (PLL), potential loss of containment (PLC), and potential loss of property (PLP). The responsibility to maintain each of these primary risks at an acceptable level rests with the shipping company, government legislation, the maritime regulatory authority, and the individual mariner. The calculated tolerable risk is directly related to the product of casualty-related events and the economic value of the assessed business, i.e., a higher business value allows for higher tolerable risks. Since the oil industry is a highly profitable business, the calculated risk criteria are presented and compared to the actual risk criteria related to accident events over the past decade to understand the evolution of risk acceptance and the necessary impact of rules and regulations on maintaining social risk acceptance.

In the following, the modelled risk level for oil tankers is evaluated using risk assessment criteria for individual risk and social risk.

2.1. Societal risk

A societal risk criterion takes the possibilities of catastrophic accidents of major societal concern into account to ensure that the risks imposed on the society from the activity are controlled. Depending on the system under consideration, both individual and societal risk evaluation criteria might apply. Societal risk posed by a tanker ship is measured by the probability of a group of people (crew) and their direct risks of accidents, and more extensively the consequences of pollution. From the social point of view this last is the most important risk because an accident could directly influence the living environment and have indirect negative economic impacts. The societal risk is dependent on both the density of people in the vicinity of an accident and the location of the population in relation to the event. The societal risk is generally presented in the form of an F-N curve, expressing the relationship between the annual probability (F) of exceeding a given number of fatalities and the number (N). There are exceptions that cannot be generalised like for low population coastal communities with virtually a single economic activity like fishing. An accident in that case risks destroying an entire culture. This kind of societal risks are not considered here.

In most countries, the risk assessment is performed on the basis of potential fatalities to the exposed population. Different countries use slightly different criteria for risk acceptability. In the UK, the Health and Safety Executive (HSE) guidelines are available for use for individual risk as the principal measure, but also for use as the societal risk criteria for land use planning. Facilities are permitted only when these (published) criteria are met. In the Netherlands, however, both the individual risk criteria and the societal risk criteria must be met when considering those events whose hazardous effects extend to such distances at which the conditional probability for lethality is higher than 1%.

F-N curves are, however, a common way of presenting societal risk and are considered by some parties the best way of illustrating this data. The method of deriving societal risk evaluation criteria in this report is based on IMO MEPC 58-INF-2 [8], decision parameters including risk acceptance criteria [8] and updated by the EMAS report on Risk level acceptance criteria [24]. The risk level is plotted as a cumulative function of consequence and frequency on a log-log graph.

$$\boldsymbol{F_1} = \frac{\boldsymbol{r \cdot EV}}{\sum_{N=1}^{N_u} \frac{1}{N}} \qquad (1)$$

where:

- F_1 is the frequency of accidents involving one or more fatalities,

- N_u is the upper limit of the number of fatalities that may occur in one accident,
- r the number of fatalities due to transportation divided by contribution to GNP by transportation. It can be calculated as r = fatalities/$ GNP and
- *EV* is the economic value of the industry. In this case EV represents a reference vessel and is derived from the revenue of a ship per year.

The value of tolerable risk is calculated for the year 2021 and is $1.4{\cdot}10^{-4}$ fat/year. The upper tolerable limit has been obtained by multiplying the calculated tolerable risk by a factor of 10, obtaining $F_{upper}=1.4{\cdot}10^{-3}$, and the lower limit by dividing the calculated risk by factor 10, obtaining $F_{lower}= 1.4{\cdot}10^{-5}$. The criteria used are presented in Table. The boundary limits are therefore computed; however computed limits, as discussed in the introduction, could only be used as the lower boundary limit of the upper risk criteria limit. Additional reduction of the upper risk criteria limit could be based on company policy.

As presented the boundary of ALARP are calculated and presented in Table 1.

Table 1: Limits for societal risk for 2016

Parameters for societal risk criteria	Value	Denomination
F_{1_upper} (loss of life)	$1.4{\cdot}10^{-3}$	fatality/year
F_{1_lower}	$1.4{\cdot}10^{-5}$	fatality/year
F_{2_upper} (loss of containment)	1.83	spills/ship year
F_{2_lower}	$1.83{\cdot}10^{-2}$	spills/ship year
F_{3_upper} (loss of property)	$3.9{\cdot}10^{-2}$	property lost MUSD/year
F_{3_lower}	$3.9{\cdot}10^{-4}$	property lost MUSD/year

Based on equation 1 and the yearly statistics, the upper limit of the ALARP region changes its value. Taking into account only the period between 2010 and 2021 that is best documented, we can see the variation of the frequency of accidents involving one or more fatalities, spills and property loss depending on accident type. A simple trend prognosis is also applied for data up to 2024 to see the evolution of risk acceptability. Figure shows the calculated tolerable frequency of fatalities per year (F_1). Similarly, the tolerable spill frequency (F_2) and tolerable property loss (F_3) are presented. First of all, the magnitude of each is distinguished. The higher acceptability likelihood is for spill events that occurs continuously. The continuous large number of these events influence their higher acceptability. The loss of containment itself gives just a first answer to oil spill acceptability; the second is the quantity of the spill directly related with the loss of property. The frequency of both loss of containment and loss of property have an increasing trend related with oil production and seaborne trade. Simply, more oil production and trade, higher acceptability of spill related accidental events. Fortunately, the trend event frequency acceptability is much slower than the seaborne trade of oil. This could indicate that rules adopted by IMO, as mentioned in the introduction, have had positive results on tanker safety. Last is the acceptability for the loss of lives due to accidents.

2.2. Accident frequency calculation

The exposure during the 1980-2016 period has been 71,422 ships-years and will be used for the accident frequency calculations. The frequency calculations can be summarized as the fraction of accidents per accident type and the total number of accidents. However, the number of accidents with fatalities is too few to represent any significant accident trend. As already mentioned in paragraph the frequency of accidents is increasing: the average frequency value from 1980 to 2008 was $4.3{\cdot}10^{-2}$/year, but has increased to $4.6{\cdot}10^{-2}$/year over the last decade. That is a relatively small change that yet confirms the statistical relation between seaborne trade growth and accidents occurrence.

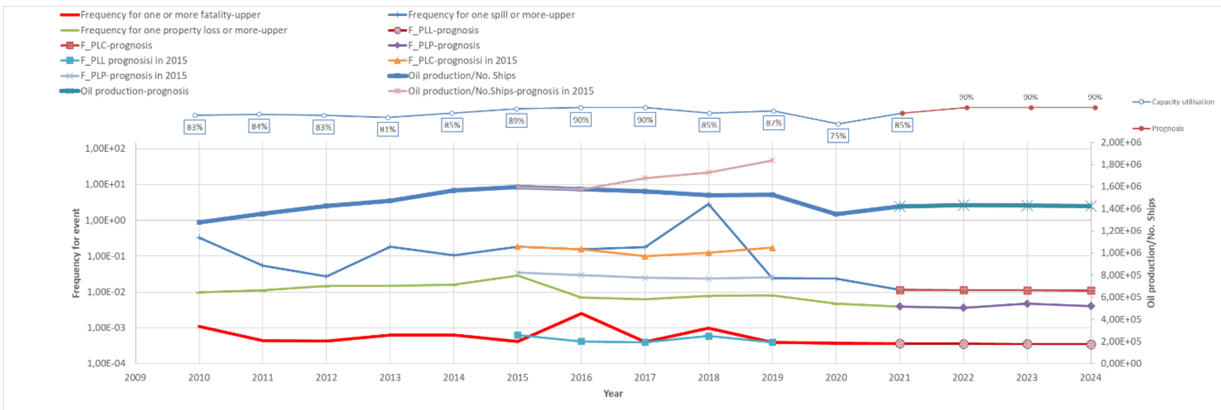


Figure 2: Calculated upper border of ALARP region per year

Table 2: Accident frequency calculations for oil tankers between 1980-2021

Oil tanker	Collision/ Contact	Grounding	Fire/Exp.	Other	SUM
Ships >20,000 GRT					
No. of spills 1980-2007	420	322	111	107	962
Ship years 1980-2007 [ship years]	38,211.2	38,211.2	38,211.2	38,211.2	38,211.2
Tanker spill frequency [spill per ship year] 1980-2007	1.10E-02	8.43E-03	2.90E-03	2.80E-03	2.52E-02
No. of spills 1980-2021	457	351	127	123	1,058
Ship years 1980-2021 [ship years]	45,785	45,785	45,785	45,785	45,785
Tanker spill frequency [spill per ship year] 2008-2021	8.08E-04	6.33E-04	3.49E-04	3.49E-04	2.14E-03
Return period [no. of spills per ship years]	100.19	130.44	360.51	372.24	43.28
Oil spilled [tonns] 1980-2021	346,078	382,182	848,351	225,591	1,802,202
Tanker spill frequency [tonns per ship year]	7.56E+00	8.35E+00	1.85E+01	4.93E+00	3.94E+01

On the other hand, the consequences of these accidents have been reduced. The table indicates that an average oil spill frequency has been reduced by factor 10 in the last decade, compared to the period between 1980 and 2021.

3. CONSEQUENCES

The consequences of an accident are defined as the expected number of fatalities if such an accident occurs. In order to provide consistent and comparable consequence estimates, fixed ranges for the expected number of fatalities are established. As suggested by MEPC [8], the ranges are defined according to the reference vessel. In our case, tankers are classified according to their size from Handysize to VLCC. Each vessel band is further subdivided into 13 fatality bands covering the full spectrum of accident severity, from a minor scenario to a catastrophic accident with a large number of fatalities. The same approach is used for oil spill consequences and property damage consequences. The ranges of each consequence category are based on the average characteristics of the ship and can be seen in Table 3 as values for a given range size. In the second table, the categories are listed for Panamax vessels only, but each vessel size in Table 3 has a similar bandwidth distribution based on its cargo capacity, vessel value, and number of crew members. We can see that the value of the ship is different in the two tables. The reason is that the second table contains the value of the transported cargo, which is calculated based on the export price.

Table 3: Ship size characteristics and consequence bands

	Capacity 100% [m3]	Capacity 95% [m3]	Ship value [€]	Crew members
Other	4,200	4,116	10,000,000	
Handysize	30,000	29,400	25,000,000	20
Handymax	55,000	53,900	35,000,000	24
Panamax	79,000	77,420	50,000,000	26
Aframax	122,600	120,148	65,000,000	28
Suezmax	170,000	166,600	85,000,000	32
VLCC	340,000	333,200	130,000,000	32

Panamax	% of fatalities on board	Panamax	% of cargo spilled	Panamax	% Damage extent
Crew		Environment		Property [€]	
0	0.00%	0	0.00%	-	0.00%
1	4.00%	77	0.10%	74,193	0,10%
2	10,00%	193	0,25%	185,484	0.25%
3	15.00%	387	0.50%	370,968	0.50%
5	20.00%	774	1.00%	741,937	1.00%
6	25.00%	1935	2.50%	1,854,843	2.50%
9	35.00%	3871	5.00%	3,709,687	5.00%
13	50.00%	11,613	15.00%	11,129,062	15.00%
15	60.00%	19,355	25.00%	18,548,437	25.00%
18	70.00%	23,226	30.00%	22,258,125	30.00%
20	80.00%	38,710	50.00%	37,096,875	50.00%
23	90.00%	54,194	70.00%	51,935,625	70.00%
26	100.00%	77,420	100.00%	74,193,750	100.00%

It is important to note that the identified fatality bands only apply to the referenced vessels defined for this study. Each final event is connected to an estimated number of fatalities. The expected number of fatalities is selected from one of the thirteen possible bands, as defined before. The event tree and probabilities for each event have been carried out together with other participants involved in the Hazard Identification process. The basic structure of the event tree is based on the MEPC report [8]. The same event tree and calculated frequencies for each branch is used for the calculation of PLL, PLC and PLP. The assumption of fatalities, spill quantity and property loss is based on Table. The event tree for an oil spill occurring near a cruise ship is presented in Figure.

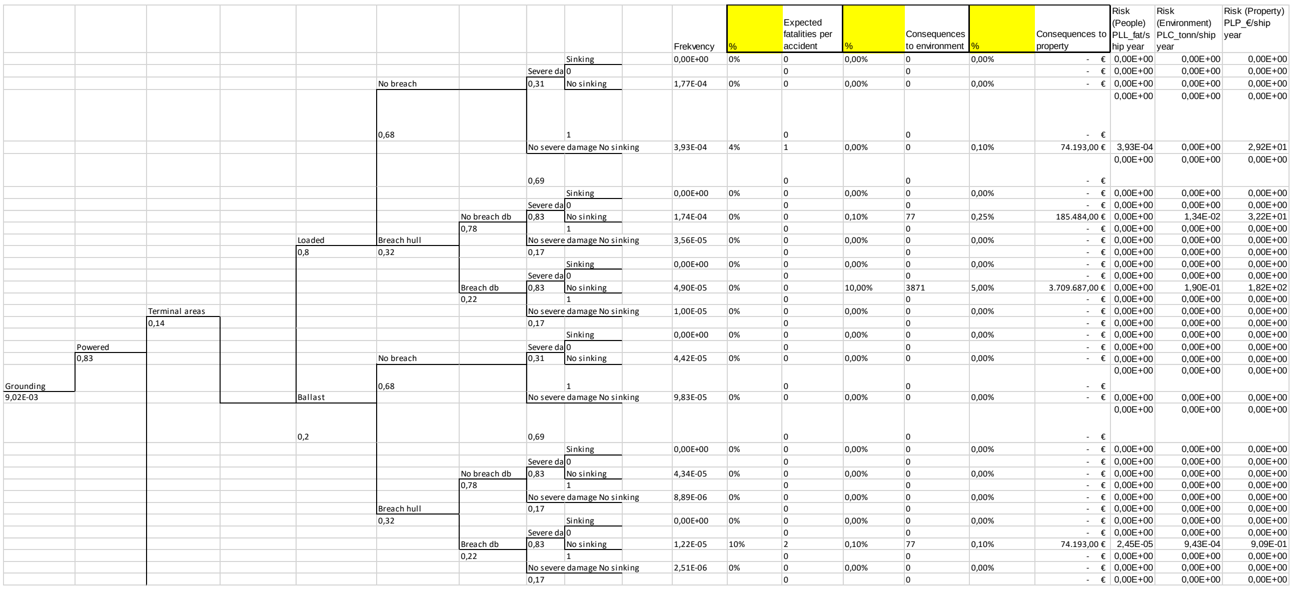


Figure 3: Tanker ship grounding event tree (part)

The percent value represents the share of the total number of crew on the analyses ship band. Similarly, the percent of spill quantity is used in the second column and the percent of cargo loss in the third column. The initial frequency of the accident event in Figure for grounding is calculated using statistical data from 1980 to 2021 and is explained in Table. The intermediate probabilities of tree branches are used as in MEPC, however further improvement of them is possible applying wider HAZOP assessment. In the proposed event tree, the percent of fatalities, oil spill quantity and property loss for each event is predicted on a qualitative basis, proposed by the HAZID group of experts; in our case the authors and port safety department. Those values could therefore be enhanced. Data is also partially based on a review of several oil tanker accident reports, available on EMSA and the ITOPF database.

4. RISK LEVELS

Based on the calculated individual risk frequencies the societal (collective) risk is computed. Integrating the probability of death for each event over the population specified N_u, represents the number of people killed by a given event. The next paragraphs illustrates the modelled risk level for tanker ships in the F-N diagram. The risk level is calculated as the sum of the frequency per ship year for analysed accidents. The risk control options taken into consideration in recent decades by the international community allowed the reduction of the tolerable risk by almost 40%, from 1.1×10^{-3} to 4.16×10^{-4} fat/year [Figure]. As noticed above the risk limit is not only a calculated value, but also a matter company and country policy.

4.1. Overall risk for the oil tanker fleet

The overall risk is the sum of all individual risks of accidents. Risk curves in Figure are considered for Panamax tanker size, because it’s the average size in a fleet. Comparison of event risk yields the information that explosion accidents have a potentially unacceptable risk for releases between 200 and 800 tons and grounding accidents have a potentially unacceptable risk for releases between 4,000 and 20,000 tons. Other accidents fall within the acceptable range. The sum of the risk curves shows that the overall F-N curve is above the acceptable level. The conclusion regarding SPS risks is that risk control measures should be implemented with particular attention to explosion and grounding accidents. Going deeper into specific accidents within the event tree model provides the information on which accidents are critical. These are loaded or ballasted accidents that occur in cargo or runway areas (including the pump room and piping) and cause severe damage. Further investigation into the nature of such accidents and the reason for their occurrence could lead to control options. One consideration might be that more concise and preventive maintenance is needed for critical equipment, and responsible crew members should focus on understanding the risks that occur during transloading operations and pay more attention to these procedures.

A similar intervention in the event tree could be made for grounding. Grounding in the loaded and powered state is most critical when the hull and double bottom are breached. The result is fairly obvious. Most high risk groundings occur in confined to congested waters, indicating needed control options. At the system level, this means that vessel traffic must be controlled by VTS and that updated nautical charts, mandatory ECDIS with updated online charts, and trained (experienced) vessel officers are required for navigation watch.

The application of control measures would change the probabilities in a sequence of the event tree or the magnitude of the consequences. The values themselves could be qualitatively estimated by expert judgement, calculated as probabilities by analysing vessel data (AIS trajectory data), or statistically analysed in the near future.

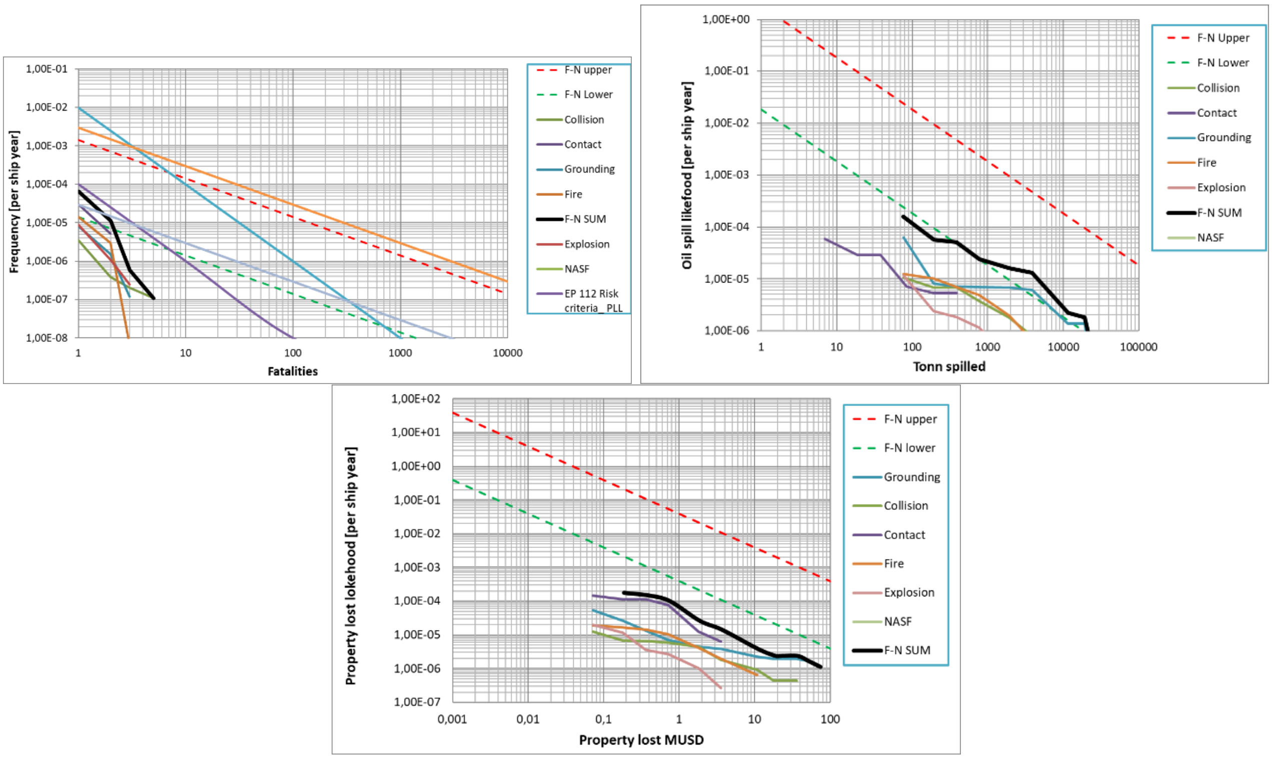


Figure 4: Overall collective risk level based on accident event

5. CONCLUSION

Safety inspections are currently an integral part of any transportation activity, mainly due to the need for transportation reliability, which is closely linked to service revenues. Tanker shipping is particularly sensitive to safety issues, mainly because of the potential environmental risks in coastal areas, which can greatly affect the life and economy of the place concerned. The paper presents the methodology in which different approaches, mainly statistical, deterministic and some qualitative, are applied together with others to obtain more reliable answers to the transportation risks. Operational (technical) risks are analysed and discussed with a view to further improving their management. Risks for different types of accidental events such as collision/contact, grounding, fire/explosion, and structural failure will be statistically analysed on a global scale to provide an overview of changes in risk over the last decade compared to previous decades. Calculated acceptable risk is calculated for potential loss of life, potential loss of containment, and potential loss of property. The key finding is that the risk of containment exceeds the acceptable level and therefore control measures are needed to reduce small and medium accidental and operational releases. The relationship between risk assessment for loss of containment and loss of property is relevant because the strong economic influence of the oil trade is also prevalent in the ecological sector. While the economic aspect is more related to oil trading companies, the environmental aspect is more related to regulators, especially IMO. The results of the study may suggest that, with respect to oil trade revenues, regulators should take additional control measures to reduce the risk of global loss of pollutants from ships.

REFERENCES

[1] Burgherr P., In-depth analysis of accidental oil spills from tankers in the context of global spill trends from all sources, Journal of Hazardous Materials 140 (2007) 245–256

[2] Eliopoulou E., Papanikolaou A., Casualty analysis of large tankers, Journal of Marine Science and Technology, 2007, 240-250

[3] Skjong R., Vanem E., and Endresen Ø., SAFEDOR, Design, Operation and Regulation for Safety, Integrated Project Report, DNV 2005

[4] EMSA, Maritime Accident Review (2007 – 2016), European Maritime Safety Agency, (http://www.emsa.europa.eu/)

[5] EMSA, Annual Overview of Marine Casualities and Incidents 2016, European Maritime Safety Agency, (http://www.emsa.europa.eu/)

[6] Etkin D., Low probability high consequence events and risk of oil spills, 2015 (http://vancouver.ca/images/web/pipeline/David-Etkin-estimating-oil-spill-risk.pdf)

[7] Etkin D., Methodologies for Estimating Shoreline Cleanup Costs, Proceedings of 24th Arctic and Marine Oilspill Program Technical Seminar: pp. 647-70

[8] International Maritime Organization, MEPC 58/INF.2, Formal Safety Assessment – Crude Oil Tankers, 2008.

[9] Goerlandt F., Montewka J., A framework for risk analysis of maritime transportation systems: A case study for oil spill from tankers in a ship–ship collision, Safety Science 76 (2015) 42–66

[10] Montewka J., Weckström M., Kujala P., A probabilistic model estimating oil spill clean-up costs – A case study for the Gulf of Finland, Marine Pollution Bulletin 76 (2013) 61–71

[11] Gucma L. (2007). Evaluation of oil spills in the Baltic Sea by means of simulation model and statistical data. International Maritime Association of Mediterranean, Balkema.

[12] Vidmar P., Perkovič M., Methodological approach for safety assessment of cruise ship in port, Safety Science 80 (2015) 189–200

[13] ISL (ISL Institute of Shipping Economics and Logistics), Shipping Statistics and Market Review (SSMR), World Tanker Market 2007 – 2016

[14] Penelope T., Andreas M., International Shipping and World Trade, University of Piraeus, 2012 (http://dione.lib.unipi.gr/xmlui/bitstream/handle/unipi/4680/Tsaini.pdf?sequence=2)

[15] Crénès M., Hafner M., Criqui P., Global Energy Scenarios to 2040, Understanding our Energy Future 2017 (https://www.enerdata.net/publications/reports-presentations/world-energy-forecasting-scenarios-2017-edition.html)

[16] Whelan R., Ship Owners Cut Oil Tanker Orders, The wall street journal, 2016 (https://www.wsj.com/articles/ship-owners-cut-oil-tanker-orders-1462815137)

[17] The International Tanker Owners Pollution Federation (ITOPF=, Oil Tanker Spill Statistics 2016, UK 2016 (http://www.itopf.com/fileadmin/data/Photos/Publications/Oil_Spill_Stats_2016_low.pdf)

[18] International Maritime Organization (2000). MSC 72/16, Formal Safety Assessment – Decision Parameters Including Risk Acceptance Criteria – Submitted by Norway''.

[19] Bottelberghs, P.H., Risk analysis and safety policy developments in the Netherlands, Journal of Hazardous Materials, Volume 71, Issues 1–3, 7 January 2000, Pages 59-84

[20] Bichard E. M., Health & Safety Executive, Risk criteria for land-use planning in the vicinity of major industrial hazards, UK 1989

[21] Trbojevic, V.M., 2005. Risk criteria in EU, ESREL'05. Poland, 27–30.

[22] Cornwell, J.B., Meyer, M.M., 1997. Risk Acceptance Criteria or ''How Safe in Safe Enough''. Risk Control Seminar, Venezuela.

[23] Lohansen, I.L., 2009. Foundations and Fallacies of Risk Acceptance Criteria, Norwegian University of Science and Technology (NTNU). Department of Production and Quality Engineering, Norway.

[24] Spoure J., Harmonised Risk Acceptance Criteria for Transport of Dangerous Goods, DNV-GL Project Report, UK 2014

[25] International Association of Oil & Gas Producers, Water transport accident statistics, Report No. 434-10, UK 2010 (www.ogp.org.uk)

[26] Cross R. B., A Quantitative Risk Assessment Model for Oil Tankers, ABS TECHNICAL PAPERS 2003 (https://www.eagle.org)

[27] Shahriari M., Frost A., Oil spill cleanup cost estimation—Developing a mathematical model for marine environment, process safety and environment protection 86 (2008) 189–197

[28] Ugurlu O., Analysis of fire and explosion accidents occurring in tankers transporting hazardous cargoes, International Journal of Industrial Ergonomics 55 (2016) 1-11

[29] UNCTAD, Raview of Maritime Transport 2015, United Nations Conference on Trade And Development, Genova 2015 (http://unctad.org/en/PublicationsLibrary/rmt2015_en.pdf)

[30] UNCTAD, Raview of Maritime Transport 2016, United Nations Conference on Trade And Development, Genova 2016 (http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf)

REMOTE MONITORING AND ANALYSIS OF OPERATING PARAMETERS OF THE MARINE ENERGY SYSTEM

Kristijan Vidović, B.Eng.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatiaž
kvidovic@pfst.hr

Gojmir Radica, Ph.D.
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
Ruđera Boškovića 32, Split, Croatia
goradica@fesb.hr

Zdeslav Jurić, Ph.D.
Nikola Račić, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
zdeslav.juric@pfst.hr, nikola.racic@pfst.hr

ABSTRACT

The development of new technologies and their application in marine systems has increased the complexity of propulsion systems. The increase in the number of ships within the merchant fleets has resulted in difficult monitoring of the condition of ships and the need for expertise in electronically controlled propulsion systems. The introduction of diagnostic systems enables easier analysis of operating parameters, and thus improves the efficiency of the marine energy system. The paper examines new diagnostic systems, one of which is a remote monitoring system applied to a marine engine during its operation. During the research, the most influential parameters of the tested engine were identified and its operation was analyzed. Conclusions were drawn on the advantages and disadvantages of the application of remote monitoring systems for marine engines and provided guidelines for determining the remote monitoring system of marine energy systems that should be installed in ships to increase energy efficiency.

Keywords: Marine energy systems, Analysis of operating parameters, Remote monitoring

1. INTRODUCTION

Remote monitoring systems have proven to be reliable and accurate. Current measures prevent external theft while this system provides protection against theft within the company. They can easily monitor and keep track of the amount of fuel being loaded into the ship's tank and how much is consumed every minute just by adding a fuel gauge to the tank. To avoid any fraud in the data, only authorized persons have access to the settings via password. By monitoring the fuel level in the tank, companies can prevent fuel theft by their own staff. Tank fuel level monitoring provides a solution to reduce fuel consumption to eliminate problems caused by fuel prices, delays, mismanagement, theft and losses. It has high commercial viability and other benefits. Most money is spend to investigate missing amount of fuel and security costs. Over time, this will increase the company's profits and reduce operating costs [1], [2], [3]. The implementation of the Intelligent Predictive Decision Support System (IPDSS) for condition-based maintenance has shown an improvement in the efficiency of maintaining functions in the marine energy system. The data collected by the analysis help to detect irregularities. Depending on the problem, the system suggests solutions to solve it. Maintenance costs can be reduced by timely action before critical equipment failure. Defects in equipment can occur even before major repairs, so they need to be detected and remedied in a timely manner to avoid possible shutdowns. The duration between planned overhauls is not necessarily corrected because the budget assumes that the failure is unlikely to happen sooner. It can therefore be extended when really needed if the implementation of intelligent predictive decision support systems is successful. Reduced damage can be ensured by early indication of a fault that leaves more time to plan for proper maintenance. Maintenance activities and their frequency are decreasing. Procurement of spare parts has been reduced due to timely replacement instead of when prescribed and the accumulation of storage of unnecessary parts has been reduced [4], [5]. The diesel generator can be monitored and controlled by the Internet of Things (IoT) platform. It is no longer necessary to be physically present to control the operation of the diesel generator. Mathworks works with the ThingSpeak service, which enables the integration of advanced analytical functions into it from Matlab, which enables predictive analysis and processing of IoT data

[6]. The IoT-based Supervisory Control and Data Acquisition (SCADA) System aims to increase availability, flexibility, cost-effectiveness, optimization and scalability. They are widely applicable and data is stored on servers [7], [8]. Problems such as shutdown of the generator when it is overloaded, lack of fuel, lack of electricity and service can be avoided by real-time remote monitoring. It improves engine performance and represents cost reduction with alarm control directly from the cloud [9]. To help diagnose the problem, experts in the domain build a diagnostic tree depending on the functions of the device. The decision-making method determines the diagnostic priorities of devices that contribute to the preservation of functionality. Domain experts create a database of possible failures contained in the diagnostic tree for each device that detects a possible cause of the failure [10]. Advantages of knowledge are transfer to diagnostic system to ensure a highly reliable operating system. It is used as a platform for operational data from marine energy systems via the Internet to onshore experts without interfering with maritime operations. Data access is enabled via a secure connection remotely via the network [11]. Trying to automate as many ship systems as possible leads to an increase in costs, which is why partial automation is maintained. The introduction of automation increases security because many failures are caused by human factors. A well-designed and programmed system does not have to be expensive, but it ensures the reliability of the power plant and also increases longevity [12].

The aim of this paper is to conduct remote monitoring and control of the parameters of the marine energy system on a real ship in operation and to define and analyze the operation of the engine. The use of remote monitoring devices, will help us to make conclusions about the advantages and disadvantages of remote monitoring systems and provide guidelines for choosing a system during installation to increase efficiency.

2. EXPERIMENTAL ENGINE PARAMETERS

Caterpillar C32 engine is a fast four-stroke, marine V12 engine, 1045 kW at 1800 rpm. The C32 marine engine has a cylinder capacity of 32.1 dm3. The diameter of the engine cylinder is 145 mm and the connecting rod 162 mm. The total weight of the dry engine is 2548 kg while the dimensions are 1,997 m long, 1,378 m high and 1,413 m wide [13].

Table 1: Marine engine test reference data

Speed [rpm]	Upper fuel consumption limit [lit / h]	Lower fuel consumption limit [lit / h]
600	34,5	5,5
700	45,2	7,6
800	55,5	10,5
900	59,8	14,0
1000	77,6	18,5
1100	80,9	24,3
1200	79,9	31,5
1300	114,9	39,5
1400	118,4	47,6
1500	121,1	57,8
1600	121,1	69,8
1700	121,3	89,3
1800	122,2	97,8

Source: Radica, G.: Dijagnostika brodskog 4-T dizelskog motora, Pomorski fakultet u Splitu, Split, 2008.

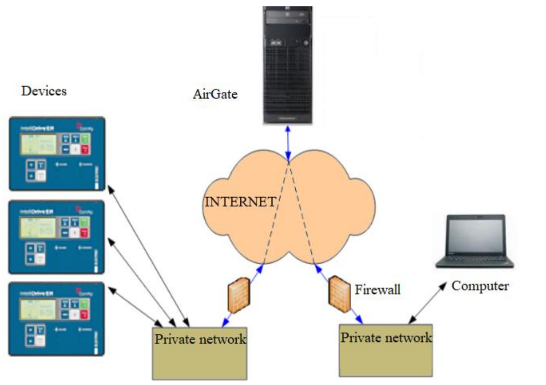
Using remote monitoring devices, it is possible to monitor parameters such as: engine speed, processor temperature, fuel temperature, lubricating oil temperature, intake air temperature, boost pressure, fuel pressure, oil pressure, IC thermostatic valve opening, fuel speed, engine load, desired speed, electric potential, etc. but the influential parameters could not be read. For this reason, Caterpillar Electronic Technician (ET) was used to read the parameters.

Table 2: Parameters indications

Performance testing	The value of the first test [1700 rpm]	The value of the second test [1800 rpm]	Unit
Cooler temperature	78	79	°C
Turbocharger pressure	1,166	1,221	bar
Fuel pressure	7,764	7,68	bar
Fuel consumption	120,9	123,2	lit/h
Fuel temperature	30	31	°C
Oil pressure	4,1	4,03	bar
Force	492,2	497,2	kW
Exhaust emission temperature	540,7	541	°C

3. DIAGNOSTIC SYSTEM WITH REMOTE MONITORING CAPABILITY

Data Logger is a device specially developed for the control, monitoring and protection of engines used in marine power plants and large industrial and similar plants. It can collect and store data directly from the engine control unit (ECU) using the CAN J1939 bus. The controller itself comes with a variety of manufacturer applications that allow you to connect the controller to a computer, read data and adjust device settings [14].



Source: KKMN; RJZD: ID-Mobile, Reference Guide, Praha, 2013.

Figure 1: Schematic representation of the connection

To use Data Logger, you need to use a set of programs that allow you to program, monitor or read records [14].

4. ANALYSIS AND RESULTS

To provide diagnostics, service and communication with electronically controlled engines, it is necessary to have ET which is diagnostic software. When connected to the Electronic Control Module (ECM) it has options such as: see parameter status, active diagnostic options, assembly and disassembly instructions, review and delete recorded diagnostics, manipulate ECM configuration, perform diagnostic tests and their calibration, review various parameters and perform analysis of results and have the ability to print reports [15].

Using the Caterpillar ET device, the influential engine parameters were considered and analyzed. The efficiency of the engine is concluded via the fuel consumption rate parameter. Exhaust emission temperature measurements were performed locally.

The test of the ship's engine was performed on the passenger ship during the standard route. During the voyage, the C32 engine was tested, which worked 20224 operating hours, at speeds in the range of <600, 600-799, 800-999, 1000-1199, 1200-1399, 1400-1599, 1600-1799 and 1800> rpm and load percentage <50, 50-59.9, 60-69.9, 70-79.9, 80-89.9, 90-99.9.

From Tables 3 and 4 and Figures 2 and 3, it can be seen that the C32 marine engine operates in a maximum of two operating areas. These are from 600-799 rpm at an engine load of less than 50% while the ship is in port, and at 1400-1599 rpm at an engine load of 50% to 70%, during navigation.

Table 3: Total operating time at specified engine speeds and loads

% / rpm	<600	600-799	800-999	1000-1199	1200-1399
<50,0	18,75	7396,25	566,8	488,4	442,95
50-59,9	0,00	1,80	29,05	80,75	110,2
60-69,9	0,00	0,50	4,70	44,20	57,80
70-79,9	0,00	0,05	0,80	18,35	25,00
80-89,9	0,00	0,00	0,20	7,65	14,90
90-99,9	0,00	0,00	0,05	5,25	27,85
Total operating hours at certain speeds	18,75	7398,6	601,6	644,6	678,7

Table 4: Total operating time at specified engine speeds and loads

% / rpm	1400-1599	1600-1799	1800>	Total
<50,0	510,80	2,10	0,15	9426,20
50-59,9	4021,85	326,65	0,05	4570,35
60-69,9	3378,35	821,70	0,05	4307,30
70-79,9	631,55	882,75	0,00	1558,50
80-89,9	111,55	124,85	0,25	259,40
90-99,9	36,50	28,80	4,35	102,80
Total operating hours at certain speeds	8690,60	2186,85	4,85	20224,55

Table 5: Engine parameters at 1588 rpm and 71% load.

Performance testing	Test value at 1588 rpm [71% load]	Unit
Cooler temperature	79	°C
Turbocharger pressure	0.72	bar
Fuel pressure	6.70	bar
Fuel consumption	86,5	lit / h
Fuel temperature	26	°C
Oil pressure	3.27	bar
Exhaust emission temperature	540.6	°C

Taking into consideration the operation of the engine in the area of maximum load, a measurement was performed within these values. It can be seen that all parameters are within normal limits, especially fuel consumption that is closer to the lower consumption limit.

Figure 4 shows a graph of engine parameters measured in a time interval of 650 seconds.

Figure 5 shows a graph of four engine parameters measured in a time interval of 900 seconds.

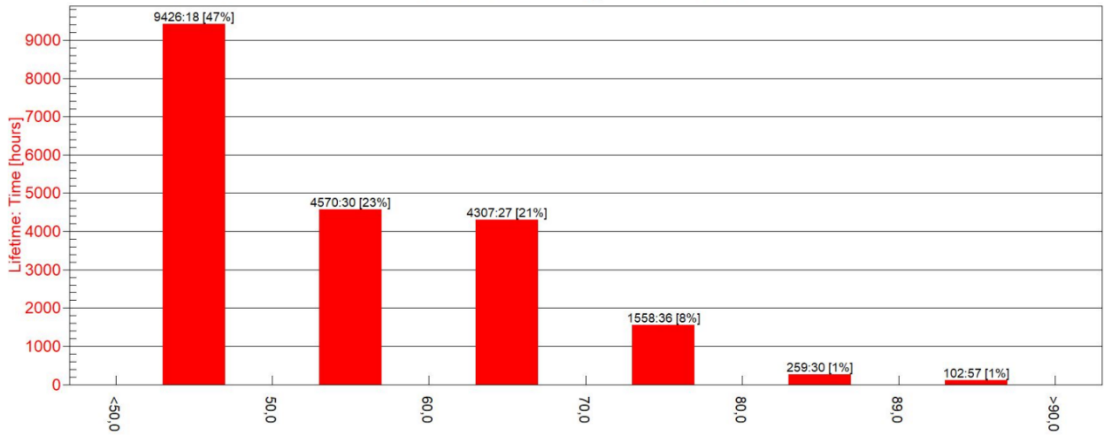


Figure 2: Engine Load during operation

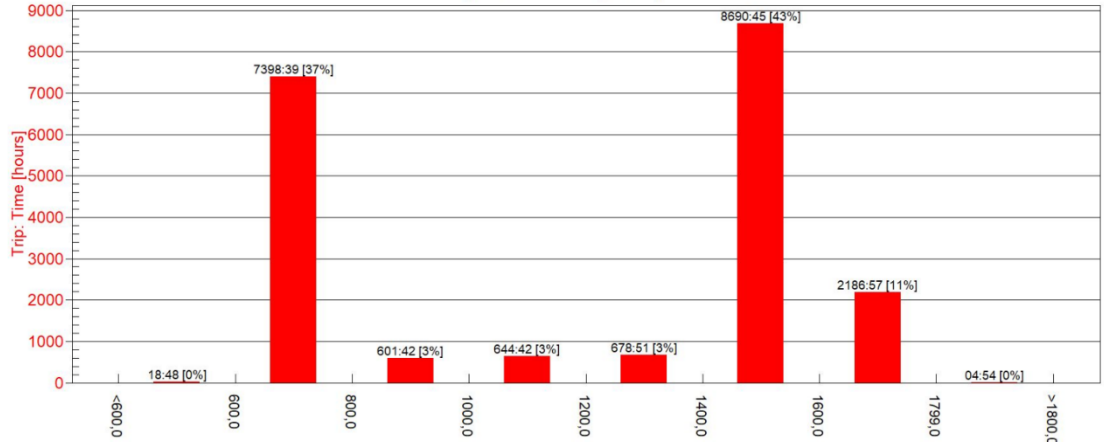


Figure 3: Engine Speed during operation

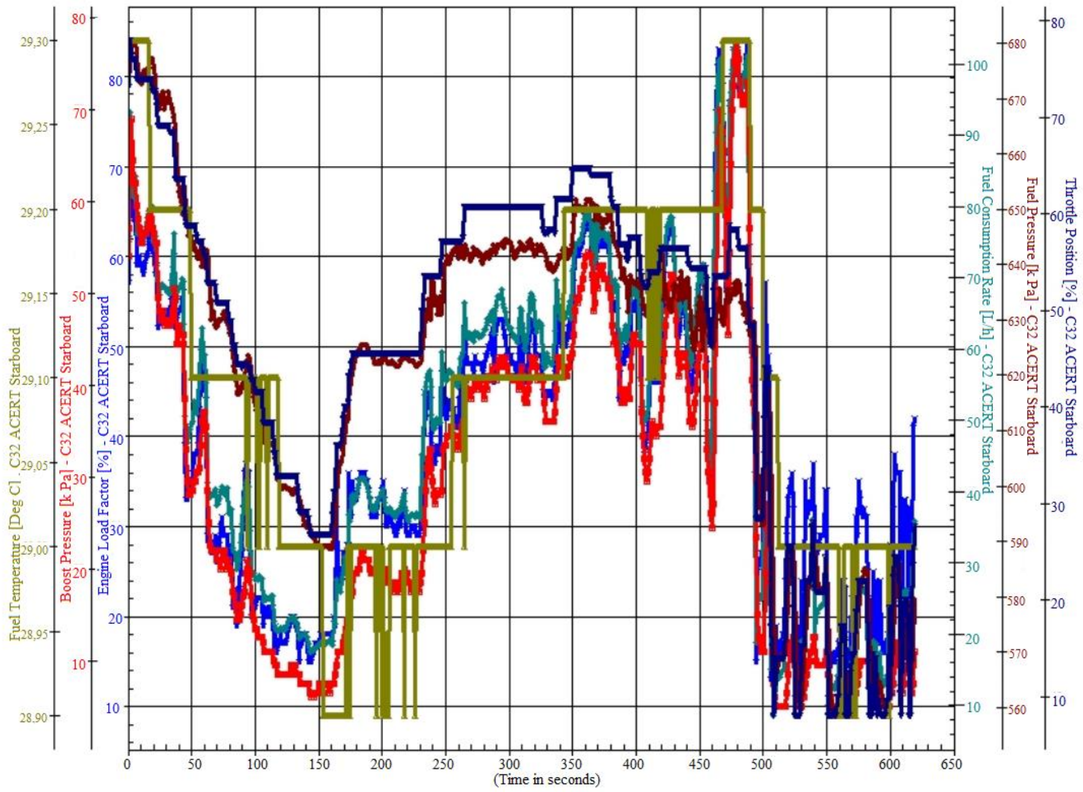


Figure 4: Graphical representation of six engine parameters over time during maneuvering

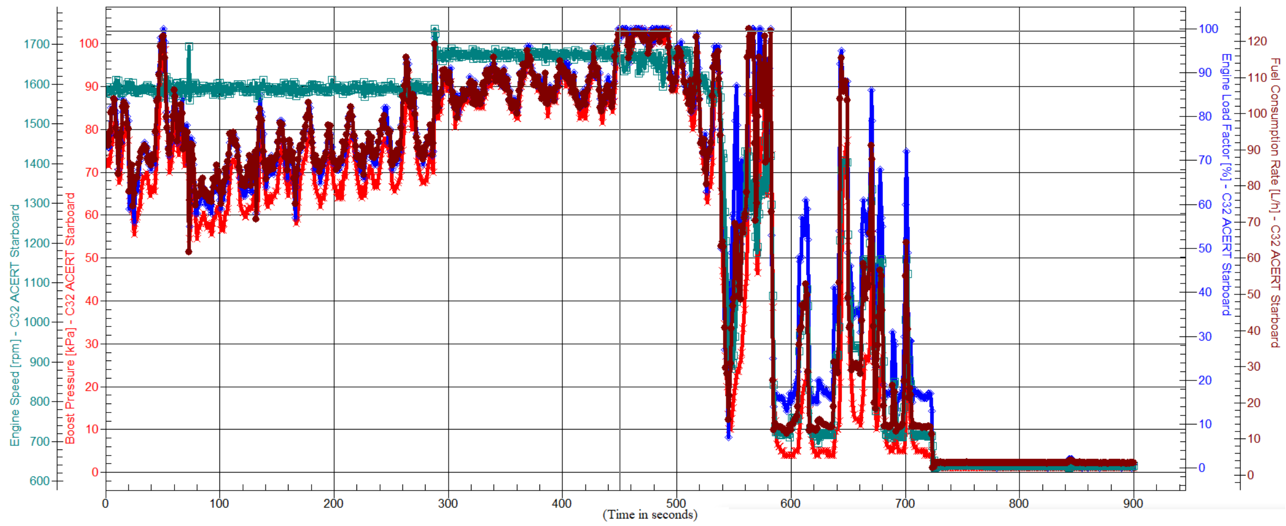


Figure 5: Graphical representation of four engine parameters over time during maneuvering

Table 6 shows the operating parameters of the engine, while the marine engine is running at a speed of 1700 rpm and at a load of 100%.

Table 6: Engine operation at a speed of 1700 rpm and 100% load

Test time [sec]	Load [%]	Speed [rpm]	Fuel consumption [lit / h]
450	100	1660	122,6
453	100	1654	122,6
456	100	1636	122,3
459	93	1663	116,8
462	100	1662	122,6
465	100	1670	122,3
468	100	1633	122,2
471	97	1678	119,9
474	98	1676	120,7
477	96	1666	120,3
480	97	1677	121,0

To diagnose engine condition, an engine operating range of 1700 rpm with a 100% engine load will be considered. From Table 6 it can be read that the average fuel consumption at a speed of 1700 rpm and 100% load is 122 lit / h. Comparing the newly obtained results from Table 6 with the results of reference tables, which were obtained during the testing of the marine engine, it can be seen that fuel consumption increased from 121 lit / h to 122 lit / h. The engine was properly maintained during the 20,000 operating hours, and injector controls and synchronization were performed to achieve optimal engine performance.

Figure 6 shows the values of the engine operating parameters at 1800 rpm read via the Data Logger device. The values of the monitored parameters are shown in the graph: fuel pressure, coolant temperature, fuel temperature, oil pressure and temperature, exhaust gas temperature.

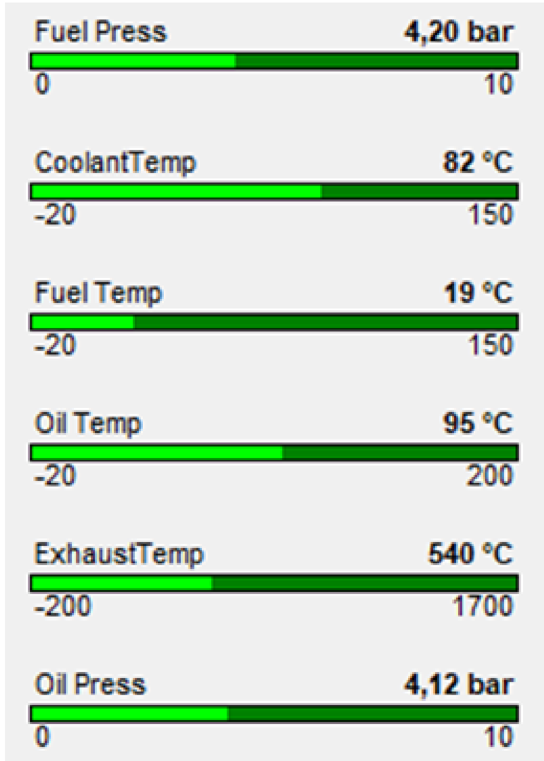


Figure 6: Graphical representation of engine parameters

5. CONCLUSION

During the research, the most influential parameters of the tested engine were identified and its operation was analyzed. With dedicated diagnostic tool of engine manufacturers proper analyses and diagnostic were performed on engine during normal operation. During remote monitoring, few parameters were monitored, such as: oil pressure, water temperature, etc. These parameters were not sufficient for detail analyzing of engine conditions, they can be used just for limited conclusions about some engine condition. For useful and satisfactory analysis remote monitoring system has to provide all influence parameter which can be lead to energy efficiency improvement.

ACKNOWLEDGMENT

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REFERENCES

[1] Obikoya, G.D. Design, construction, and implementation of remote fuel-level monitor system. EURASIP J. Wirel. Commun. Netw. 2014.

[2] Khan, S.R.; Ferdousi, A.; Khan, S.R. Real Time Generator Fuel Level Measurement Meter Embedded with Ultrasound Sensor and Data Acquisition System. J. Autom. Control Eng. 2013.

[3] Khan, M.A.; Waqas, A.; Khand, Q.U.; Khan, S. Context Aware Fuel Monitoring System for Cellular Sites. Int. J. Adv. Comput. Sci. Appl. 2017.

[4] Yam R.C.M.; Tse P.W.; Li. L.; Tu P. Intelligent Predictive Decision Support System for Condition-Based Maintenance, International Journal of Advanced Manufacturing Technology 17, Springer-Verlag London Limited, 2001.

[5] Maulidevi, N.U.; Khodra, M.L.; Susanto, H.; and Jadid, F. Smart online monitoring system for large scale diesel engine, in Editor (Ed.)^(Eds.): 'Book Smart online monitoring system for large scale diesel engine' IEEE, 2014.

[6] Chandra, A.A.; Jannif, N.I.; Prakash, S.; Padiachy, V. Cloud Based Real-time Monitoring and Control of Diesel Generator using the IoT Technology. 20th International Conference on Electrical Machines and Systems (ICEMS), Sydney, NSW, Australia, 11–14 August 2017.

[7] Gaushell D.J.; Darlington H.T. Supervisory Control and Data Acquisition (SCADA) System, Technical Information Bulletin 04-1 National Communication System, 2004.

[8] Sajid A.; Abbas H.; Saleem K. Cloud-Assisted IoT-Based SCADA Systems Security.: A Review of the State of the Art and Future Challenges. IEEE, 2016.

[9] Memon G.S.; Jaffer S.S.; Zaidi S.; Sheikh M.M.; Jabbar M.U.; Ahad A. An IOT-Enabled Generator for Power Monitoring and Load Management with Power Factor Improvement. (Presented at the 1st International Conference on Energy, Power and Environment, Gujrat, Pakistan, 11–12 November 2021)

[10] S. C. Liu.; S. Y. Liu. An Efficient Expert System for Machine Fault Diagnosis. International Journal of Advanced Manufacturing Technology 21, Springer-Verlag London Limited, 2003.

[11] Bogdan M. A Diagnostic System for Remote Real-Time Monitoring of Marine Diesel-Electric Propulsion Systems. University of Leipzig Faculty of Mathematics and Computer Science Institute of Computer Science. Leipzig, September 2011.

[12] Albrecht A.; Muc A. CAPABILITIES OF LOCAL AND REMOTE MONITORING AND CONTROL OF EQUIPMENT USED IN MARINE SHIP INDUSTRY. Sciendo 2018.

[13] Radica, G.: Dijagnostika brodskog 4-T dizelskog motora, Pomorski fakultet u Splitu, Split, 2008.

[14] KKMN; RJZD: ID-Mobile, Reference Guide, Praha, 2013.

[15] Cat Electronic Technician. Accessed on 14. April 2022. from https://www.empire-cat.com/online-tools/cat-et

THE IMPORTANCE OF COASTAL RADIO STATIONS AND MARITIME SAFETY INFORMATION IN COASTAL ZONE PROTECTION

Kristina Vladislavić, M.Eng.
Plovput d.o.o.
Obala Lazareta 1, Split, Croatia
kristina.vladislavic1@gmail.com

Mirjana Kovačić, Ph.D.
Matea Horvat, Ph.D. student
University of Rijeka, Faculty of Maritime Studies
Studentska ulica 2, Rijeka, Croatia
mirjana051@gmail.com, kapitanovic.matea@gmail.com

Ivan Karin, M.Eng.
Plovput d.o.o.
Obala Lazareta 1, Split, Croatia
ivan.karin@plovput.hr

ABSTRACT

Maritime safety information (MSI) are the information and the data provided to seafarers to increase the safety and the efficiency of the maritime navigation, but at the same time used for the purpose of protecting the coastal area. The fact is that the coastal radio stations have the preventive and the consequential role in the segment of the navigational safety and protection from the sea pollution. The paper analyses navigational warnings, meteorological information and other important information related to the navigational safety that are broadcasted by the coastal radio stations, currently and/or at certain regular or special times, through the navigational safety systems. The authors research the impact of the safety aspects of the navigation on the coastal area protection, from the aspect of up-to-date distribution of the maritime safety information to the end users, and determine the correlation between the navigational safety and the coastal area. The paper emphasizes the importance of improving the process of informing seafarers and the timely distribution of the necessary data and observes how they are reflected on various aspects of the coastal area.

Keywords: coastal radio stations, maritime safety information, navigation safety, environmental protection, coastal area

1. INTRODUCTION

A significant part of the population of the Republic of Croatia lives in coastal areas and on the islands. The quality of life largely depends on the cleanliness of the sea, which is closely related to marine and coastal activities. The importance of the maritime environment for human survival raises the awareness about the need and necessity for increasing the safety of navigation to a higher level. This is primarily the responsibility of the coastal state itself, which, by taking various prescribed measures, ensures the required level of safety of navigation in its territory. Accidents may have consequences of catastrophic proportions and directly endanger the interests of the coastal state and the quality of life of the population in the coastal area. It is common knowledge that most maritime accidents occur due to human error and untimely response to a new situation. A maritime accident can also be caused by incorrect interpretation or untimely observation of information relevant to the safety of navigation.

In the protection of human lives and the protection of the coastal area, it is important to collect accurate data and distribute them in a timely manner by navigational safety system as well as promptly mediation in search and rescue interventions.

The paper explains the impact of safety aspects of navigation on the protection of the coastal area through an analytical review of coastal radio interventions through channels for navigational safety with emphasis on the importance of maritime safety information distribution. The paper analyzes the data in the four-year period of the total participation of the coastal radio station in the search and rescue operations and distributed maritime safety information (MSI) in the eastern part of the central Adriatic. The purpose of this paper is to enhance understanding and awareness of the presence of risks of human impact on specific coastal ecosystems. The aim of this paper is to determine the importance of radio communications performed by coastal radio stations of the Republic of Croatia as a key element of navigational safety and protection of the sea from pollution from vessels.

During the research, several professional papers dealing with this topic were found, compared to scientific papers, which is why this paper is a contribution to the development of ideas about the importance of the role of coastal radio stations in navigational safety and coastal protection.

2. STATISTICAL OVERVIEW

The coastal area most commonly defined as the land affected by the proximity of the sea and the part of the sea affected by the proximity of the land is the area where the processes that depend on sea-land interaction are most pronounced [10]. Integrated coastal zone management implies a dynamic process and use of coastal resources, while taking into account the fragility of coastal ecosystems and landscapes, the diversity of activities carried out in this area, their interaction and the focus and impact of maritime and other activities at sea and on land [2]. During the last decades, the Mediterranean coastal ecosystems have been under significant pressure due to coastal population growth, uncontrolled urban sprawl in the coastal zone, increased tourism, especially nautical, resulting in environmental degradation and increased marine and coastal pollution [13].

According to the Croatian Central Bureau of Statistics, there is a trend of constant increase in the total traffic of all types of vessels, goods and passengers.

Thus, the number of nautical tourism ports in the Republic of Croatia has been constantly increasing. In 2019, the number of nautical ports was 167, which is 15% more than in the previous year, and in 2020 there were 185 ports, which is almost 9.7% more than in 2019. Also, the number of vessels on permanent berth in nautical tourism ports in the Republic of Croatia in 2019 was 14249, which is 4.6% more than in the previous year, and in 2020 it was 14312, which is 0.4% more than in 2019. The number of vessels in transit in the same ports in 2019 was 5.5% higher than in the previous year, and in 2020 as much as 40.7% lower than in 2019, which may be related to the COVID-19 virus pandemic [1].

In the maritime transport of the Republic of Croatia in the period from 2018 to 2020, 1761 search and rescue interventions were undertaken in the area of responsibility of MRCC Rijeka due to various maritime accidents and incidents, 30% of which were events that could directly affect coastal pollution (grounding, powerless vessel, sinking, capsizing, collision, impact, fire). According to the reports in 2021, there were 610 search and rescue interventions, most of which were in the central Adriatic in the summer months. A total of 13 ships, 110 boats and 12 yachts were rescued in the central Adriatic [9].

3. ORGANISATION AND ROLE OF THE MARITIME RADIO SERVICE

The adoption of the Barcelona Convention in 1976 instigated the composition of an institutional framework for integrated coastal zone management in the Mediterranean which continued in 1994 with the adoption of the MED Agenda 21. It is an umbrella document covering the protection of the Mediterranean marine and coastal environment, implemented by the adoption and application of the protocols, among which the "Protocol on Integrated

Coastal Zone Management of the Mediterranean" (ICZM Protocol) is considered as the most important (adopted on 21 January 2008-UNEP/MAP/PAP, 2008). According to the authors [7], the adoption of the Protocol on Integrated Coastal Zone Management of Croatia is of great importance, whereby it is especially important to consider the ecological aspect of the coastal area, so that timely action can be taken.

The Act on Ratification of the Protocol on Integrated Coastal Zone Management on 12 October 2012, Croatia has accepted the international obligation to include spatial planning, environmental and nature protection, cultural heritage protection and sustainable coastal economy development policy in its coastal area [6].

According to the Global Maritime Distress and Safety System (GMDSS), the eastern part of the Adriatic Sea belongs to the A1 sea area, where the Republic of Croatia is obliged to provide VHF, VHF DSC and NAVTEX signal coverage.

The organization and performance of the radio service is of public interest and is provided for the protection of human lives and safety of navigation in the internal sea waters and the territorial sea of The Republic of Croatia [8]. Jobs related to the performance of radio service on behalf of the Republic of Croatia are performed by Plovput LLC – Split [12].

This includes a 24-hour watch of coastal radio stations and appropriately equipped vessels (SOLAS vessels) on VHF channel 16 and DSC channel 70. Vessels that have radio equipment and do not fall under the SOLAS convention (so-called non-SOLAS vessels) are recommended to listen constantly, whenever possible, and especially when they are underway [3, 4].

In addition to permanent watch on the frequencies for distress and safety of navigation, in order to protect human lives at sea, the task of coastal radio stations is: mediation in communication in distress, urgency and safety interventions coordinated by the National Search and Rescue Center (MRCC) in Rijeka [11], mediation in communication in seeking medical advice from ships, broadcasting maritime safety information (MSI) through the navigational safety system, broadcasting messages about changing the level of security protection for ports and/or ships, commercial radio service with ships [12], providing radio services to state administration bodies (Search and Rescue Center, Harbor Master's Office, VTS, Ministry of Internal Affairs, Croatian Navy, ministries, etc.) .

Maritime Safety Information (MSI) includes navigational and meteorological warnings, meteorological forecasts and other emergency safety messages transmitted by ships [3].

For example, in the Republic of Croatia they are broadcast by three coastal radio stations (CRS Rijeka Radio, CRS Split Radio, CRS Dubrovnik Radio) at set times, four times a day, via the VHF system and via the Navtex system six times a day, in English and Croatian. Navtex messages of international importance are delivered to the Navarea coordinator in English.

Navigation warnings include urgent information related to safety at sea. Warnings must be clear, unambiguous and concise, and they must contain the position and description of the danger, while it is common to provide all other information that facilitates navigation in the vicinity of the danger, information on the establishment of new or malfunctioning navigation equipment at the existing maritime signal facility, missing buoys, shipwrecks, floating obstructions in the fairway, etc. Dominant activities in the coastal area disclosed to seafarers may be related to: aquaculture areas, fishing areas, facilities and infrastructure for exploration, exploitation and extraction of oil, gas, minerals and aggregates and other energy resources and production of energy from renewable sources, maritime traffic routes and traffic flows, areas of military training grounds, nature protection and protection of species, habitats and protected areas, areas of extraction of raw materials; scientific research, submarine pipelines and pipeline routes, tourism, underwater cultural heritage, beaches.

Weather reports include storm warnings, synoptic data and weather forecasts for seafarers. Weather reports are published together with navigational warnings on appropriate working channels, in English and Croatian, at certain times of broadcasting of each coastal radio station.

Information on search and rescue operations includes information on areas where search and rescue operations are carried out in coordination with MRCC Rijeka, Harbor Master's Offices and other participants in the operation, including the rescue facility. Information is mutually distributed by coastal radio stations VHF system, fixed and mobile telephony and fax, etc.

Other emergency information related to the safety of navigation includes security messages that do not fall into the category of navigational warnings, weather reports or search and rescue information. These may include notifications related to the failure of maritime communication systems or the performance of work on them, the amended System of mandatory reporting from ships, etc. [5].

Coastal radio stations (CRS) are vital in all systems related to navigational safety and protection of the sea from the pollution from maritime facilities because they have a preventive and consequential role.

The preventive role of coastal radio stations in navigational safety and marine environment protection is directed towards constant and timely information to seafarers about the actual situation at sea, changes and activities on navigational routes by broadcasting maritime safety information (MSI) through the navigational safety system. From the point of view of communication connectivity, the eastern part of the Adriatic meets the criteria of communication coverage by radio signal to coastal radio stations (CRS Rijeka Radio, CRS Split Radio and CRS Dubrovnik Radio) in VHF and Navtex area, although due to terrain configuration and indented coastline. VHF radio coverage is not fully achieved near the shore or at the approaches to bays/anchorages for smaller vessels. It can be concluded that all ships sailing on the Adriatic have information support by maritime safety information (MSI) on the entire waterway from Otranto Strait to the northern Adriatic.

Consequently, the role of coastal radio stations in navigational safety and marine environment protection is visible in search and rescue operations (SAR) in terms of providing communication support between centers or subcenters and persons at the scene of an incident. It is vital that coastal radio operators respond in a timely and effective manner to maritime incidents in order to identify distress and urgency calls on Channel 16 and to intervene as quickly as possible. It is equally important to communicate and coordinate with MRCC Rijeka as soon as possible in cases of pollution caused by an accident (fuel spill or dangerous cargo) in order to prevent or minimize it and remove the pollution ensuing from a maritime accident.

4. ANALYSIS OF THE ACTIVITIES OF THE COASTAL RADIO STATION SPLIT RADIO

The chapter provides an overview of the number of interventions of the coastal radio station Split Radio in search and rescue interventions (SAR) and the number of distributed maritime safety information (MSI) in the period from 2018 to 2021. SAR actions are divided into categories of mayday / distress, pan-pan / urgency, securite / safety, medico / medical assistance and MSI into categories of weather warnings and navigational warnings and displayed by months of the year.

Table 1: Interventions of CRS Split Radio in SAR actions and MSI distribution in 2018 (Central Adriatic)

SAR/MSI \ month	January	February	March	April	May	June	July	August	September	October	November	December
Mayday	0	0	0	0	2	4	11	9	6	0	0	1
Pan-Pan	0	0	3	1	8	3	5	2	3	2	0	0
Securite	6	9	5	11	15	7	6	4	9	6	12	5
Medico	0	0	0	0	0	0	3	0	2	0	0	0
Weather w.	121	106	108	105	109	104	105	89	97	100	110	98
Navig. w.	16	17	11	21	27	31	33	26	28	32	23	40
Total	143	132	127	138	161	149	163	130	145	140	145	144

Source: Made by authors according to the original data by the CRS Split Radio

In 2018, the weather warnings were mostly distributed through navigational safety channels, as well as navigational warnings throughout the year, while the number of SAR interventions increased in the summer months (Table 1).

Table 2: Interventions of CRS Split radio in SAR actions and MSI distribution in 2019 (Central Adriatic)

SAR/MSI \ month	January	February	March	April	May	June	July	August	September	October	November	December
Mayday	0	0	0	2	8	1	10	10	4	8	0	0
Pan-Pan	0	1	2	0	5	0	6	5	3	0	1	0
Securite	5	6	4	3	13	13	15	8	5	1	19	11
Medico	0	0	0	1	0	1	1	1	0	0	0	0
Weather w.	115	95	95	107	113	70	75	67	84	95	138	109
Navig. w.	11	33	46	22	30	20	22	20	21	30	22	30
Total	131	135	147	135	169	105	129	111	117	134	180	150

Source: Made by authors according to the original data by the CRS Split Radio

During 2019, the largest number of total communications on all navigational safety channels was recorded in November and May (Table 2).

Table 3: Interventions of CRS Split radio in SAR actions and MSI distribution in 2020 (Central Adriatic)

SAR/MSI \ month	January	February	March	April	May	June	July	August	September	October	November	December
Mayday	0	0	0	0	1	5	8	10	2	1	0	0
Pan-Pan	0	0	0	1	0	2	7	3	1	0	0	0
Securite	10	9	1	15	0	3	4	7	6	6	7	8
Medico	0	0	0	0	0	1	2	1	0	0	0	1
Weather w.	103	108	99	64	149	98	70	89	86	103	107	118
Navig. w.	19	11	11	10	19	19	34	21	18	29	21	22
Total	132	119	111	90	169	128	125	131	113	139	135	149

Source: Made by authors according to the original data by the CRS Split Radio

Table 3 shows that during 2020 the highest number of total communications on safety channels was recorded in May and the lowest in April. Regardless of the COVID-19 virus pandemic, the total number of all communications did not decrease significantly compared to previous years.

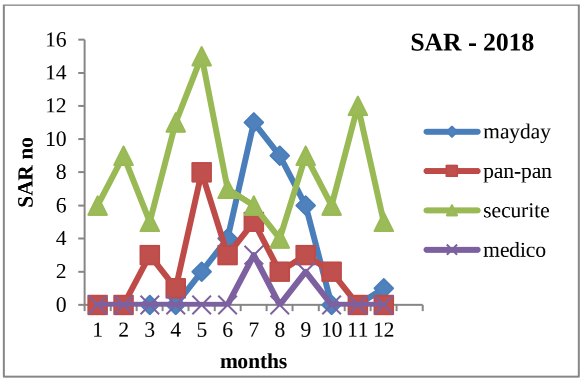
During 2021 (Table 4), the largest number of activities on navigational safety channels was recorded in April, then in October and December. The lowest number of activities was recorded in April.

Table 4: Interventions of CRS Split radio in SAR actions and MSI distribution in 2021 (Central Adriatic)

SAR/MSI \ month	January	February	March	April	May	June	July	August	September	October	November	December
Mayday	0	0	0	2	0	7	7	8	5	6	0	0
Pan-Pan	0	0	0	0	0	1	3	5	5	3	0	0
Securite	12	7	4	7	9	4	8	10	5	6	10	10
Medico	0	0	0	0	0	1	0	6	0	1	0	0
Weather w.	111	104	117	112	97	52	74	85	85	101	110	109
Navig. w.	16	10	14	28	34	18	8	23	28	29	23	27
Total	139	121	135	149	140	83	100	137	128	146	143	146

Source: Made by authors according to the original data by the CRS Split Radio

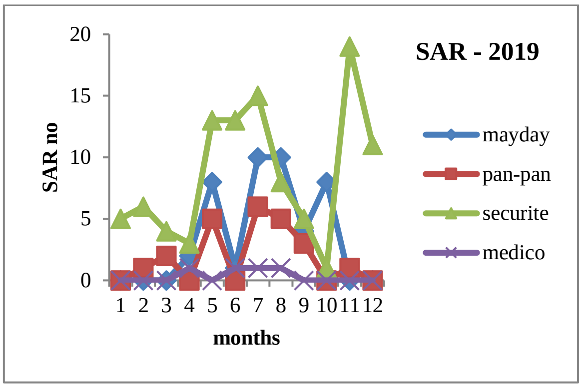
In order to recognize a trend in the interventions of the coastal radio station Split Radio in search and rescue actions and in the distribution of maritime safety information, it is important to analyze the results of statistical processing of interventions and distributed information in the past period.



Source: Made by authors according to the original data by the CRS Split Radio

Figure 1: SAR interventions in 2018

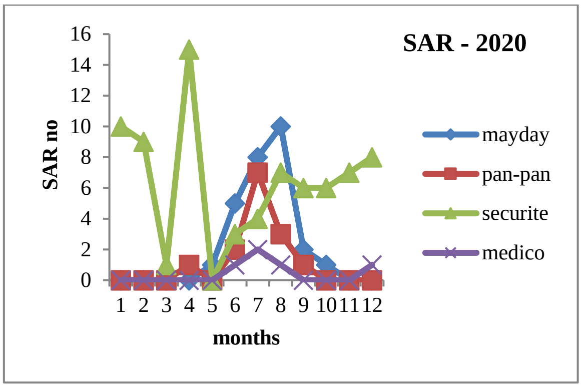
During the observed period, the number of Mayday and Pan-pan messages increased in the summer months, after which there was a continuous decline. Securite messages oscillate throughout the year, while there is a slight increase in the number of Medico messages in the summer months.



Source: Made by authors according to the original data by the CRS Split Radio

Figure 2: SAR interventions in 2019

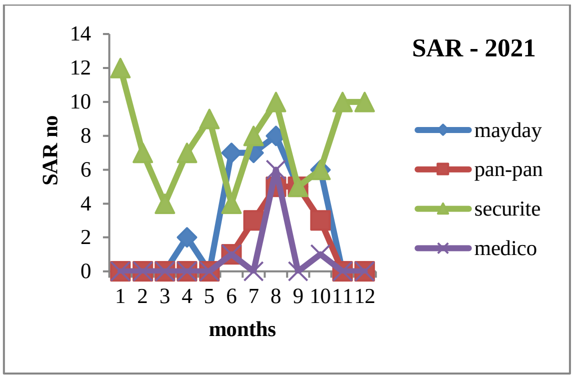
In 2019, the number of Mayday and Pan-pan messages was the highest in July and August, after which there was a decline. In the months of May, June and July, a significant number of Securite messages were noticed, recording a sharp increase in November, while the number of Medico messages was insignificant.



Source: Made by authors according to the original data by the CRS Split Radio

Figure 3: SAR interventions in 2020

The number of Mayday and Pan-pan messages increased in June, July and August, after which there was a continuous decline towards the end of the year. There is an oscillation in the number of Securite messages in the first part of the year, after which they slightly increased. There was a negligeable number of Medico messages in July.

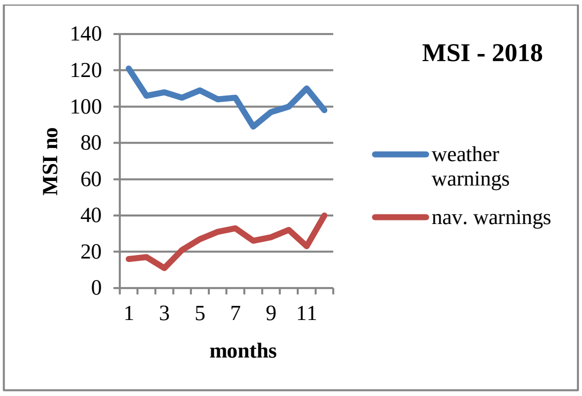


Source: Made by authors according to the original data by the CRS Split Radio

Figure 4: SAR interventions in 2021

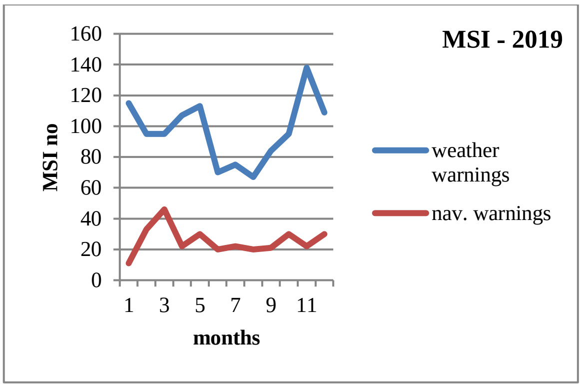
During 2021, it can be seen that the number of Mayday and Pan-pan messages increased in the summer months, after which there was a continuous decline. The number of Securite messages fluctuated throughout the year, with a noticeable increase in the number of Medico messages in the summer months.

Figures (5, 6, 7 and 8) show the total number of distributed weather warnings and navigational warnings for the area of the Croatian part of the central Adriatic in the period from 2019 to 2021. During the observed four-year period, there were slight oscillations in the number of weather warning messages, whose number was higher in spring and winter, due to frequent wind gusts, while in summer there was a slight decrease due to occasional summer storms. The number of navigational warnings was relatively constant throughout the observed period, which indicates a continuous activity at sea in terms of work, for example: on safety facilities, removal of extinguished coastal lights, arrangement of breakwaters and coast, installation of submarine pipelines, underwater research, etc.



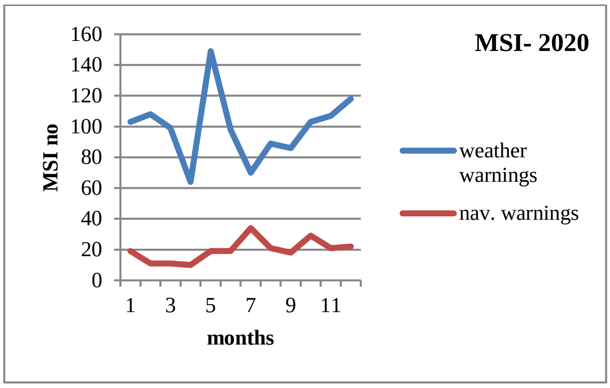
Source: Made by authors according to the original data by the CRS Split Radio

Figure 5: MSI distribution in 2018



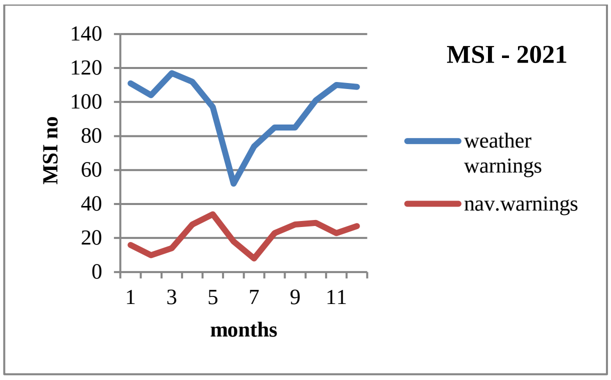
Source: Made by authors according to the original data by the CRS Split Radio

Figure 6: MSI distribution in 2019



Source: Made by authors according to the original data by the CRS Split Radio

Figure 7: MSI distribution in 2020



Source: Made by authors according to the original data by the CRS Split Radio

Figure 8: MSI distribution in 2021

5. CONCLUSION

The Maritime Safety Information (MSI) exchange flow uses different ways of transmitting information. Various processes and sub-processes may slow down the exchange of information before it reaches the end user. The conducted analysis indicates the need for further scientific and professional research related to the assessment of safety risk analysis based on the distribution of MSI according to the time of creation, receipt, broadcast and distribution of MSI to the end user and listening/reading time of MSI by seafarers. There is a continuous tendency to improve the existing maritime radio communication system, where it is necessary to raise the quality of maritime safety information broadcasting, optimize work processes, provide IT support to CRSs with electronic navigation charts, and if necessary introduce control over listening to daily weather reports and navigational warnings.

It is necessary to insist on improving the radio service of coastal radio stations of the Republic of Croatia, which with its activity, 24-hour watch servise on distress and safety channels, timely response to emergencies and distribution of relevant MSI messages to seafarers represent the foundation of the Adriatic navigational safety and consequently coastal area protection.

REFERENCES

[1] Central Bureau of Statistics. (2022). Series Statistics, Transport and Communications. Zagreb. https://podaci.dzs.hr/hr/statistika-u-nizu/ Accessed on 17.03.2022.

[2] ICZM Protocol. (2008). Protocol to the Barcelona Convention on Integrated Coastal Zone Management. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22009A0204(01)&from=EN. Accessed on 05.01.2022.

[3] International Maritime Organization. (1974). International Convention for the Safety of Life at Sea(SOLAS). https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx. Accessed on 08.04.2022.

[4] International Telecommunication Unit. (2020). Radio Regulations. Resolutions and Recommendations. https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.44.48.en.103.pdf. Accessed on 08.01.2022.

[5] Joint IHO/IMO/WMO. (2009). Manual on Maritime Safety Information (MSI). (Special Publication No. 53) Monaco. International Hydrographic Bureau

[6] Kordej-De Villa, Ž., Rašić Bakarić, I. & Starc, N. (2014). Coastal Zone Management in Croatia. Društvena istraživanja, 23 (3), 449-468. https://doi.org/10.5559/di.23.3.04 .

[7] Kovačić, M. & Komadina, P. (2011). Coastal Zone Management and Sustainable Development. Univerity of Rijeka. Faculty of Maritime Studies.

[8] Maritime Code. Official Gazette no 181/04, 76/07, 146/08, 61/11, 56/13, 26/15, 17/19

[9] National Center for Coordination of Search and Rescue at Sea. (MRCC Rijeka). (2021). https://mmpi.gov.hr/more-86/traganje-i-spasavanje-109/statistika/13773 Accessed on 07.01.2022

[10] Radman, Z., Madiraca, M., Radman G., Bubić, I. & Madiraca, M. (2014). Integrated Coastal Zone management. Hrvatski zavod za prostorni razvoj – Zagreb. URBOS doo. Split

[11] Republic of Croatia: National Maritime Search and Rescue Plan. Official Gazette no 164/98

[12] The Plovput Split Act. Official Gazette no 73/97. https://zakon.hr/z/1543/Zakon-o-Plovputu%2C-Split Accessed on 10.01.2022.

[13] Yalciner Ercoskun, O. (2017). Coastal Zone Protection in the Mediterranean Countries and Turkish Efforts. Gazi. University Journal of Science 30 (2):1-16

ANN IN COUNTING AND CLASSIFICATION OF VESSELS FOR TRAFFIC RESEARCH

(INVITED SESSION PAPER)

Igor Vujović
Miro Petković
Ivica Kuzmanić
Joško Šoda
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, 21000 Split, Croatia
ivujovic@pfst.hr

ABSTRACT

Data on traffic and types of ships are important for many researches. Manual counting of ships is impractical. Therefore, automated systems should be used. Ships with AIS can be counted automatically, but many ships do not have AIS transponder installed. Ships outside AIS can only be counted automatically by some kind of video surveillance. In order to count and classify ships in the maritime zone of Port of Split, we used artificial neural network and long range high resolution Dahua camera. Since the Port of Split is mainly a passenger and commercial terminal, we classified the ships into nine classes: small craft, motorboat, pleasure boat, fishing boat, yacht, excursion boat, high speed craft, ferry and cruiser.

Keywords: Yolo 4, maritime zone surveillance, counting of no-AIS vessels, classification of maritime vessels

1. INTRODUCTION

Researchers around the world use vessel traffic data to analyze traffic volume, flow, and density [1, 2] or to analyze marine accidents [3]. Vessel traffic data are usually obtained by automatic identification system (AIS) and/or vessel traffic surveillance systems (VTS), but it is also noted that not all vessels are equipped with AIS on board [1] and the coverage by VTS is quite limited [3]. Therefore, video surveillance can help to obtain detailed information about maritime traffic in a particular sea area. According to [4], a basic maritime video surveillance system consists of:

- initial detector,
- image processor,
- classifier,
- tracker,
- behavior analyzer (if required).

Moreover, according to [5,6], they have to overcome several challenges, such as a large surveillance area, weather problems (rain, snow, fog...), changing nature of the sea (waves, white foam, sun reflections), non-uniform size of tracked objects, multiple tracked objects with possible occlusions.

Video surveillance in maritime environments can range from small surface vehicles (manned or unmanned) with cameras or buoys on the water [7], to static cameras on land [8], to aerial surveillance by drones. The ARGOS system [8] was used in the Grand Canal of Venice for vessel detection and tracking without ANN. It was used to count ships, but could not distinguish between different categories of ships. Moreover, it had problems to reliably track fast moving ships due to the low FPS. In [9], the authors proposed and evaluated ship detection and tracking without ANN. However, it lacked classification of ships and had problems in detection due to sea state and illumination problems.

Some object detection techniques for maritime surveillance based on ANN were presented in [10], where an overview of the currently available datasets is also given. The authors classified 16 ship types into 4 main categories and concluded that the ANN techniques are a good choice for a real-time detection system. In [11], real-time ship detection was studied based on ANN for port surveillance. The system detected different types of vessels with 90% accuracy, but had problems in detecting small vessels.

Since video-based systems can provide high-quality metadata for further traffic analysis, the use of camera systems was proposed in [12,13]. In [12], the authors tested a video-based vehicle counting and classification on public highways using novel ANN object detection techniques. They also classified vehicles into four different categories and tested them using different Convolutional Neural Networks (CNN) as detectors. This approach provided promising results in counting and classifying vehicles, thus validating the concept. Deep learning object detectors with multi-target trackers based on the Kalman filter were also used in [13] to extract information about traffic flow in complex areas. It is concluded that the proposed system needs to distinguish even more different types of vehicles, and some problems are identified due to high traffic density (specific to this application).

In [14], a ANN based vessel tracking with object detection is proposed for counting sea vessels in real time. The counting system achieved a stable count and proved to be very robust, despite complex scenarios and weather conditions. However, it lacks ship classification since the network was trained to recognize all ships as one class.

2. EXPERIMENTAL SETTINGS

Access to a long range surveillance camera (LR) was obtained as part of 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) with the aim of developing real-time object detection and tracking of sea vessels entering and leaving the port of Split. Also, the H.264 video stream in 1080p and 25 FPS was forwarded to our lab computer. Camera hardware details:

- Model: Dahua DH-TPC-PT8620A-T,
- Image sensor: 1/1.9″ Sony CMOS,
- Focal length: 6 ~ 180 mm,
- Angle of view: H: 59°~2.4°,
- Optical zoom: 30x.

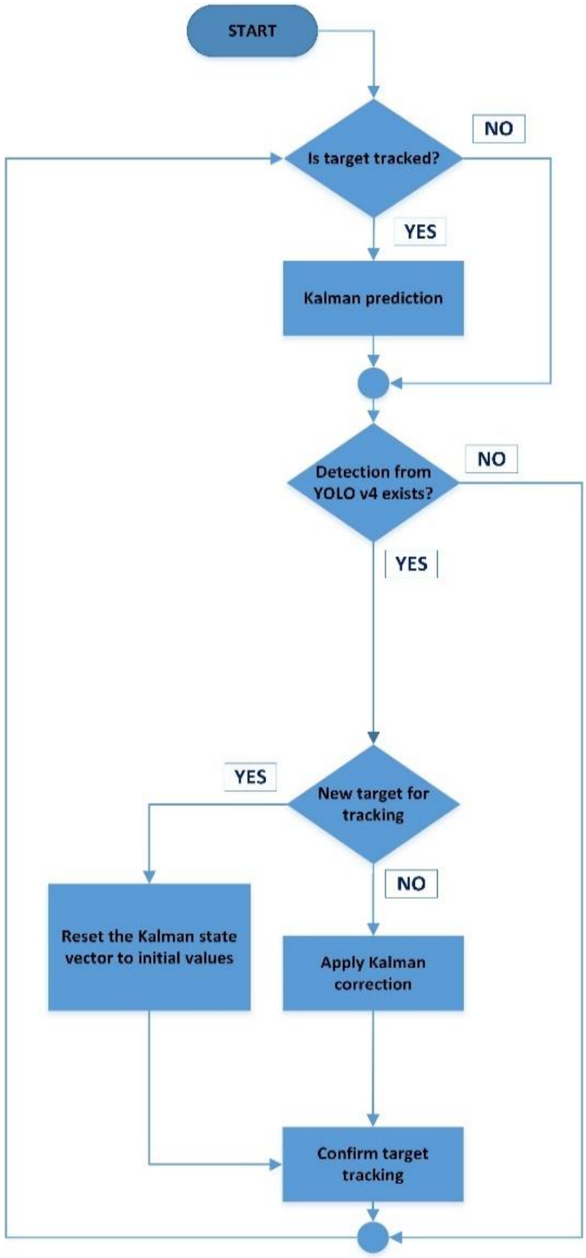
To detect the vessels in real time, the convolutional neural network You Only Look Once Version 4 (YOLOv4) [15] is used as an object detector and classifier. Then, the ANN was trained with our custom dataset consisting of 13000 images captured by Dahua LR camera of various vessels entering or leaving Split port. Moreover, the images were taken at different times of the day, weather conditions and seasons (winter and summer). The vessels in the dataset were manually labelled and, after consultation with colleagues from the Department of Nautical Science, classified into nine different categories:

- small craft (rubber boats, small motorboats, small fishing boats, jet-skis, dinghies, kayaks),
- motorboat (medium-sized motorboats),
- pleasure boat (sailboats, catamarans),
- fishing boat (large fishing boats),
- yacht (large motorboats),
- excursion boat (large boats for tourist excursions),
- high speed craft (high speed boats for passenger transfer),
- ferry,
- cruiser (large passenger cruiser).

The main purpose of the classification is to distinguish different types of vessels for future use of the obtained data.

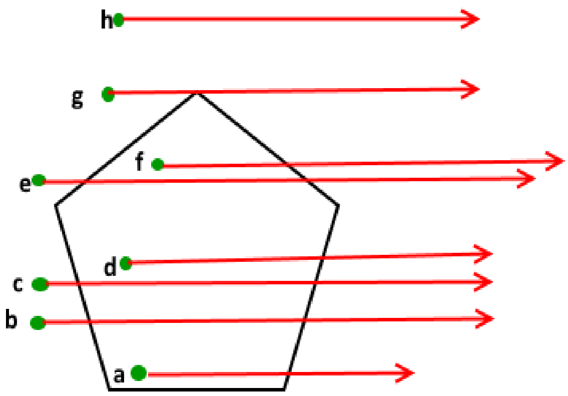
When a maritime target is detected by the object detector, the tracking algorithm must estimate the position and parameters of the target in motion. In addition, the object detector may not be able to detect the object of interest (OOI) in each successive frame, so the tracking algorithm's task is to fill in the gaps between detections. Due to its robustness and real-time performance, the tracker based on the Kalman filter (KF) with the Hungarian association algorithm is selected as the multi-target tracker.

In order to count vessels, we need to define the tracked target detection zone, which can have any shape as long as it maintains the shape of the polygon. The main task of this zone is to count the targets in such a way that the counter for this particular class of ships is increased by one when the target enters the zone. To check if the target is inside the detection zone, we use a simple method. First, a horizontal line is drawn from the centre of the target and extended to the right, as shown in Figure 2.



Source: Authors

Figure 1: Flowchart of the Kalman tracker



Source: Authors

Figure 2: Method to determine if the target is within the detection zone

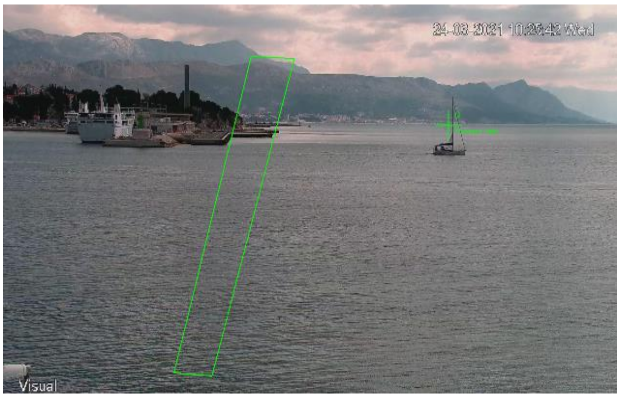
3. RESULTS

Figure 3. shows the detected and classified vessels in a real situation with severe illumination problems due to sun reflections on the sea surface. The vessels are counted when they enter the defined zone marked with a green polygon.

Source: Authors

Figure 3: Detected and classified vessels approaching the defined zone

YOLOv4 proved to be very robust and detected ships in video sequences with different illumination problems (Figure 3) and weather conditions (Figure 4).



Source: Authors

Figure 4: Detected and classified vessel in cloudy weather

Figure 5. shows that vessels can be detected even in heavy fog.

Source: Authors

Figure 5: Detected and classified vessel in heavy fog

During system evaluation, we found that YOLOv4 sometimes incorrectly detects seagulls and sea reflections as OOI. An example of this problem can be seen in Figure 6.

Source: Authors

Figure 6: False detection

4. CONCLUSION

The application of YOLOv4 ANN for real-time vessel detection has proven to be very robust. It detected vessels in video sequences with high illumination and weather problems. However, it sometimes incorrectly detected seagulls and reflections from the sea surface as objects of interest. We calculated that these false detections occur once every 20 to 40 frames. To address this problem, in the future we will improve the Kalman tracker with a routine that evaluates the stability of detections. A tracked object will be considered stable if it has more than 2 detections within 20 frames. Also, the training dataset for ANN needs to be extended with more annotated images because some vessel classes were represented with a smaller number of images. Our simple method for counting vessels achieved a stable count without any problems.

ACKNOWLEDGMENT

The equipment used was obtained by 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". The work is performed by the research group for application of new technologies in maritime affairs (https://brod.pfst.hr/~ivujovic/zn_grp.html).

REFERENCES

[1] Q. Meng, J. Weng, and S. Li, "Analysis with automatic identification system data of vessel traffic characteristics in the Singapore Strait," Transportation Research Record, vol. 2426, pp. 33–43, Dec. 2014, doi: 10.3141/2426-05.

[2] L. Wang et al., "Use of AIS data for performance evaluation of ship traffic with speed control," Ocean Engineering, vol. 204, May 2020, doi: 10.1016/j.oceaneng.2020.107259.

[3] Y. Wang, J. Zhang, X. Chen, X. Chu, and X. Yan, "A spatial-temporal forensic analysis for inland-water ship collisions using AIS data," Safety Science, vol. 57, pp. 187–202, Aug. 2013, doi: 10.1016/j.ssci.2013.02.006.

[4] D. K. Prasad, D. Rajan, L. Rachmawati, E. Rajabally, and C. Quek, "Video Processing From Electro-Optical Sensors for Object Detection and Tracking in a Maritime Environment: A Survey," IEEE Transactions on Intelligent Transportation Systems, vol. 18, no. 8, pp. 1993–2016, Aug. 2017, doi: 10.1109/TITS.2016.2634580.

[5] D. D. Bloisi, F. Previtali, A. Pennisi, D. Nardi, and M. Fiorini, "Enhancing Automatic Maritime Surveillance Systems with Visual Information," IEEE Transactions on Intelligent Transportation Systems, vol. 18, no. 4, pp. 824–833, Apr. 2017, doi: 10.1109/TITS.2016.2591321.

[6] R. Gladstone, Y. Moshe, A. Barel, and E. Shenhav, "Distance estimation for marine vehicles using a monocular video camera," in 2016 24th European Signal Processing Conference (EUSIPCO), Aug. 2016, pp. 2405–2409. doi: 10.1109/EUSIPCO.2016.7760680.

[7] Fefilatyev, S., Goldgof, D., Shreve, M., & Lembke, C. (2012). Detection and tracking of ships in open sea with rapidly moving buoy-mounted camera system. Ocean Engineering, 54, 1–12. https://doi.org/10.1016/j.oceaneng.2012.06.028

[8] Bloisi, D., & Iocchi, L. (2009). ARGOS - A video surveillance system for boat traffic monitring in venice. International Journal of Pattern Recognition and Artificial Intelligence, 23(7), 1477–1502. https://doi.org/10.1142/S0218001409007594

[9] Wawrzyniak, N., Hyla, T., & Popik, A. (2019). Vessel detection and tracking method based on video surveillance. Sensors (Switzerland), 19(23). https://doi.org/10.3390/s19235230

[10] Nalamati, M., Sharma, N., Saqib, M., & Blumenstein, M. (2020). Automated Monitoring in Maritime Video Surveillance System. 2020 35th International Conference on Image and Vision Computing New Zealand (IVCNZ), 1–6. https://doi.org/10.1109/IVCNZ51579.2020.9290533

[11] Zwemer, M. H., Wijnhoven, R. G. J., & de With, P. H. N. (2018). Ship detection in harbour surveillance based on large-Scale data and CNNs. VISIGRAPP 2018 - Proceedings of the 13th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, 5,153–160. https://doi.org/10.5220/0006541501530160

[12] Liu, C., Huynh, D. Q., Sun, Y., Reynolds, M., & Atkinson, S. (2020). A Vision-Based Pipeline for Vehicle Counting, Speed Estimation, and Classification. IEEE Transactions on Intelligent Transportation Systems, 1–14. https://doi.org/10.1109/tits.2020.3004066

[13] Nam Bui, K. H., Yi, H., & Cho, J. (2020). A multi-class multi-movement vehicle counting framework for traffic analysis in complex areas using CCTV systems. Energies, 13(8). https://doi.org/10.3390/en13082036

[14] Liu, C., & Li, J. (2021). Self-Correction Ship Tracking and Counting with Variable Time Window Based on YOLOv3. Complexity, 2021. https://doi.org/10.1155/2021/2889115

[15] Bochkovskiy, C. Y. Wang, and H. Y. M. Liao, "YOLOv4: Optimal Speed and Accuracy of Object Detection," arXiv, 2020.

DESIGN SPECIFICATION BACKGROUND FOR THE SLIDING BEARINGS INSTRUMENTED TEST RIG

Nenad Vulić, Ph.D.
Ivan Komar, Ph.D.
University of Split, Faculty of Maritime Studies
Ruđera Boškovića 37, Split, Croatia
nenad.vulic@pfst.hr, ivan.komar@pfst.hr

ABSTRACT

Over the past 15 years research dealing with sliding journal bearings in maritime applications, to improve their energetic efficiency and ecological acceptability, has gained special attention. If inadequately designed, sliding bearings, either of radial type (shaft bearings) or axial type (thrust bearing) may produce relatively high energy losses. Numerical models (such as numerical solutions to the Navier-Stokes equations) and sometimes even analytical models (Reynold's equation in special cases) have been well developed over the years, but the validation of these theoretical models can still be an issue. Therefore, the aim of the paper is to present the first step in the process of the test rig design, i.e. formulating its design specification background. The instrumented test rig for sliding bearings and related components has been designed, constructed, manufactured, assembled and prepared for commissioning tests at the Faculty of Maritime Studies, University of Split, Croatia. It is capable of testing radial and axial bearings, with the journal diameter within the range of 60 through 300 mm. Bearing materials can be either metallic or nonmetallic (e.g. polymers) with different types of lubricants (water, sea-water or oil). Shaft journals can be either aligned with the radial bearing axis or misaligned. The rig has been developed within the EU financed research project intended mostly for research purposes (80% of time). Remaining 20% belongs to commercial purposes, thus offering bearing manufacturers the testing services for their bearings. Based upon the design specification, some essential issues had to be resolved during this phase, e.g. implementing of low stiffness drive shaft, couplings to reduce inclination, hydrostatic bearings and several other items.

Keywords: marine propulsion; shafting systems; shaft line bearings; thrust bearings; lubrication

1. INTRODUCTION

Marine propulsion system of modern ships always comprise a variety of shaft line bearings, mostly of sliding type. The essential role of these bearings is to enable rotation of the shafts, to hold the shafts and to transmit reaction forces to surrounding structural parts through the bearing lubricant layer. The mechanism enabling automatic formation of this layer is hydrodynamic lubrication in the bearings, owing to the relative velocity between the shaft journal and the bearing sleeve, viscosity of the fluid and relative inclination (in form of an edge). In normal operating conditions shafting journals are in not in direct contact with the bearing sleeves, because they are lying on the lubricant layer. The shape and dimensions of the clearance space between the shaft journal and the bearing sleeve, together with the physical properties of the lubricant (its viscosity and density) significantly affect the bearing performance, especially in the terms of its power loss due to friction. Bearing in mind general requirements for the economic efficiency and ecological acceptability of modern merchant marine ships, it follows that both of these categories may be improved implementing proper design, verification and validation methods for the ship bearings.

In order to meet the requirements the bearings have to be properly designed and calculated and, if necessary, also numerically modelled. Designs of sliding bearings for marine shafts are in certain cases prescribed by standards (e.g. SB 6789 [1] for intermediate shaft bearings) or in some aspects by the classification societies rules, e.g. the Croatian Register of Shipping Rules for the Classification of Ships [2]. Calculation procedure for sliding bearings is also very well-known and based upon Reynold's differential equation and its solutions. These solutions have been published in the national [3] and international standards [4]. The basics of this calculation procedure are somewhat very common and the design or service engineering students of maritime faculty are acquainted with these calculations within the courses such as machine elements in marine engineering [5].

On the other hand, though the theoretical procedure for the sliding bearings calculation and testing has been very good defined, the increasing requirements for the reduction of ship fuel consumptions and stricter ecological requirements lead to new bearing designs, possibly not covered by the standards or established calculation procedures, with the emphasis to the details of grooves, clearances, new lubricant materials, etc. Development of these new designs require numerical modelling of the lubricant film behavior in the bearings, where the issue of verification and validation of these new designs is essential. Without proper experimental validation, the new bearing designs would lack a reliable basis for their practical acceptance. Validation needs the proper experimental equipment and laboratory with the instrumented test rig for sliding bearings as its central part.

The aim of this paper is to present the process of defining the design specification background, in accordance with the requirements of the bearings testing laboratory owners, that the future instrumented bearings test rig concept, design and construction is to rely upon. So, the aim is not to present the actual development of the concept and design details, but solely the requirements that the test rig design shall meet.

Once the bearings test rig has been designed and produced, the next step will be validation of the actual instrumented bearings test rig itself to check out whether it meets here defined design specification background, in other words "testing of the test rig" itself. These tests of the rig are based upon the appropriate testing procedure, which has been presented within a separate paper.

2. DESCRIPTION AND THE PURPOSE OF THE BEARINGS TEST RIG

In order to start defining the design specification background, the basic requirements for the test rig to be developed and designed shall be defined as the first step of the entire process.

The instrumented test rig is intended for scientific research purposes related to the radial and axial sliding bearings primarily used in sea-going ships and other maritime objects. The test rig shall enable users to test loading capacity of the sliding bearings of various design shapes, types and sizes, operating under various load cases and shaft journal positions relative to the bearing itself. These bearings shall be able to operate under pure hydrodynamic or mixed (transient) lubricating conditions, where the elastic properties of the bearing material itself shall also be taken into account, thus leading to elasto-hydrodynamic lubrication conditions.

The test rig shall be able to examine and test various quantities measured at the bearings of different design shapes, various dimensions, several bearing material types and different lubrication systems with the lubricants of various properties. The test rig shall be able to expose bearings to different operating conditions, with the additional aim to test influence of bearing materials and lubricating systems to the environment. The test rig shall also be capable of setting up various deviations of the geometry of bearings, journals and shafts from the ideal ones and to set up their relative positions.

These tests of sliding bearings are planned to be performed in the adequately equipped laboratory of the Faculty of Maritime Studies at the University of Split, Croatia.

3. BACKGROUNDS AND METHODS

3.1. Basic concept of the test rig

Defining the concept is always the initial step in designing of any component or machine and this applies to the instrumented test rig as well. The initial idea as a good starting point may easily be found in literature, even in international standards, e.g. [6-7], though the test rig presented there applies to bearings intended for automotive connecting rods, rather than for marine shafts. The initial concept presented hereafter has been defined in the Technical specification prepared by the test rig designer as the basis of the public tender [8]. The predeveloped concept is based upon the requirements to be met for the bearings planned to be tested.

3.2. Bearing design shapes and layout

Test bearing design shapes and layout depends upon the actual bearings used in real marine shafting systems. Radial bearings are implemented there as intermediate shaft bearings, forward stern tube bearings, aft stern tube bearings or strut bearings. Axial bearings operate as thrust shaft bearings, mostly of Michell type. The two conceptual layouts apply to radial bearings: between the two supports (similar to simple supported beam) simulating intermediate shaft bearings or fore stern tube bearings, as well as bearings on overhang, simulating thus strut or aft stern tube bearings.

3.3. Bearing dimensions

Dimensions of test bearings are defined in terms of shaft diameter ranges, ratio of bearing length per unit diameter and the bearing clearance. In accordance with the experience obtained on the bearings in the ships classified by the Croatian Register of Shipping (CRS) the shaft diameter range in the test rig is from Ø60 mm through Ø300 mm. Though in larger ships propeller shaft diameters may exceed the maximal value stated above, the upper limit of 300 mm has been chosen for the practical operating reasons in the laboratory. The lower limit covers the bearings in small ships and yachts. With respect to bearing length per unit diameter ratio, the highest value has been selected as 4.0 for strut bearings and aft stern tube bearings (so common for lignum vitae bearings used in the past), though in todays practice this ratio rarely exceeds the value of 2.0.

In accordance with the request to cover bearings of different sizes by single shafts, the shafts for the test rigs are to be designed stepwise, with several discrete selected diameter values along the shaft itself.

3.4. Materials

Materials shall be considered as shaft materials, bearing materials and lubricant materials.

Shafts journal materials for the test rig are to be manufactured of stainless steel. In order to test the bearings there is no need to change the material of the shafts, i.e. the selected stainless steel AISI 304 as shaft material may be applied in each and every situation, because the subject of testing is the bearing and not the shaft journal.

Bearing materials are either babbit metal or polymer. The basic idea for the development of such an instrumented bearing test rig initially originated from the comparison of the effects of implementation of water-lubricated polymer bearings in actual ships with the conventional oil-lubricated babbit metal bearings [9-11].

Bearings in the test rig are lubricated either by oil, fresh water, pure sea-water or emulsion of grease in sea-water. Sea water for testing purposes may be obtained by automatic adding of salt to fresh water in order to match the density of sea water (about 1025 kg/m³). Fresh water is ordinary water taken from the communal waterworks pipe lines without any additives or processing.

3.5. Service loading

Service loading of the test rig is determined in terms of the prime mover power, shaft journal rotational speed, as well as the radial or loading of the test bearing.

The prime mover is to be the electric motor with the frequency controller, enabling any rotational speed within the operating range to be selected and preset. There is neither brake nor propeller in the test rig mechanical system, meaning that the entire system torque loading originates only from the friction in the bearings and from hydraulic cylinders applying load to the shafts.

Shaft journal rotational speed is in the range of 80 rpm up to 3000 rpm. Though the upper limit exceeds values expected in normal marine engineering practice, it has been selected to cover other possible applications of radial bearings. During the start of the shaft journal with the highest diameter and the test bearing of polymer type, the highest torque load to be expected amounts to 4500 Nm during about the maximal time of 2 seconds. In continuous operation at the steady-state rotational speed the nominal continuous torque loading will not exceed 400 Nm.

The electric motor may be directly coupled to the rest of the system (transmission ratio 1:1) or through the planetary reduction gearbox (transmission ratio 7:1). The former concept is recommended for nominal shaft speeds of 300 rpm and above, where the latter concept shall be used in case of lower speeds, because the reduction gearbox enables output of higher torques when necessary. This especially applies to the test cases with higher amounts of journal misalignment. The time of speeding-up and stopping of the shaft drive can be set up and it is to be controlled. The shaft can rotate in both directions and it can also oscillate.

Misalignment of the shaft journal with respect to the sliding bearing in practice mostly originates from the difference of propeller weight and its buoyancy in sea-water. Setting up of misalignment is essential for the tests of the strut bearings and aft stern tube bearings. Shaft journal misalignment is to be conceptually enabled in the test rig by means of the three hydraulic cylinders positioned on the circle at 120 degrees apart. Such layout enables any position of misaligned journal against the test bearing to be preselected and set up.

3.6. Ambient and operating conditions

The instrumented test rig is to be placed in the suitable noise insulated air conditioned and ventilated room with the controlled ambient temperature between 18 °C and 26 °C. The test rig and its components shall be able to properly function within the temperature range between 0 °C do 45 °C. This condition has been based upon the classification society requirements, e.g. [2].

3.7. Lubrication and cooling system

Possibility of operation of the test bearings in different lubrication conditions is to be provided at the test rig by applicable lubrication systems. These lubrication conditions are:

- oil lubrication;
- fresh water lubrication;
- sea-water lubrication;
- absence of lubrication (dry friction operation).

The lowest operating temperature in the case of sea-water lubrication amounts to 2 °C. The inlet lubricant temperature of lubricants other than sea-water shall be controlled by means of the adequate cooling system, which is to be able to set it up to any chosen value between 2 °C through 32 °C, with the allowable deviation of ±1 °C.

Design flow of the sea-water through the test bearing is 60 liters/min. The expected heat to be transmitted in the heat exchanger will be about 25 kW.

The cooling system is to be equipped with tanks for the above mentioned lubricant types, appropriate filters and circulating pumps. The roles of inlet vs. outlet of the lubricant are to be automatically changed upon the change of shaft rotation direction. This system shall meet the rules for the classification of ships of one of the IACS classification societies.

3.8. System response measurement quantities

Bearing in mind that the essential purpose of the instrumented test rig are scientific research experiments in the process of validation of sliding bearings designs, it is of utmost importance to define the system response in terms of the quantities to be measured during the testing process itself.

These quantities may be specified as follows:

- Electric motor power and shaft rotational speed;
- Relative displacements defining the position of the shaft journal with respect to the test bearing;

- Pressure distribution along the inside surface of the test bearing journal at the sufficient number of points;
- Frictional torque acting on the bearing as the consequence of lubricant viscosity;
- Lubricant flow and viscosity;
- Test bearing temperature;
- Inlet and outlet temperature of cooling medium;
- Number and size of particles in the lubricant due to wear of the test bearing.

3.9. Control and automation

Custom made software applications are to be developed, prepared and tested in order to cover all of the following test phases:

- planning of the experiment;
- determination of the initial state of the components that are subject to testing;
- quantity and properties of bearing lubricant;
- ambient conditions;
- conduction of the testing process in accordance with the plan;
- monitoring, presentation and documenting of all the input and output values in the course of the tests, in accordance with the testing program;
- alarms and safety functions;
- determination of the condition of tested components (shaft journal and test bearing);
- preparation of the final test report

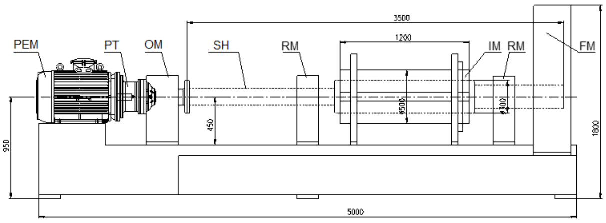
The test rig is to be operated from an ergonomically designed control panel, continuously displaying data on shaft rotational speed, loading, ambient temperature, bearings and lubricants, drive motor torque, vibration amplitudes and lubricant flow. These data are also the basis for setting the alarms and are to be transmitted to the central location of the device management (PC monitoring computer), as well as alarm notification on mobile devices by the staff conducting the test of the rig.

4. RESULTS

4.1. Basic concept of the test rig

The initial basic concept of the instrumented test rig for testing of sliding bearings has been developed by the design office of one engineering company located in Split, Croatia, on the basis of the requirements specified in Section 3. This concept has been developed in modular form, where the actual particular modules cover their dedicated function.

Conceptual design sketch of the rig has been presented schematically in Figure 1. The figure presents the test rig layout applicable to the testing of radial intermediate shaft bearings.



Source: [8]

Figure 1 Basic schematic of the test rig concept

The basis of the device is a welded, annealed and machined stand of appropriate rigidity and strength on which the appropriate working groups of devices (modules) are placed. The dimensions of the stand must be such that they are able to accept all modules and enable testing of bearings of the largest diameters, as well as shafts of the largest length.

4.2. Test rig modules

The test rig has been designed modularly as an assembly consisting of the following modules:

- drive module (PEM);
- connection module (PT);
- gear transmission module (OM);
- low stiffness shaft with elastic couplings (SH);
- test module (IM);
- radial module (RM);
- thrust module (TM);
- load module (FM);
- lubrication module (MP);
- cooling module (MH); and
- control module (UM).

The actual prime mover machine of the test rig shafting is the regulated three-phase asynchronous electric motor with a nominal power of about 42 kW at a nominal speed of 730 rpm and a maximum speed of 3600 rpm. When testing bearings of the largest diameters the reduction gearbox comprising the planetary gear transmission is to be installed between the electric motor and the shaft.

The drive module (PM) consists of electric motor (PEM) and connection module (PT) to connect the prime mover with the reduction gearbox (OM). Module (OM) has two input and two output shafts, with the transmission ratios of 1:1 or 7:1. Radial bearings are denoted as (RM) and they are actually roller bearings of self-align type. The required bearing life is minimally 10 000 operating hours with the nominal load and the mean rotation speed of 700 rpm.

The bearings in (RM) allow precise shaft guidance within limits that allow sliding bearings to be tested (IM) without affecting the shaft bearing interference.

The bearing under test (i.e. the test bearing) is located in the test module (IM). The test module can be located between both of (RM) modules (as presented in Figure 1), or outside of the (RM), i.e. overhang. This module (IM) allows controlled eccentric placement of the bearing bush in relation to the (RM)-(RM) axis within the clearance amount of ±1 mm. Module (IM) is affected by the friction reactive torque moment of the bearing, which is measured directly during the test. This means that this torque moment is to be precisely determined in relation to the friction moments in other bearings. Module (IM) also includes connections for lubricant supply and drainage, 4 temperature sensors and 21 pressure sensors. There are also 6 capacitive sensors, measuring the relative position of the shaft and the test bearing and determining thus the lubricant layer thickness.

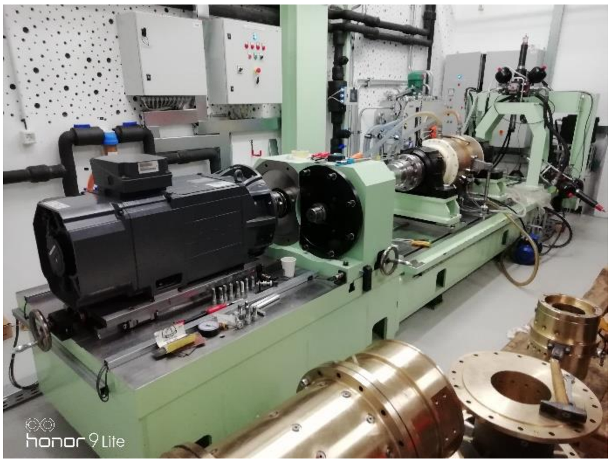
The load of the test bearing test (IM) or its bearing sleeve is realized by the load module (FM). The load module has been realized by means of hydraulic cylinders, hydraulic accumulators, pressure regulators, servo distribution valves, measuring cells and other elements. The FM is able to occupy any position within the operating range of the device.

In order to quickly and accurately place the module on the stand, it was necessary to install guides attached to the stand. Their design enables determination of the radial accuracy of the shaft rotation, as well as deviations of axes of the modules in unloaded and loaded conditions.

Functionality and deviations from the set points of all modules and installed sensors are to be individually tested and verified within the appropriate testing program.

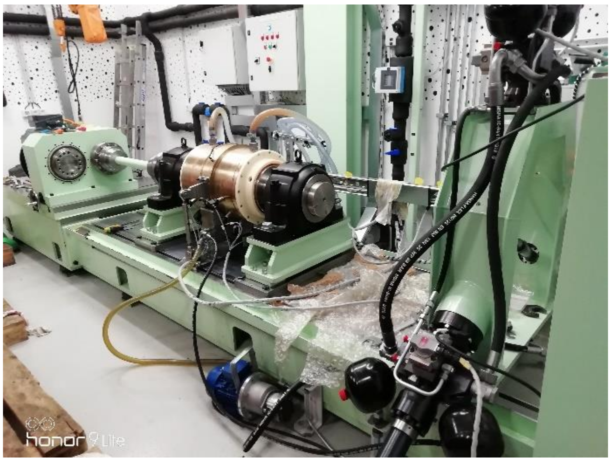
5. DISCUSSION

The finally assembled and installed instrumented test rig ready for the testing of sliding bearings has been shown in Figures 2 and 3. The presented layout of the test rig modules in these figures is the one applicable to the testing of radial sliding bearings intended for intermediate shafts, i.e. supported the same way as the simple supported beam on two supports. The upper surface of the stand and the central guide allows all the modules to be moved and precisely positioned in the axial direction.



Source: photo taken by N. Vulić

Figure 2: Installed test rig (view from drive module side)



Source: photo taken by N. Vulić

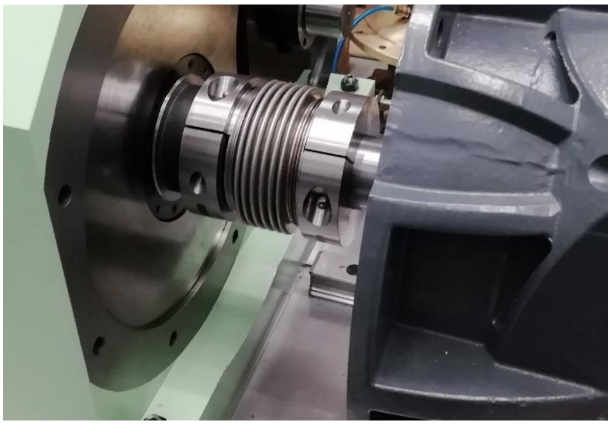
Figure 3: Installed test rig (view from load module side)

The final execution of the test rig had to slightly deviate from the before presented basic concept, owing to several difficulties which have arisen during the process of its assembly and the initial testing. Just a few essential details about these changes are briefly presented hereafter.

5.1. Connection module redesign

In the initial basic concept the electric motor within the drive module (PEM) was directly connected to the input shaft of gear transmission module (OM), because the connection module (PT) consisted just of a shaft and a hub with key connection. The problem of this concept was that the electric motor had to be both aligned on its stand and on its flange connection with the gearbox. This was one of the reasons for excessive vibrations of the drive shafting.

This problem has been solved by the redesign of the connection module (PT) by introduction of elastic coupling between the (PEM) and (OM), see photo in Figure 4.



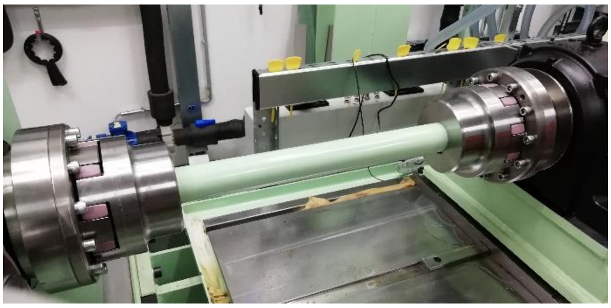
Source: photo taken by N. Vulić

Figure 4: Elastic coupling in the connection module

This elastic coupling allows the electric motor to be aligned only with respect to the test rig stand upper surface. It also allows compensation of relative axial vibratory movements between the electric motor and the gearbox input shaft, so the drive module (PEM) and gear transmission module (OM) could have been eliminated as the cause of the vibration excitations.

5.2. Transmission shaft with elastic couplings

The transmission shaft of low stiffness (SH) with the two elastic couplings attached is used to transmit the electric motor torque and rotation towards the shaft in the test module (IM), Figure 5. The role of these elastic couplings is to eliminate any bending moments originating to the system from its drive side.



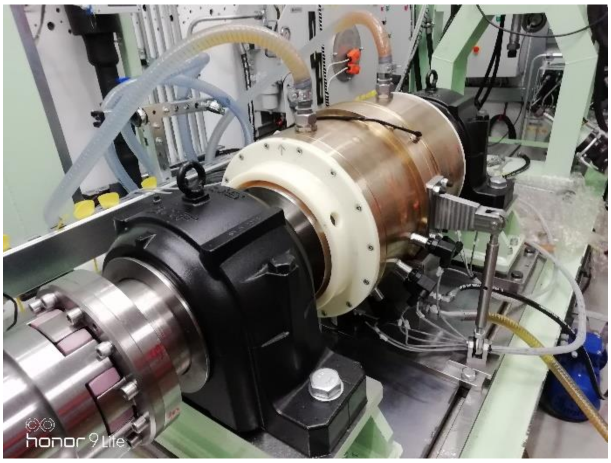
Source: photo taken by N. Vulić

Figure 5: Transmission shaft with elastic couplings

In order to reduce vibrations the two modules connected by this transmission shaft had to be properly aligned. Setting the alignment criterion between the two flanges to 0.05 mm in terms of their relative position measured by dial gauges on their flanges (sag and gap) and meeting this criterion completely eliminated the observed vibrations and their cause.

5.3. Supports of the test module

It is important that the conceptual design of the test module is exactly opposite to the practical situation onboard ship. In practice, the bearings retain their fixed position that in the case of stern tube bearings cannot even be adjusted and the shaft line is moved athwarts by adjustment of other bearings. The test rig implements completely opposite paradigm, i.e. the shaft in the test bearing is fixed in two roller bearings and the test bearing in its housing is "floating around" the shaft. Figure 6 shows the test module and its supports.



Source: photo taken by N. Vulić

Figure 6: Test module with supports

Proper supporting of the test module enables the test rig users to measure the reactive torque in the test bearing originating from the lubricant friction in a proper way. The test module is supported by the hydrostatic bearing below the test module housing and two rigid supports with differential screw threads on each side. These rigid supports enable the test module housing to behave as statically determinate simple supported beam. Measurement of force by means of the only a single tension-compression test probe (Figure 7) installed below one of the supports is enough to determine the reactive torque, when the hydrostatic bearing lifts the test module housing by a small amount.

Source: photo taken by N. Vulić

Figure 7: Tension-compression test probe

There are also a lot of additional details that may have been presented here, such as positioning of pressure sensors, temperature sensors and precise capacitive sensors of relative displacement, and similar. These details had to be omitted in order to keep the focus of the reader on the details essential to enable the test rig to be properly put in operation during its commissioning phase.

Experimental validation of the test rig will be essential in this sense.

6. CONCLUSION

The operational behavior and efficiency of sliding bearings in marine shafting system becomes an important issue today, when shipping companies are struggling to reduce operational costs and keep their ships within the prescribed economic and ecologic frames. Any theoretical research in the field of hydrodynamic lubrication of these bearings needs the proper experimental validation and the proper certified competent laboratory. The essential central component of such a laboratory is the sliding bearing test rig.

The paper presents the design requirements as the initial point of designing the instrumented test rig for marine sliding bearings in terms of the background for defining the rig prototype and the physical quantities that are to be measured. Technical description of the test rig, as prepared by its designers (design engineering company from Split, Croatia) and its modular concept has been briefly described, together with the description of its modules.

Results section presents the actually manufactured, produced, assembled and installed test rig upon these design requirements with the necessary details to understand its functioning. Discussion presents a few selected details that had to be changed or redesigned due to several problems encountered during preparation of the test rig for its own experimental validation.

The testing of the rig itself, test program and test results are the matter of further work, so they will be presented in the separate paper.

ACKNOWLEDGEMENTS

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REFERENCES

[1] SB 6789 (1987). Shaft line - Bearings with upper and lower shell. Croatian shipbuilding standards. Zagreb: Jadranbrod

[2] Rules for the classification of ships, Part 7- Machinery Installation (2021). Split: Croatian Register of Shipping

[3] DIN 31652 (2017). Plain bearings - Hydrodynamic plain journal bearings under steady-state conditions, Parts 1-3. Berlin: Deutsches Institut für Normung

[4] ISO 7902-1 (2020). Hydrodynamic plain journal bearings under steady-state conditions - Circular cylindrical bearings, Parts 1-3. Geneva: International Organization for Standardization

[5] Kulenović, Z., & Vulić, N. (2020). Elements of ship machinery and maritime structures (in Croatian). Split: University of Split - Faculty of Maritime Studies

[6] ISO 21866-1 (2020). Plain bearings - Automotive engine bearing test rig using actual connecting rods - Part 1: Test rig. Geneva: International Organization for Standardization

[7] ISO 6281 (2020). Plain bearings - Testing under conditions of hydrodynamic and mixed lubrication in test rigs. Geneva: International Organization for Standardization

[8] Technical specification for the device for testing of radial journal bearings, ver. 001a (in Croatian) (2018). Split: Faculty of Maritime Studies

[9] Komar, I. (2012). Contribution to the metodology of selection of the most convenient stern tube bearings for marine shafing systems (doctoral thesis, in Croatian). Rijeka: University of Rijeka - Faculty of Maritime Studies

[10] Roldo, L., Komar, I. & Vulić, N. (2013). Design and materials selection for environmentally friendly ship propulsion system. Strojniški vestnik - Journal of Mechanical Engineering, 59(1), 25-31.

[11] Komar, I., Vulić, N. & Roldo, L. (2013). Hydrodynamic and elastohydrodynamic lubrication models to verify performance of marine propulsion shafting. Transactions of FAMENA, 37(1), 15-27.

THREE DECADES OF PORT DEVELOPMENT IN ADRIATIC AND BALTIC REGION: FOCUS ON THE PORT OF KOPER AND THE PORT OF KLAIPĖDA

Marina Zanne, Ph.D.
University of Ljubljana, Faculty of Maritime Studies and Transport
Pot pomorscakov 4, Portoroz, Slovenia
Marina.Zanne@fpp.uni-lj.si

Rima Mickienė, M.Sc.
Lithuanian Maritime Academy
I. Kanto g. 7, 92123 Klaipėda, Lithuania
r.mickiene@lajm.lt

ABSTRACT

Ports are complex systems that play a central role in the transport of goods and have an undeniable importance in global economic development. The operation of ports requires many resources, while their performance and efficiency depend on many factors. This puts pressure on port management.

The article focuses on the port of Koper in Slovenia and the port of Klaipėda in Lithuania. These ports are located in countries with a similar recent history when they evolved from relatively closed countries to sovereign states and eventually to EU members, which among other things influenced the development path of these two ports.

The authors analyze and compare the organization, performance and efficiency of the Port of Koper and the Port of Klaipėda over the last three decades and identify the main factors that drove the development of these ports. In the final part of the paper, the authors analyze the potential for transferability of best practices between the ports.

Keywords: Koper, Klaipėda, port development, port performance, comparative analysis

1. INTRODUCTION

The sea route is the cheapest mode available for transporting large quantities of cargo. About 11 billion tons of cargo are transported by sea each year. The pre Covid-19 forecast for maritime trade projected an average annual growth rate of 3.5% from 2019 to 2024 (UNCTAD, 2019). However, the COVID-19 pandemic affected seaborne trade, especially in the first half of 2020, resulting in a 3.8% decline compared to 2019. In 2021, seaborne trade increased at an estimated 4.3% (UNCTAD, 2021) and similar growth is expected for the next five years.

Ports are complex systems that play a central role in the transportation of goods and, as such, have an undeniable importance for national and global economic development, including the economies of landlocked countries, as the impact of ports reaches far into the interior of continents. Ports are centers of concentration of different transport modes and various cargoes, providing, besides transport function, also a commercial or even industrial function, thus representing a massive economic concentration (Kesić & Jugović, 2010), 2010). The World bank (2007) estimated that worldwide market for port services generates revenues of $50–55 billion annually, while more recent data suggest that the number is already more than $70 billion and is projected to increase with the rate of almost 5% in the forthcoming years (Fortune business insights, 2021).

In this paper, we focus on the port of Koper, the only international cargo port in Slovenia, and the port of Klaipėda, the main international cargo port in Lithuania. We analyse and compare the organization, performance and efficiency of these two ports over the last three decades and identify the main factors that have influenced their development. In the last part of the paper, we analyse the potential for transferability of best practices between the ports.

The paper is divided into six sections. The introduction in the section one is followed by a literature review of factors affecting port development and port performance measurement in section two. Section three describes the data and methodology used to conduct the study, while section four is the core of the paper and comprises the analysis of the ports. Section five contains the discussion and section six is devoted to the conclusions.

2. LITERATURE REVIEW

There are many ports in the world today, but not all are equally developed, important or competitive. Generally, ports (or port authorities) can be classified by throughput into small ports (ports handling less than 10 million tons of cargo per year), medium ports (ports handling from 10 to 50 million tons of cargo per year) and large ports (port handling more than 50 million tons of cargo per year) (Verhoven, 2010). Another classification of ports that considers shipping services and trading routes distributes ports into network ports, transhipment ports, direct-call ports and feeder ports (Bichou, 2009).

The competitiveness of ports is affected by many factors and the research of these factors has been often addressed in theoretical and empirical literature. In the 1980s, the authors emphasized the confidence in schedule, port accessibility as well as port facilities and port capacities (eg. Peters, 1990; Willingale, 1981). Brooks (1984) and Slack (1985) highlighted the importance of port dues and service charges as well as sailing frequencies for the performance of the ports. Besides the cost aspect, the study of UNCTAD from 1992 accentuated the geographical position, hinterland connections and port reliability. Tongzon (2002) added to the list the economic activities in port's hinterland, port's infrastructure and equipment, port's efficiency and quality of service, costs of auxiliary services, reputation of the port etc. Similarly, (Kesić & Jugović, 2010) summarize that the port needs adequate transhipment and storage capacities, good land and sea connections and sufficient quantity and concentration of cargo to successfully perform its transport and trade function.

Also the port performance measurement is addressed broadly in literature. Performance can be defined as the effective use of a set of input variables to produce a set of output variables (Ng, Lim, Leong, & Cheng, 2010), and the concept of port performance can be observed by two interconnected components, namely efficiency and effectiveness (Pallis & Notteboom, 2022). Ports use various indicators to measure their performance or create production functions (Tovar, Jara-Díaz, & Trujillo, 2003). Port performance indicators are measures of various aspects of the port's operation, and just like any other indicator, they have be easy to calculate and simple to understand (UNCTAD, 1976); however, the absence of a common standard for data collection combined with limited data availability often limit the comparability among ports. Still, port cargo throughput in terms of volume and structure, annual revenues and added value can serve as a basic elements in indicators calculation (Talley 2011; UNCTAD 2019; Rødseth & Wangsness, 2015).

3. DATA AND METHODS

In the initial phase of this paper, we presented the port development and port performance-related literature. This was done by reviewing books and academic articles which are available at the Science Direct and Google Scholar. The search was made by using the words "port", "port performance", "port development", "factors affecting port development".

Then we described the port of Koper and the port of Klaipėda and created the port performance indicators as suggested by literature, and based on the available data. Majority of data on the ports was obtained from the ports' websites and ports' annual reports; however also existing studies dealing with these two ports have been considered.

These ports were selected because the countries in which they are located share similar recent history; Slovenia was a part of Yugoslavia while Lithuania was a part of Soviet Union. Both countries were rather closed and centrally developed before the 1990s when a democratic transition occurred, and both joined the European Union (EU) at the same time, in May of 2004. Today, they have similar GDPc, corruption index and competitive ranking (Country Economy, 2022), and belong to same organisations, namely EU, North Atlantic Treaty Organization (NATO), Organisation for Economic Co-operation and Development (OECD), International Monetary Fund (IMF), Organization for Security and Co-operation in Europe (OSCE), European Economic Area (EEA), Council of Europe (CoE) and Euro Area (EA).

After the countries gained the independence, the markets and operation of both ports changed significantly. We wanted to find out which port succeeded better in this transition.

4. THE ANALYSIS

Ports are essential for the European economy, as about three quarters of EU international trade and almost one third of EU internal trade is done by sea (Pastori, 2015). Ports represent huge employment potential; around 1.5 million workers are employed in European ports directly and a similar number in accompanying activities. The general perception of ports is thus that they are engines of socio-economic development for the regions they serve (e.g., Danielis & Gregori, 2013; Valantasis-Kanellos & Song, 2015; Jouili, 2016).

In total, European ports handle more than 3 billion tonnes of cargo annually (according to Eurostat (2021), 824 million tons of goods were handled in the main EU ports in the 1st quarter of 2022). There are around 1,200 ports in 23 EU member states, of which 328 are included in the TEN-T core network, among these are also the port of Koper and the port of Klaipėda.

Ports differ in organizational, operational, physical and spatial, as well as in regulatory view (Bichou, 2009). For this reason we focused on port administration and business strategy, port throughput and revenues, port hinterland and hinterland connection and finally, port expansion plans.

4.1. The Port of Koper

The Port of Koper is the only Slovenian international cargo port. In more than six decades of operation, it developed from a single berth port on which they handled 61,500 tons in 1959 to a port with 12 specialized terminals, with 3,300m of the quayside and 26 berths. Annually around 2,000 ships call to the port, and in 2021 the port handled roughly 21 million tons of cargo and almost 1 million TEUs (Luka Koper, 2022).

Located in the north Adriatic region, the port of Koper faces competition of the neighbouring ports, namely Trieste and Venice in Italy and Rijeka in Croatia. These ports together handle around 120 million tons of cargo per year; however, they are largely specialized for different cargo types and the only competing element are the containers. Nevertheless, the north Adriatic ports are joined within the North Adriatic Port Association (NAPA) and they devotedly promote the north Adriatic as a shortest route from Far East to Central Europe.

Table 1: The port of Koper in the north Adriatic context (2021)

	Koper	Trieste	Venice	Rijeka
Throughput (mio t)	20.82	55.0	24.20	13.6*
TEU	997,574	652,319	513,814	344,091*
Area (ha)	280	230	2,045	150
Quayside (km)	3.3	12	30	
Terminals	12	20+	27	9
Draught (m)	18	18		17
Specialization	Cars	Crude oil	Refind products	General cargo

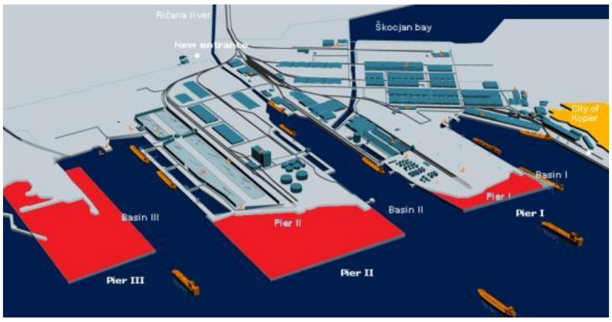
*Note: * - data for 2020*

Source: authors, based on (Luka Koper, 2022); (NAPA, 2022)

The port of Koper is managed and operated by the public limited company Luka Koper according to the 35-year concession agreement between the State of Slovenia and Luka Koper from 2008. It currently covers 280 hectares of area, but Luka Koper is planning a significant expansion of the port area and, consequently, an increase in the throughput; according to pre Covid-19 forecast it should range between 27.4 and 35.1 million tons by 2030 (Luka Koper, 2015), depending mainly on the construction of improved rail connection with the hinterland. In fact, rail connections are important as the Baltic-Adriatic and the Mediterranean corridor link the port of Koper to the inland Europe, even up to the Gdansk in the north. This is a huge potential for the port of Koper to partnership with Gdansk for the Scandinavian trade with the East.

The area of the port of Koper has increased by almost 100 ha and the length of quayside for 1,150 m in the last three decades. Additional 155,000 m² of closed storage areas have been constructed, and new 14 km of rails have been laid in the port area, resulting in tripled volume of cargo transported on the railways. The total throughput has increased four to five times and the container traffic is now fifteen times higher than in the beginning of the 1990s (Jazbec, 2021). The port of Koper recorded the highest throughput in 2018, at 24 million tons, but even before the Covid-19 crisis this throughput declined, while other northern Adriatic ports recorded growth.

Slovenia's National Spatial Plan confirmed port's expansion plans back in June 2011, but since then only 100 m of quayside on Pier I (container terminal) have been constructed and opened to service in 2021. This EUR 235 million investment increased the capacity of container terminal to 1.5 million TEU. Some other plans have been in meantime reconsidered (construction of Pier III), but still Luka Koper plans an estimated EUR 450 million of investments in infrastructure and superstructure by 2030. These investments include (summarized and redefined from Luka Koper, 2015): extension of Pier II, extra storage areas as well as provision of rail tracks, seabed dredging, and sediment disposal sites.



Source: (Luka Koper, 2012)

Figure 1: Expansion plans for the port of Koper

With the Slovenian independence and the war in Balkans, the port of Koper lost more than 20% of its throughput in the first year and needed to position itself on new markets. The port managed to catch up with the total throughput in five years, while in the segment of containers it took more than a decade (2002) to reach the volume of the pre- secession year 1990. Now the port of Koper serves several central European markets; one third of the cargo handled in the port of Koper is intended for the Slovenian economy, the next third for the Austrian economy, and the rest is distributed among Hungary, Croatia, the Czech Republic and Slovakia, and to a lesser extent Germany, Poland, Serbia and Romania.

The port of Koper is the most important container port in the north Adriatic and in meantime Luka Koper focused on new cars (car terminal was constructed in 1996), and now ranks among the top automotive ports in the Mediterranean and Europe.

Luka Koper pays a lot of attention to the quality of service, sustainability and good coexistence with the local community. They started to integrate principles of quality back in 1994 and today they hold ISO 9001, ISO 14001 and EMAS, ISO 22000, ISO 45001, ISO 50001, business excellence and several other more specific certificates (Luka Koper, 2022). Luka Koper strives to improve its environmental footprint and local population acceptance in various ways (eg. (Zanne & Twrdy, 2021); (Zanne, Twrdy, & Beškovnik, 2021); (Twrdy & Zanne, 2019)) and the support of local community suggests that the efforts are being recognized. Luka Koper provides real—time information on pollution and noise arising from the port activities, they do survey within the local community on yearly basis and also financially support citizens and activities in the coastal area.

4.2. The Port of Klaipėda

Klaipėda is the third largest city in Lithuania. With its convenient geographical location, it has become an important industrial and transport centre: a hub for sea, air, motorway and railway transportation.

The port of Klaipėda was the only Lithuanian international cargo port until 1999 when an oil terminal was opened in Butinga. Nevertheless, Lithuanian government decided to establish the Port Authority in 1991. A year later, Klaipėda port got the status of state seaport. By the legislation adopted in 1996 the land and water territory, the quay-walls, hydro-technical equipment navigation routes, canals and other objects of port infrastructure belong to the state and can not be privatized (Port of Klaipeda, 2015).

Around 15% of total seaborne trade is happening in the Baltic Sea (Baltic LINes, 2016). The competition in the east Baltic sea consists of several ports; Ust Luga, Primorsk, Vysotsk, Kaliningrad and St. Petersburg in Russia, Riga, Ventspils and Liepaja in Latvia, and Tallinn in Estonia (Liebuvienė & Čižiūnienė, 2022). These ports handle around 360 million tons of cargo per year, and Klaipėda has ranked fourth among them with the annual throughput of around 45 million tons.

The port of Klaipėda, a multipurpose deep-sea port, was growing together with the Lithuanian state; in the period from 1991 to 2016 around EUR 710 million were invested in port's infrastructure. Today this landlord port covers more than 1,440 hectares and comprises 20 cargo terminals and two cruise terminals. More than 800 independent stevedoring companies operate within the port. In addition there are ship building and ship repair yards and other port related companies employing together around 58,000 people. The port has almost 25 kilometres of quays and offers 119 berths. It annual capacity is around 65 million tons. The port can accept large-tonnage vessels including dry-cargo vessels of approximately 200,000 DWT, tankers of approximately 170,000 DWT, and container carriers up to 19,500 TEU's (Port of Klaiepda, 2022). The current throughput of the port of Klaiepda is around 45 million tons and the port generates more than 6% of Lithuanian GDP (Submariner Network, 2022), The significance of the port is quickly growing as only a decade ago it had the estimated annual capacity of 52 million tons and employed around 23,000 people that generated around 4.5% of Lithuanian GDP (Port of Klaipeda, 2012).

There are two container terminals in Klaipėda; one is dedicated Maersk container terminal. This terminal has the capacity of 1,200,000 TEU or around 9 million tons and the operating quay length of 1,430 meters. It covers the area of 40 hectares and can accommodate the largest container ships (TIL, 2020). Five ship to shore gantry cranes are installed on the terminal and two mobile harbour cranes support the ship to shore operations. The year 2018 was a record year for the terminal with almost 390,000 TEUs handled (only 253,000 in 2019 and similar in 2020). Gdansk deep-water container terminal (DCT) is the largest in Baltic sea region and acts as a hub, thus taking certain amount of cargo from Klaipėda MSC container terminal (2M - Maersk Line and MSC – alliance is using Gdansk DCT), and making the second Klaipėda mixed container and general cargo terminal only a spoke point.

In the next 4 years, until 2026, the Klaipėda Port Authority plans to invest around EUR 400 million supported by EU funding in the port area, This will include the expansion of port area and the reconstruction of wave breakers, which should grant a qualitative advantage to the port (MTC, 2021). Moreover, The Klaipėda Port Authority revealed an ambitious plan to build an artificial island of 120 ha with 17.5 draft with an annual capacity of 35 million tonnes to accommodate a new container terminal and ferry facilities (ADB, 2021). These investments are expected to help achieve the planned 83 million tons of cargo throughput in 2030 (Port of Klaipeda, 2016).

In addition, the port of Klaipėda hosts free economic zone since 2002 which attracts capital from different countries around the world. It spans on the area of 412 hectares and employs more than 3,000 workers. Currently it has the turnover of almost EUR 1 billion, and attracts investors from 14 different countries (Uznys, 2016).

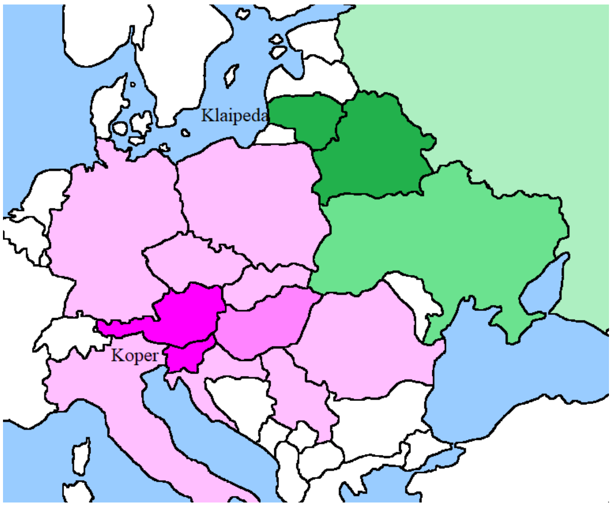
Until the turn of the millennium, most of the throughput of the port of Klaipėda was in transit, more precisely around 65% or even 77% in 1994, and it was mainly intended for Russia. Back then, the cargo flows were very uneven; around 80% of total throughput were in export and the remaining 20% were imports. Majority of cargo was general cargo (Rytkönen, Siitonen, Riipi, Sassi, & Sukselainen, 2002). At that time, there were even plans to develop the port of Klaipėda in parallel with the port of Kaliningrad and to share cargo, as Lithuania was to became important for Russia when it would join the EU. Currently, the share of cargo for the domestic market is about 60%, and among the hinterland markets, Belarus has become the most important partner. The throughput for Russia is four times lower now than in the late 1990s, while for Belarus or more precisely its state-owned company Belaruskali, the second largest potash producer in the world, the port of Klaipėda handles around 13 million tons per year; back in 2009 this amount was only 1.4 million ton. Kazakhstan and Ukraine are also markets served by the port of Klaipėda, while the Klaipėda Port Authority sees port's potential also on other markets, like Norway, Sweden, Finland, Poland or Germany (Uznys, 2016). Developing these markets would be very important for the port itself, as Russia and, more recently, Belarus are subject to economic sanctions.

The port of Klaipėda is connected by rail with Russia, Belarus, Latvia, Poland, Germany and Ukraine, but also with China, and shuttle trains operate regularly. In fact, around 80% of cargo for or from hinterland locations is carried by rail.

5. DISCUSSION

The analysed ports are not in a competitive relationship because their hinterland markets do not overlap and probably also in the future the overlap will not be significant. They also cannot intensively cooperate because none of the corridors links them, so they actually can learn from each other.

In the period from 1993 to 2020 the throughput of the port of Koper and of the port of Klaipėda show very high correlation (0.963), which is statistically significant at the 0.01 level. Growth in the port of Koper was slightly higher at 5.5% compared to 4.6% in Klaipėda with the port of Koper declining by 14.3% in 2020, while growth in Klaipėda was 3.3%; exclusion of 2020 from the analysis increases the growth in Koper to 6.3% and in Klaipėda to 4.7%.



Source: authors, based on ports' documents

Figure 2: The hinterlands of Port of Koper and port of Klaipėda; core markets in darker shade

The location of both ports is very competitive; the north Adriatic ports provide shortest route towards central Europe from the far and mid East, while port of Klaipėda is the north most ice free port in Baltic Sea, and like other Baktic ports, it has important role on transit corridors, connecting not only East and West, but also South and North (Gaidelys & Benetyte, 2021). However, some relatively recent studies show that the location of a port tends to be less important factor of the port's success than the port's ability to offer services and connections that meet the needs of carriers and shippers (Musso, Ferrari, & Benacchio, 2006). This is supported by the studies de Langen, 2008 and Tongzon (2009) proving that the quality of service and thus the competitiveness of a port diminish when the port or its hinterland links are approaching the maximum capacity utilization. If this is the case, the time required to fulfil the services increases, causing higher costs and reduced reliability of the service.

And indeed, in 2019 the port of Koper lost more cargo than other north Adriatic ports; and the analysis of cargo structure in ports suggests some cargo shifting within the region (Zanne & Borkowski, 2021) which can point to the problem of Koper's limited hinterland connections. The existing one-track electrified railway line between Koper and Divača is the only railway connection of the port of Koper to the hinterland. The capacity of the line is limited due to its technical characteristics and the utilization level of the track is at the maximum. The second track should be in operation by the end of 2026.

Ports within the core TEN-T are supported by the EU; however, also port managers and states need to be proactive in order to achieve more efficient and more competitive position of the port. This is especially the case, when the port lies in enclosed seas, which both Baltic and Adriatic are. Because of their restricted communication with the open ocean, enclosed seas have several specificities, physical ones as well as economical ones (Serry, 2020).

Free economic zones allow investors to avoid paying taxes and customs duties. Such zones allow semi-finished products from third countries to enter the territory of the economic zone without being burdened with any duties, as they are not in the territory of a particular country from a tax and customs point of view. By finishing the product in the area of the zone, the product obtains the label "made in a certain country". Even more, when traveling from the zone to EU customers, these products still do not have to pay taxes and duties that would otherwise apply to products from third countries.

There was an economic zone in Koper until the end of 2013. The extension of its validity was not provided due to poor use. EU is not supporting the establishment of new free zones; however, on the example of the port of Klaipėda it is possible to see that they can be very successful. Losing it in Koper was a mistake.

The ports that we have analysed are organized in different ways; the port of Koper has the unique managing system where the mixed capital company Luka Koper acts as the port authority and the concessionaire in the port at the same time, while the port of Klaipėda is organized as the landlord port. The managing structure of port of Koper allows for quick communication, but requires governmental consent, guarantees and more public money in investment decisions and probably generates fewer revenues than similar sized tool ports or landlord ports.

Certain indicators concerning port services and operations can be evaluated from financial and operational points of view (Ibrahimi, 2009). Due to the pandemic, we decided to only include data through 2019; the year 2020 was turbulent almost everywhere and would slightly distort the picture.

Table 2: Some port-performance indicators in 2019

	Koper	Klaipėda
Revenues per employee (EUR)	134,280	
Added value per employee (EUR)	88,494	
Investments per employee (EUR)	22,396	
ROA	6.9%	5.9%
ROE	9.9%	6.7%
ROS	19.8%	
EBIT (EUR million)	45.31	
EBITDA (EUR million)	73.09	
Cargo per ship call	13,384	9,558
Cargo per km of quays	6,908,863	1,872,875
Cargo per ha	81,402	32,125
TEUs per sq km of container terminal		
Energy consumption (kWh/t)	1.31	
CAGR (1993-1999)	8.5%	-1.0%
CAGR (1993-2009)	6.1%	3.6%
CAGR (1993-2019)	5.9%	4.2%
CAGR (2000-2009)	3.9%	4.1%
CAGR (2000-2019)	4.8%	4.7%
CAGR (2010-2019)	4.5%	4.4%

Source: Authors, based on various sources

The growth of throughput is faster in Koper, especially in terms of containers. However, the structure of throughput is more diversified in Klaiepda, which can be helpful during crisis; the data on ports' throughput confirms this as the port of Koper lost 18.1% of throughput in 2009 and 14.3% in 2020, while Klaipėda lost only 6.7% in 2009 and recorded an increase of 3.3% in 2020.

Both ports are following the green development idea and offer reliable and flexible ports services supported by digitalization; the managing structure of the port of Koper allows Luka Koper to have a broader picture and to implement the environmental protection system on all terminals and for all its activities (Zanne & Twrdy, 2021) which is highly appreciated by the local community. The port of Klaipėda is also developing sustainably, with plans to build wind farms, modernize the port authority's fleet, and dredging vessels that will run on electricity. In this segment the ports could exchange good practices.

6. CONCLUSIONS

Lithuania and Slovenia are two small countries on the edge of Europe. They became independent in the early 1990s and joined the EU together in 2004. Lithuania's area is three times that of Slovenia, and its population is only 50% larger than Slovenia's. These countries are too small to be sufficient for the efficient development of their ports, so ports' hinterlands are important. The hinterlands of both ports have great economic potential; however, the hinterland of port of Klaipėda is politically unstable and hit by severe economic restrictions, which can and will affect port's performance (in particular that of bulk cargo terminal) and port's plans in future years. Port of Koper faced similar problem and successfully overcame it in the early 1990s, when the port was left without important markets due to the war in the Balkans.

We have used physical and monetary input variables in our analysis. The organization of the port of Koper allows relatively easy access to comprehensive data on port performance, but this is not the case with the port of Klaipėda, which is organized under the landlord management model. Unfortunately, most of the financial indicators thus could not be compared, while the operational indicators show better capacity utilization in Koper, which is not fully consistent with the theory that port privatization has the positive effect of increasing productivity.

The port of Klaipėda is a larger port and has a higher turnover than Koper. It still has better possibilities for expansion than Koper and its organizational model allows the port to develop with the lower need of public money. This is important because the increasing seaborne trade and the need to accommodate ever bigger vessels while respecting ever stricter environmental regulations put the pressure on ports to provide more capacities. On the other hand, the analysis can not prove that the formation of the Port Authority in Klaipėda boosted the increase of turnover in the port. However, the area of the port of Klaipėda increased for more than one third in the analysed period and the port of Klaipėda currently has the spare capacity of more than 50% with ambitious development plans yet to be completed, while the port of Koper is much closer to reaching the maximum capacity.

REFERENCES

[1] ADB. (2021). Ports and logistics scoping study in CAREC countries - Volume II: Ports and shipping. Manila: Asian Development Bank.

[2] Bichou, K. (2009). Port operations, planning and logistics. London: Informa business.

[3] Brooks, M. (1984). An alternative theoretical approach to the evaluation of liner shipping-Part 1. Situational factors. Maritime Policy and Management, 11(1), 35-43.

[4] Country Economy. (2022). Country comparison Lithuania vs Slovenia. Retrieved March 2022, from Country Economy: https://countryeconomy.com/countries/compare/lithuania/slovenia

[5] Danielis, R. & Gregori, T. (2013). An input–output-based methodology to estimate the economic role of a port; The case of the port system of the Friuli Venezia Giulia Region, Italy. Maritime Economics and Logistics, 15(2), 222–255.

[6] de Langen, P. W. (2008). Ensuring hinterland access; the role of port authorites. Research round table, Paris 10-11 April 2008.

[7] Eurostat. (2021, October). Maritime transport of goods - quarterly data. Retrieved March 2022, from Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_transport_of_goods_-_quarterly_data

[8] Fortune business insights. (2021). Marine port service market size. Retrieved March 2022, from Naval marine and prot technologies: https://www.fortunebusinessinsights.com/marine-port-services-market-103540#:~:text=The%20market%20is%20projected%20to,cargo%20%26%20people%20and%20ship%20docking.

[9] Ibrahimi, K. (2009). Performance indicators and Port authority management. 5th International Conference of ASECU, "Market Functionality and Institutional Reforms". Tirana: Faculty of Economy, University of Tirana.

[10] Jazbec, T. (2021). Luka Koper od osamosvojitve do danes. Luški glasnik.

[11] Jouili, T. (2016). The Role of Seaports in the Process of Economic Growth. Developing Country Studies, 6(2), 64–69.

[12] Kesić, B., & Jugović, A. (2010). Menadžment u lukama. In F. Mitrović, B. Kesić, & A. Jugović, Menadžment u brodarstvu i lukama. Splt: Sveučilište u Splitu, Pomorski fakultet.

[13] Liebuvienė, J., & Čižiūnienė, K. (2022). Comparative analyis of ports on the Eastern Baltic Sea Coast. Logistics, 6(1). doi:https://doi.org/10.3390/logistics6010001

[14] Luka Koper. (2012). Projects. Retrieved March 2012, from Port handbook: http://www.luka-kp.si/eng/port-handbook

[15] Luka Koper. (2015). Summary of Luka Koper d.d. and the Luka Koper Group Business Strytegy until 2030 and the Company's and Group's Startegic Business Plan 2016-2020. Koper: Luka Koper.

[16] Luka Koper. (2020). Annual and sustainability report 2019. Koper: Luka Koper.

[17] Luka Koper. (2022). Maritime throughput 2021 - 2020 in tons. Retrieved from Cargo statistics: https://www.luka-kp.si/en/news/cargo-statistics/

[18] Luka Koper. (2022). Quality. Retrieved February 2022, from Luka Koper: https://www.luka-kp.si/en/company/quality/

[19] MTC. (2021). Investments in the Port of Klaipėda: reconstruction of wave breakers, expansion of the port area. Retrieved March 2022, from Ministry of Transport and Communications: https://sumin.lrv.lt/en/news/investments-in-the-port-of-Klaipėda-reconstruction-of-wave-breakers-expansion-of-the-port-area

[20] Musso, E., Ferrari, C., & Benacchio, M. (2006). Port investment: profitability, economic impact and financing. In K. Cullinane, & W. K. Talley, Port economics. Amsterdam et al.: Elsevier.

[21] NAPA. (2022). North Adriatic Ports Association. Retrieved from https://www.portsofnapa.com/

[22] Ng, A. S.-F., Lim, A. L., Leong, C. H., & Cheng, C. H. (2010). A competitiveness measurement framework for regional container hub ports: A case study in East Asia. International Journal of Logistics Systems and Management, 7(3), 368-392.

[23] Pallis, A., & Notteboom, T. (2022). In T. Notteboom, A. Pallis, & J.-P. Rodrigue, Port Economics, Management and Policy (p. 690). New York: Routledge.

[24] Pastori, E. (2015). Modal share of freight transport to and from EU ports. Brussels: European Union.

[25] Peters, H. (1990). Structural changes in international trade and transport markets: The importance of markets. 2nd KMI International Symposium, (pp. 58-75). Seoul.

[26] Port of Klaipėda. (2022). Port of Klaiepda. Retrieved March 2022, from https://www.portofKlaipėda.lt/the-port-of-Klaipėda

[27] Port of Klaipėda. (2012). Port of Klaipėda: discover a proven way! Klaipėda.

[28] Port of Klaipėda. (2015). About Port Authority. Retrieved February 2022, from State Enterprise, Klaipėda State Seaport Authority: https://www.portofKlaipėda.lt/about-port-authority

[29] Port of Klaipėda. (2016). Discover a proven way! Port of Klaipėda. Klaipėda: Port of Klaipėda.

[30] Rødseth, K. L., & Wangsness, P. B. (2015). Production analysis in port economics: A critical review of modeling strategies and data management. Oslo: Institute of Transprot Economics, Norwegian Centre for Transport Research.

[31] Rytkönen, J., Siitonen, L., Riipi, T., Sassi, J., & Sukselainen, J. (2002). Statistical analysis of the Baltic maritime traffic. VIT.

[32] Serry, A. (2020). Shipping in peripheral seas: The case of Baltic Sea region and Adriatic Sea. 19th International Conference on Transport Science (pp. 289-295). Portoroz: Faculty of Maritime Studies and Transport.

[33] Slack, B. (1985). Containerization, inter-port competition and port selection. Maritime policy and management,, 12(4), 293-303.

[34] Submariner Network. (2022). The Submariner Network in Lithuania. Retrieved March 2022, from https://www.submariner-network.eu/country-profile-lithuania

[35] Talley, W. K. (2011). Is port throughput a port output? . Advances in Maritime Logistics and Supply Chain Systems, 2, 117-129.

[36] TIL. (2020). Port of Klaipėda, Lithuania. Preuzeto March 2022 iz TIL - Terminal Investment Limited: https://www.tilgroup.com/terminal/port-Klaipėda

[37] Tongzon, J. (2009) Port choice and freight forwarders. Transportation Research Part E: Logistics and Transportation Review, 45(1), 186-195.

[38] Tovar, B., Jara-Díaz, S. R., & Trujillo, L. (2003). Production and cost functions and their application to the port sector: A literature survey. Policy research working papers. doi:https://doi.org/10.1596/1813-9450-3123

[39] Twrdy, E., & Zanne, M. (2019). Improvement of the sustainability of ports logistics by the development of innovative green infrastructure solutions. Transportation Research Procedia, 539-546. doi:https://doi.org/10.1016/j.trpro.2020.03.059

[40] UNCTAD. (1976). Port performance indicators. Geneva: United Nations Conference on Trade and Development.

[41] UNCTAD. (2019). Review of maritime transport. Geneva: UNCTAD. Retrieved February 2022, from https://unctad.org/system/files/official-document/rmt2018ch4_en.pdf

[42] UNCTAD. (2021). Review of maritime transport. Geneva: United Nations Conference on Trade and Development.

[43] Valantasis-Kanellos, N. & Song, D.-W. (2015). Port-centric logistics in concept and practice. In Song, D.-W. & Panayides, P.M. (Eds.), Maritime logistics: A guide to contemporary shipping and port management. London, Philadelphia, New Delhi: Kogan Page.

[44] Uznys, H. (2016, March). Port of Klaipėda. Retrieved from https://slidetodoc.com/port-of-klaipda-general-information-stockholm-445-km/

[45] Verhoven, P. (2010). The ESPO fact finding report: European port governance. Brussels: European Sea Ports Organisation.

[46] Willingale, M. C. (1981). The port routing behaviour of short sea operator theory and practices. Maritime Policy & Management, 8(2), 109-120. doi:10.1080/03088838100000032

[47] World Bank . (2007). Port Reform Toolkit Second Edition: Module 3 - Alternative port management structures and ownership models. Washington: World Bank .

[48] Zanne, M., & Borkowski, P. (2021). The comparative analysis of two sea-ports located on Baltic-Adriatic corridor. Transactions on maritime science, 10(1), 171-177.

[49] Zanne, M., & Twrdy, E. (2021). The economic feasibility of port air emissions reduction measures: the case study of the port of Koper. Economic and business review, 23(3), 141-151.

[50] Zanne, M., & Twrdy, E. (2021). The economic feasibility of port air emissions reduction measures: the case study of the port of Koper. Ecopnomic and business review, 23(3), 141-151.

[51] Zanne, M., Twrdy, E., & Beškovnik, B. (2021). The effect of port gate location and gate procedures on the port-city relation. Sustainability. Sustainability(9).

LABORATORY POWER CONVERTER – ANALYSIS AND MODELLING FOR STUDENT TRAINING

Marko Zubčić, M.Sc.
Nediljko Kaštelan, M.Sc.
Maja Krčum, Ph.D.
University of Split, Faculty of MAritiem Studies
Ruđera Boškovića 37, Split, Croatia
mzubcic@pfst.hr

Tomislav Peša, M.Sc.
Ministry of Defense of Republic of Croatia
Trg kralja Petra Krešimira IV 1, 10000 Zagreb, Croatia
tomopesa@yahoo.com

ABSTRACT

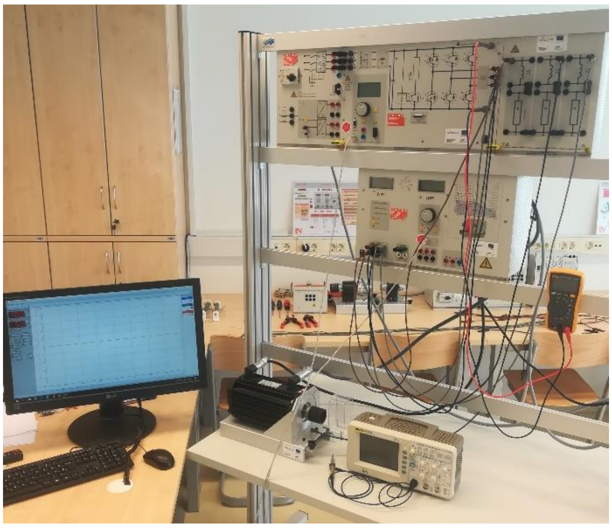
The laboratory facilities of the faculty play an important role in training future maritime electrical engineers. With the electrification of the marine industry, the importance of understanding electrical laboratory equipment is increasing. Technological advances will expose future maritime electrical engineers to increasingly complex systems, circuits, and topologies. In this paper, the focus is on a widely used component, the self-commutated power converter. The aim of the paper is to familiarize the students with the topology of the converter used in the laboratory exercises. The used converter is built on black-box principle i.e., the students cannot see the discrete components. The schematic that can be seen on the converter itself represents the mains filter and the dU/dt filter on black-box principle, i.e. the manufacturer does not provide any technical details about the filters. The model of the converter with mains and dU/dt filters is created using Matlab/Simulink Simscape components. To validate the model, the voltage and current waveforms measured on the actual device using an oscilloscope and the original manufacturer's software are compared with the simulated output waveforms.

Keywords: Laboratory equipment, Power converter, Simulink model

1. INTRODUCTION

Continuous global efforts to reduce greenhouse gas (GHG) emissions and decrease dependence on fossil fuels (Mostafaeipour et al., 2022; Olabi & Abdelkareem, 2022) place great emphasis on the electrification of ships in the maritime industry (Anwar et al., 2020; Bortuzzo et al., 2021; Campillo et al., 2019). Considering the increasing importance of electrical technologies on ships and the consequent higher complexity of these systems, future marine engineers are more than ever expected to have a profound understanding of these technologies. The preceding step is their education, and laboratory facilities play an important role in demonstrating how theoretical knowledge is applied in the real world. Considering that the components that control the most commonly used components on ships, the electric motor, it is important to familiarize the future engineers with their operating principles. Continuing on (Zubčić et al., 2021), the two-level voltage source inverter (2L-VSI) is further analyzed to improve the accuracy of inverter simulation with the implementation of the dU/dt filter, which was omitted in the previous work. There are many possibilities and different topologies of the dU/dt filter (Habetler et al., 2002; Korhonen et al., 2009), this work is ultimately about developing a simple model to familiarize students with the subject.

The validation of the Simulink model is done by comparing the simulated outputs with the outputs provided by the manufacturer's software and measurements on the actual device. Due to the superiority of space vector pulse width modulation (SVPWM) over sine pulse width modulation (SPWM) (Gujjar & Kumar, 2017; Sabarad & Kulkarni, 2015) which are included in the analyzed converter, the experiment is performed using SVPWM at a frequency of 50 Hz. To simplify the experiment, the motor is replaced by a combination of resistive and inductive loads provided by the original equipment manufacturer in the form of a module. The experimental setup is shown in Figure 1.

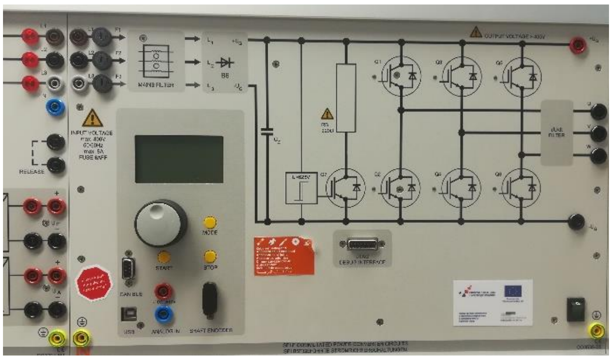


Source: Authors

Figure 1: Power converter experimental setup

2. CONVERTER MODEL

The manufacturer's self-commutated converter (Lucas-Nulle) has implemented several modulations with variable carrier frequency. The possible carrier frequencies are 1, 4 and 8 kHz, while the possible modulations are SVPWM, SVPWM line, SPWM with 3rd harmonic injection, SPWM and block. The converter is shown in Figure 2.



Source: Authors

Figure 2: Power converter module

In this work, the base model of the inverter model from the aforementioned work is used and a dU/dt filter is added, as shown in Figure 3, and the Simulink SVPWM signal generator in Figure 4. Since the topology of the filter is not accessible, the topology and parameters are assumed.

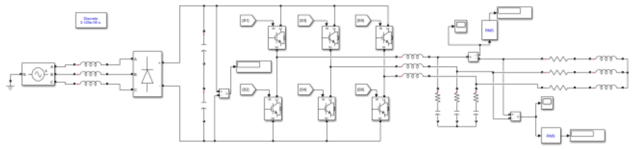


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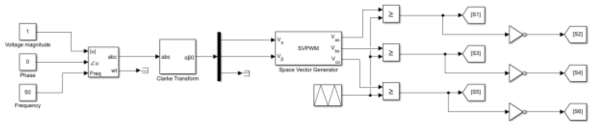
Figure 3: Power converter Simulink model



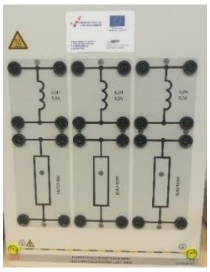
Source: Authors

Figure 4: SVPWM signal generator Simulink model

The power electronics load 300W module CO3636-3F is used to analyze the outputs at a fully resistive load and a combination of inductive and resistive loads in star configuration. The nominal values are:

- Single resistive component: 600 Ω / 100 W
- Single Inductive component: 0,2 H / 0,5 A

The module is shown in Figure 5.



Source: Authors

Figure 5: Power electronic load module

The experiment is performed on the fully resistive load with voltage amplitude set on 50%, 75% and 100% with 8 kHz carrier frequency SVPWM. The comparison is based on the output voltage/current waveforms and values measured with the software and measurements on the actual devices against the simulated outputs. The DC link voltage and RMS output values were measured using a "Fluke 115" multimeter, while the output voltage waveform was obtained using a galvanically isolated "RIGOL DSO1052E" digital oscilloscope.

3. MEASUREMENT RESULTS

From the results shown in Table 1, it can be seen that with a purely resistive load, the results agree well, while the introduction of a resistive/inductive load leads to discrepancies in the current values. The difference between the equipment and software measurements can be attributed to the accuracy classes, sampling rates, and calculation methods for the RMS values.

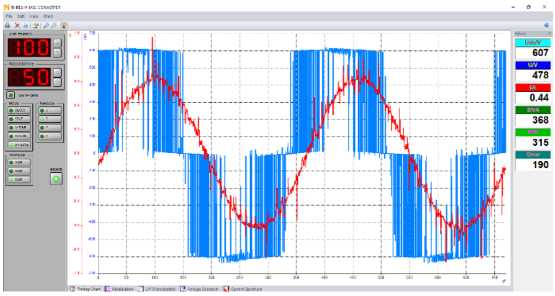
Table 1: Measurement results

U	Simulink			Software			Meas.		
	Resistive load								
	U_{dc} [V]	U_o [V]	I [A]	U_{dc} [V]	U_o [V]	I [A]	U_{dc} [V]	U_o [V]	I [A]
50%	609.1	318.6	0.307	609	329	0.25	607.5	251.2	0.259
75%	608.4	394.7	0.3804	605	404	0.36	605.9	342.6	0.353
100%	608.3	455.6	0.4397	606	474	0.47	606.4	434.3	0.451
	Resistive/inductive load								
50%	608.2	333.3	0.0428	610	335	0.23	609.1	260.3	0.204
75%	607.8	400.2	0.0514	611	411	0.34	603.7	342.8	0.306
100%	607.5	457.6	0.0588	607	478	0.44	604.7	436	0.410

Source: Authors

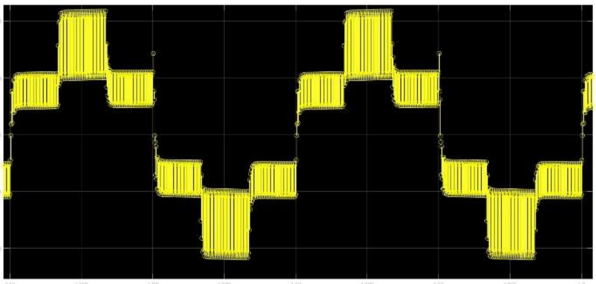
Where U_{dc} is the DC link voltage, U_o is the line output voltage and I is the phase current.

The discrepancies of the current values of the simulation and software waveforms are visible in Figures 6 and 7.



Source: Authors

Figure 6: Output voltage/current waveforms for combination load



Source: Authors

Figure 7: Simulink output current waveform for combination load

In comparison the difference is both in the waveform shape and magnitude, the resulting diagnosis leads to the conclusion that the assumptions made on the various unknown converter parameters need to be further narrowed down to accurately simulate the converters behavior with loads that also have an inductive component (as a motor).

4. CONCLUSION

The experimental results show that the unknown parameters of the frequency converter such as the IGBT characteristics, the mains and dU/dt filter parameters and their topology significantly affect the behavior of the simulation model, especially when the inductive load component is introduced. Since the main objective was to develop a simple simulation model for students to become familiar with, and various assumptions were made on the unknown parameters such that parasitic capacitances and inductances were omitted, the goal of future work will be to develop a comprehensive methodology for determining the parameters of the subcomponents of the inverter.

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REFERENCES

[1] Anwar, S., Zia, M. Y. I., Rashid, M., Rubens, G. Z. de, & Enevoldsen, P. (2020). Towards Ferry Electrification in the Maritime Sector. *Energies*, *13*(24), 6506. https://doi.org/10.3390/en13246506

[2] Bortuzzo, V., Bertagna, S., Dodero, M., Ferrari, J., Marinò, A., & Bucci, V. (2021). Electrification of Vessels for Garbage Collection and Treatment in Venice Lagoon. *2021 Sixteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, 1–6. https://doi.org/10.1109/EVER52347.2021.9456603

[3] Campillo, J., Domínguez-Jimenez, J. A., & Cabrera, J. (2019). Sustainable Boat Transportation Throughout Electrification of Propulsion Systems: Challenges and Opportunities. *2019 2nd Latin American Conference on Intelligent Transportation Systems (ITS LATAM)*, 1–6. https://doi.org/10.1109/ITSLATAM.2019.8721330

[4] Gujjar, M. N., & Kumar, P. (2017). 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)*, 924–929. https://doi.org/10.1109/RTEICT.2017.8256733

[5] Habetler, T. G., Naik, R., & Nondahl, T. A. (2002). Design and implementation of an inverter output LC filter used for dv/dt reduction. *IEEE Transactions on Power Electronics*, *17*(3), 327–331. https://doi.org/10.1109/TPEL.2002.1004240

[6] Korhonen, J., Ström, J.-P., Tyster, J., Silventoinen, P., Sarén, H., & Rauma, K. (2009). Control of an inverter output active du/dt filtering method. *2009 35th Annual Conference of IEEE Industrial Electronics*, 316–321. https://doi.org/10.1109/IECON.2009.5414941

[7] Mostafaeipour, A., Bidokhti, A., Fakhrzad, M.-B., Sadegheih, A., & Zare Mehrjerdi, Y. (2022). A new model for the use of renewable electricity to reduce carbon dioxide emissions. *Energy*, *238*, 121602. https://doi.org/10.1016/j.energy.2021.121602

[8] Olabi, A. G., & Abdelkareem, M. A. (2022). Renewable energy and climate change. *Renewable and Sustainable Energy Reviews*, *158*, 112111. https://doi.org/10.1016/j.rser.2022.112111

[9] Sabarad, J., & Kulkarni, G. H. (2015). Comparative analysis of SVPWM and SPWM techniques for multilevel inverter. *2015 International Conference on Power and Advanced Control Engineering (ICPACE)*, 232–237. https://doi.org/10.1109/ICPACE.2015.7274949

[10] Zubčić, M., Kaštelan, N., Krčum, M., & Peša, T. (2021). Motor drive experimental setup parameters determination. *NAŠE MORE 2021 - 2 Nd International Conference of Maritime Science & Technology*, 408.

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