MARITIME TRANSPORT VIII

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Francesc Xavier Martínez de Osés
Marcel·la Castells i Sanabra
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MARITIME TRANSPORT ‘20

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Sea transport of goods and passengers is constantly undergoing a meaningful rise due to the globalization of economy, thus provoking a trade speeding up and the specialization of ships and port terminals, with the support of the concept of co-modality and its environmental face eco-modality.

Ports are the decisive and needed connection in the shipment chain and must be considered in the maritime infrastructure providing a smooth change between modes of transport. These aspects shall be framed by the quality and environment-friendliness criteria that administrations and society require.

In this regard, protection of the environment, safety and security have become key points for the development of modern maritime transport. In addition, the influence of human factor on board the ships has to be strongly regarded as a decisive element for safe, secure and clean operations together with e-maritime initiatives.

The MT’20 Conference should be attended by researchers, scientists, academics, professionals, entrepreneurs, and all people involved in shipping and also in maritime training from any country. In its 2020 edition, administrations, institutions and companies will find a forum to meet, to exchange and to discuss their own achievements.
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SESSION 1. SHIPS AND PORTS SAFETY AND SECURITY
OVERVIEW OF STATUS AND PRIORITIES FOR SUSTAINABLE MANAGEMENT OF EUROPEAN SEAPORTS

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Abstract:

In the past decade a strong commitment in terms of environmental protection and sustainable development in port sector is noted. In order to achieve and maintain the environmental performance of port it is necessary to establish guidelines and priorities. This paper presents status and priorities which are marked within the European port sector through ESPO’s Ecoports environmental reports for the period 2013-2018. The change of environmental priorities in the port sector over the years has been noticed and therefore potential reasons for priority changes are addressed in this paper. The general aim of set priorities is to provide information about the high priority environmental issues and thus set the framework for guidance and initiatives that influence the environmental performance of the port. The analysis indicates that most of European ports actively work to protect the environment and thus guarantee sustainable development. From 2016 to 2018 the top 3 priorities have been the same (air quality, noise and energy efficiency), while air quality has remained the number one priority of the European ports since 2013. It is interesting to highlight that climate change priority which has been introduced in 2017 has been rapidly climbing the ranks and went up by 3 places in 2018.

Keywords:
environmental status; European port sector; port performance; environmental management system.

INTRODUCTION

In recent years, in all industries and thus in the transport and port sector, the sustainability has been the core of development. It is commonly said that there is no prosperity without business and that there is no business without transport. Hence, in terms of sustainability and the impact of transport on the environment, as an environmentally friendly mode of transport, maritime transport plays a decisive role. According to the most recent report from UNCTAD (2019), in 2018 world seaborne trade gathered momentum with total volumes of 11 billion tons [1]. In the
world seaborne trade, ports precisely, have a crucial role and good organization of the port system is the key to guarantee a smooth exchange of goods. In further development, greening of transport and transport infrastructure will be one of the key drivers which can be achieved by transport efficiency improvement and reduction of transport infrastructures and modalities footprint [2]. There are diverse environmental concerns that can arise from maritime activities in seaports, such as air pollution from port operations, loss or degradation of wetlands, destruction of fishery and endangered species, wastewater and stormwater discharges, severe traffic congestion, noise and light pollution, loss of cultural resources, contamination of soil and water from leaking storage tanks, air releases from chemical storage or fumigation activities, solid and hazardous waste generation, soil runoff and erosion [3]. In general, the impact on the port environment can be divided into the following categories: problems caused by port activities; problems caused by ship sailings; emissions from intermodal transport network which is in the function of serving the port hinterland. Namely, the fact is that the busiest port has higher risks of suffering from pollution [4]. The key component of the management of port development activities is to minimize the harmful impact of port operations on the environment [4] [5]. New challenges for the development of ports which address environmental issues and raise environmental awareness have already been incorporated into international and national legislation. Furthermore, to achieve and maintain environmental performance of port it is necessary to underline priorities and follow guidelines which are set through directives and regulatory framework. This paper aims to analyze priorities and guidelines that are marked within European port sector through ESPO’s Ecoports environmental reports for period 2013-2018, monitor their change over the years and try to address the potential reasons for priority changes [6,7,8].

1. EUROPEAN ENVIRONMENTAL PRIORITIES FOR PORT SECTOR

Ports all around the world have been demonstrating an increasing commitment to achieve a green status in port operations through a variety of actions, mandates, and initiatives. The main idea underlined in the term green port is directly connected with eco-friendly solutions in port operations (energy efficiency, collecting and recycling rainwater and waste on board, “zero emissions” policies) [9]. In the long-term, minimized environmental impact and sustainable operations are the main basis in achieving port sustainability. The mutual dependence of the concept of a “green” and sustainable development is notable. There are various definition of sustainable port, the PIANC in ‘Sustainable Ports’ A Guide for Port Authorities Report from 2014 defines a sustainable port as one in which the port authority together with port users, proactively and responsibly develops and operates, based on an economic green growth strategy, on the working with nature philosophy and on stakeholder participation, starting from a long-term vision on the area in which it is located and from its privileged position within the logistic chain, thus assuring development that anticipates the needs of future generations, for their own benefit and the prosperity of the region that it serves [2]. In the European context, there are many legal interventions related to environmental problems regarding seaport industry [10] [11] [12] [13] [14] [15] [16] [17]. Also, there are numerous initiatives in terms of sustainability achievement, and fast developing regions (like South-East Europe) will have to start developing green technologies and solutions for transport infrastructure [18].

Within European Sea Ports Organization - ESPO, EcoPorts represent a major initiative which relates to achievement of environmental sustainability in the seaport. The ESPO [19] Green
Guide upgrades European Commission efforts regarding environmental challenges and introduces measures for dealing with content like noise, water management, air quality, and climate change.

According to ESPO’s EcoPorts environmental review which followed the environmental priorities in the European port sector through regular surveys of their members since 1996 (Figure 1), it can be noted that priority areas ranked differently over time. For example, in the early beginning of monitoring (2004), air quality was ranked in 6th place. A few years after air quality went up in second place, and from 2013 is the top 1 monitored priority.

Table 1. Overview of ESPO top 10 environmental priorities over the years [8].

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<tr>
<td>1</td>
<td>Port development (water)</td>
<td>Garbage/Port waste</td>
<td>Noise</td>
<td>Air quality</td>
<td>Air quality</td>
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<td>2</td>
<td>Water quality</td>
<td>Dredging operations</td>
<td>Air quality</td>
<td>Garbage/Port waste</td>
<td>Energy consumption</td>
<td>Energy consumption</td>
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<tr>
<td>3</td>
<td>Dredging disposal</td>
<td>Dredging disposal</td>
<td>Garbage/Port waste</td>
<td>Energy consumption</td>
<td>Noise</td>
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<td>4</td>
<td>Dredging operations</td>
<td>Dust</td>
<td>Dredging operations</td>
<td>Noise</td>
<td>Relationship with community</td>
<td>Water quality</td>
<td>Relationship with the community</td>
</tr>
<tr>
<td>5</td>
<td>Dust</td>
<td>Noise</td>
<td>Dredging disposal</td>
<td>Ship waste</td>
<td>Garbage/Port waste</td>
<td>Dredging operations</td>
<td>Ship waste</td>
</tr>
<tr>
<td>6</td>
<td>Port development (land)</td>
<td>Air quality</td>
<td>Relationship with the community</td>
<td>Relationship with the community</td>
<td>Ship waste</td>
<td>Garbage/Port waste</td>
<td>Port development (land)</td>
</tr>
<tr>
<td>7</td>
<td>Contaminated land</td>
<td>Hazardous cargo</td>
<td>Energy consumption</td>
<td>Dredging operations</td>
<td>Port development (land)</td>
<td>Port development (land)</td>
<td>Climate change</td>
</tr>
<tr>
<td>8</td>
<td>Habitat loss/degradation</td>
<td>Bunkering</td>
<td>Dust</td>
<td>Dust</td>
<td>Water quality</td>
<td>Relationship with the community</td>
<td>Water quality</td>
</tr>
<tr>
<td>9</td>
<td>Traffic volume</td>
<td>Port development (land)</td>
<td>Port development (water)</td>
<td>Port development (land)</td>
<td>Dust</td>
<td>Ship waste</td>
<td>Dredging operations</td>
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<td>10</td>
<td>Industrial effluent</td>
<td>Ship discharge</td>
<td>Port development (land)</td>
<td>Water quality</td>
<td>Dredging operations</td>
<td>Climate change</td>
<td>Garbage/Port waste</td>
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Source: Made by authors using ESPO reports for 2018.

When analyzing table 1, it can be noted that in the first years of tracking port environmental priorities were generally connected with port development plans and dredging operations and disposal. From 2009, results reveal completely different factors affecting port’s development management, such as noise, air quality, and garbage waste. Since 2013, energy consumption
represents the top 3 issues for EU ports. One of the reasons for the high ranking of this priority could be direct connection between energy consumption and the carbon footprint of the ports and climate change. The European Union's efforts for reduction of carbon footprint and energy consumption are stated in [12] [13] [14] [20]. When observing period 2017-2018, it is interesting to highlight that climate change priority from the last position in 2017 has been rapidly climbing the ranks and went up by 3 places in 2018. It can be inferred that contributing ports are starting to act in order to adapt to climate change effects and to fulfill the objectives of the Paris Agreement.

Furthermore, from 2016 to 2018 the top 3 priorities have been the same, while air quality has remained the number one priority of the European ports since 2013 [8]. The fact is that ports are major sources of air pollutants that affect not only the health of people living in nearby communities but also contribute to regional air pollution problems. The major air pollutants related to port activities are diesel exhaust, particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NOx), ozone, and sulfur oxides (SOx) [21]. The ranking of air quality is in line with the European policies and efforts to enforce the existing legislation on air quality and other national initiatives which aim to comply with the EU limits and targets. Furthermore, a separate piece of legislation such as the implementation of the Sulphur Directive, the new National Emission Ceiling Directive, the introduction of the global 0.5% sulphur cap on marine fuels in 2020 and the IMO NOx requirements for vessels built from 01/01/2021 onwards operating in the North and the Baltic sea (NECAs) have been introduced [8].

Noise remains the third priority and its importance has also grown since 2004. The general aim of Directive 2002/49/EC is to define a common approach intended to avoid, prevent or reduce the harmful effects due to exposure to environmental noise. Both priorities, noise and air quality are directly connected with the number four priority that is relationship with the local community.

It is interesting to observe that the priority ship waste was introduced in 2013, and since then has been on the top 10 list of priorities. Comparing 2017-2018, it can be noted that ship waste went on higher position probably due to the introduction and adoption of the new EU Directive on Port Reception Facilities for ship waste [10]. This Directive aims to protect the marine environment against the negative effects of discharges of ship waste by using ports located in the Union and by improving the availability and use of adequate port reception facilities and delivery of waste to those facilities. Furthermore, it is important to highlight that waste has been reported as the highest priority monitoring issue by ports since 2013 (Figure 4), which shows that ports are ready to take a further step in dealing with marine litter.

Also, it can be noted that in a 20-year long period, the dredging operations and port development (land-related) are issues which have been included in all top 10 rankings. Furthermore, some priorities have been on top 10 lists in 1996 and 2004 but are not present longer, such as contaminated land, habitat loss/degradation, traffic volume, hazardous cargo, bunkering, and ship discharge. By its nature, the port sector is subject to continuous development and changes so the top 10 priority ranking changes over time (due to introduction of new legislation, the significance of topics for local port development, etc.). Ranked issues are rarely discrete subjects in themselves but are often linked with other priorities. For example, air quality, dust and noise may all be considered significant in terms of local community relations. Following the same argumentation, issues related to contaminated land and habitat loss may be subsumed under the issue of port development [22].
2. OVERVIEW OF EUROPEAN PORTS ENVIRONMENTAL PERFORMANCE IN PERIOD 2013-2018

In taking initiatives for addressing potential challenges and protecting the environment European ports are in the frontline (ESPO 2018). The passive role of ports against environmental challenges has changed drastically over the years [23]. As it has been already mentioned, within the port sector the air quality, noise, and energy efficiency are already top 3 environmental priorities since 2016. EcoPorts conduct research regarding port environmental performance through Self Diagnosis Method – SDM. SDM represents a comprehensive checklist for identifying environmental risk and establishing priorities in order to take action. This section will present and analyze obtained results within SDM for 2016, 2017, 2018. Also, the presented results will give insights about the environmental management performance of European ports and environmental monitoring programmes. The results will be compared mutually.

In 2016, 91 ports across 20 EU Member States participated in the research. In 2017, 91 ports in 21 countries were involved in the research. Ninety (90) ports from 19 EU Member States and Norway participated in 2018 study. Spain and the United Kingdom are countries with the most participants in the research, followed by France, where 10 ports participated in the research [6] [7] [8].

It is interesting to point out the results on the annual tonnage of goods handled in ports for observed period. Figure 1 shows that most of the ports are in the category of small and medium ports (less than 15 million tons per year).

Figure 1. Tonnage characteristics of the contributing ports.

Source: Made by authors using ESPO reports for 2016, 2017, 2018
2.1. ENVIRONMENTAL MANAGEMENT PERFORMANCE INDICATORS

There are 10 key indicators of environmental management in European ports that have been monitored from 2013. The indicators are:

A  Existence of a Certified Environmental Management System – EMS (ISO, EMAS, PERS)
B  Existence of an Environmental Policy
C  Environmental Policy refers to ESPO’s guideline documents
D  Existence of an inventory of relevant environmental legislation
E  Existence of an inventory of Significant Environmental Aspects (SEA)
F  Definition of objectives and targets for environmental improvement
G  Existence of an environmental training programme for port employees
H  Existence of an environmental monitoring programme
I  Environmental responsibilities of key personnel are documented
J  Publicly available environmental report

These indicators provide information about the management efforts that influence the environmental performance of the port.

Figure 2 shows the application of each of these 10 indicators in the 2013, 2016, 2017 and 2018. Also, comparisons are made between the changes in percentages for 2013 and each subsequent year (2013-2016, 2013-2017, and 2013-2018).

Figure 2. Overview of application and changes of environmental management indicators for period 2013-2018.

Source: Made by authors using ESPO reports for 2016, 2017, 2018
It can be noted from Figure 2, for 2018 that the existence of an inventory of relevant environmental legislation (a requirement of all major quality EMS standards) is the indicator that has the highest percentage of positive response (97%). Furthermore, the existence of an Environmental Policy is the second-highest-rated priority whose introduction represents a significant step towards the achievement of a certified Environmental Management System (EMS). It is important to emphasize that from 2013 the number of ports with a certified EMS has increased for 19 % (73% in 2018) which suggests the readiness of ports for the establishment of a good system to deal with environmental issues. By comparing years from 2013 to 2018, it can be noted that 8 of 10 indicators showed positive trends, especially in cases of documentation of environmental responsibilities of the key personnel (+15%) and the existence of an environmental monitoring program (+10%). The indicator regarding the compliance of Environmental Policy to ESPO’s guideline documents declines 2%, while the existence of an environmental training program for port employees declines by 8% [8]. The biggest challenge for port management and port stakeholders in the implementation of environmental sustainability refers to the involvement of employees at all organizational levels, i.e. to empower workers and make them aware of the importance of strategies and policies adopted. The decisive role in the application of sustainability issues (concerning all three sustainable pillars: economic, environmental and social) lies in management system standards (ISO 9001, ISO 14001, ISO 50001, UNE 166002, and OHSAS 18001). The two opposite objectives, economic and environmental are respected through different certification standards. The economic pillar is covered through ISO 9001 and UNE 166002, while ISO 14001 and ISO 50001 are connected with environmental performance, commitment, and responsibility. The third, social pillar is guaranteed by ISO 9001, UNE 166002, and OHSAS 18001 [24].

Also, these ten indicators can be displayed in one number, the so-called Environmental Management Index - EMI. The specific weight is attributed to each of the 10 indicators of the Index, which reflects its relative importance for environmental management. EMI is calculated by multiplying the weights associated with each environmental management indicator with a percentage of positive responses, which is illustrated by the formula [8]:

\[
EMI = A*1.5 + B*1.25 + C*0.75 + D*1 + E*1 + F*1 + G*0.75 + H*1 + I*1 + J*0.75.
\]
According to the previous figure, it can be noted the EMI has increased year after year, with achievement of 8.08 value in 2017 and 2018.

2.2. ENVIRONMENTAL MONITORING INDICATORS

Environmental monitoring is crucial for the port and therefore it is important to explore the components of environmental monitoring programmes in the European ports. Figure 2 in the previous section showed that in period 2013-2018, 10% growth has been marked for indicator regarding existence of a system for environmental monitoring.

Figure 4 shows main components of the monitoring programme and application of each of these 10 monitored issues for the 2013, 2016, 2017 and 2018. Also, comparisons are made between the changes of 2013 and each subsequent year (2013-2016, 2013-2017, and 2013-2018).
When analyzing Figure 4, it can be noted that from 2013 waste represents a top priority monitored issue. The following issues for 2018 are energy consumption (80%), water quality (76%) and water consumption (72%) [17]. Also, it should be noted that the percentage of ports that monitor waste has increased significantly between 2013 and 2018 (17%). More than half of the analyzed ports also include noise (67%), air quality (67%), and sediment (58%) in its monitoring programme. Trends concerning calculating and tracking carbon footprint remain stable since nearly half of the surveyed ports (47%) are devoted to this issue.

Besides mentioned priorities, in order to improve the environmental performance “5E” framework with following actions has been introduced: exemplifying (setting the good example in the port community when managing own operations); enabling (providing conditions for facilitating port users and improving environmental performance within the port area); encouraging (providing incentives to greener port users); engaging (sharing knowledge, means and skills between port users and/or competent authorities); enforcing (using mechanisms to enforce effective environmental practices by port users and ensuring compliance) [19].

3. CONCLUSIONS

Green ports will indisputably become the cornerstone of the development of the port sector in the future. Nowadays, the main goal of the development of (environmental) port is to reconcile the two opposite objectives: high economic efficiency and excellent ecological performance of ports. Efficient use of resources, reduction of negative impact on the environment, improvement of environmental management and quality of the port natural environment are prerequisite for sustainable development of the port. To achieve this goal, it is necessary to ensure the use of
renewable resources and the implementation of sustainable practices (such as recycling) in the port activities. The port authorities should be constantly encouraged to act and think in a greener way. Their activities should be directed to sustainable development and continuous improvement in environmental protection. It is necessary to identify the best practices and processes that can help port authorities to achieve higher levels of sustainability and thus to reduce the level of pollution affecting water, air, and noise. In this overview of the status of European ports it can be noted that EU ports are constantly working on the improvement of their environmental performance. Ports are prepared to respond to all changes and issues that have been addressed through a regulatory framework (such as waste, air quality and climate change).

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SPANISH CONTAINER PORTS INTEGRATION IN THE MARITIME NETWORK

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Abstract:

Maritime transport is the backbone of global trade, a component driving globalization. Over 80% of world trade in volume terms and over 70% in value terms is done by sea; these proportions are even higher in most developing countries. This unceasing growth in maritime trade raises important questions concerning the development of ports role in worldwide transport. In recent years, container shipping has resulted in a specific network connecting the main ports together and these ports to smaller ones by regular feeder services which tend to use smaller size containerships. The development of the port system is concentrated in large ports, which attract considerable container traffic.

This paper aims to present a survey of the current situation of container shipping in the Spanish ports which, comparing to north western European ports, have quite small markets and limited hinterlands that by consequences reduce attractiveness of ports. It focuses on the integration of ports in the containerization networks and on the organization of regular lines. The research was carried out using mainly Automatic Identification Data (AIS). The data acquired from AIS systems constitute a new means of information which allows to perform multiscale, diachronic and synchronic analyses. A desktop study as well as a statistical analysis which has required the construction of a database are also used. By focusing on vessels, shipping companies and ports, this communication considers the process of containerization in Spanish ports with a special attention on ports’ network.

Keywords: Maritime, port, transport, AIS, network, Spain.

INTRODUCTION

Maritime transport and containerization have undergone rapid growth and important transformations in recent decades. Among those, containerization transformed the configuration of freight routes with innovative services (Rodrigue, 2020), growing ship size or strategic alliances.

Since its introduction in the shipping industry in the 1960s, containerisation has reinforced the expansion of the world economy. The development of liner (containerised) shipping in the last
30 years has exceeded the growth of world trade volumes (Ducruet et Notteboom, 2012). Two factors mostly explain the achievement of containerisation: the productivity gains in cargo handling in ports and a more gradual process which involves the refinement of the container networks of largest container shipping companies (Frémont, 2007). Intense container traffic growth has led to new demand for container terminals.

Historically, on the 7,000 kilometres of coastline, ports in Spain have been at the forefront of shipping in the Mediterranean basin for several centuries but also on the Atlantic side. Due to its position in the transport chain and the importance of sea traffic over 70% of Spanish international trade is transported by sea (Díaz-Hernández, 2007). The Spanish port system consists of 28 port authorities, which transported 563.5 million tonnes of freight and 46 million passengers in 2018 (Bermúdez, Laxe, Aguayo-Lorenzo, 2019).

Even if the maritime traffic in the Spanish ports is relatively diversified, the paper will focus on containerised flows. It aims to deliver an analysis and an empirical study of containerisation dynamics and of the container network. This study is based on a literature review and on the analysis of port traffics. It also contains information about regular lines, frequencies, capacities, and operators obtained using AIS data, as well as some database on ships. Our study is mainly resulting in producing cartographical and graphical representation of the Spanish container port system.

1. CONTAINERISED TRAFFIC IN SPANISH PORTS

1.1. TRAFFIC EVOLUTION: GROWTH IN A COMPETITIVE ENVIRONMENT

In Spain, maritime transport is the most important transport mode in terms of international trade. The national port system, composed by 28 port authorities that manage 46 ports, includes one of the most important Mediterranean hubs (Barcelona, Algeciras), the largest Mediterranean in container traffic (Valencia), or Bilbao, one of the most important transport and logistics centres in the European Atlantic Arc (Gutierrez et al, 2015). In addition, the State port system's activity contributes nearly 20% of the transport sector's GDP.

Moreover, it generates more than 35,000 direct employments and around 110,000 indirectly. In the last 50 years, the tonnage moved through the Spanish maritime port system was multiplied by 7, reaching more than 500 million tons per year. This rapid growth is also impressive in container traffic going from 270,000 TEU in 1973 to 17 million TEU in 2018 (Cf. Figure 1). Furthermore, during the same period, the Spanish shipping agents handled an annual average of 16,886 exported TEU and 19,356 imported TEU.

In 2012, the overall port system moved 59% of total Spanish exports and 82% of total imports, which represented 53% of Spanish international trade with other EU countries and 96% of third countries (Núñez-Sánchez, Coto-Millán, 2012).
This evolution is strongly connected to the development of the world maritime traffic but also to regional specificities. In the Iberian Peninsula ports, proximity to the Mediterranean Sea or to large consumption and production centres has affected container terminal activity by boosting cargo flows (Felicio et al, 2014). Proximity to the Mediterranean Sea influences performance because the Mediterranean Sea marks the Asia–Europe shipping crossing point. The Spanish Mediterranean ports have tried to use their crucial position on the Asia – Europe trades to attract larger throughput by offering transhipment opportunities. The Port of Barcelona, for instance, has met with setbacks in certain infrastructure projects (Van Hassel et al, 2016).

Consequently, some Spanish ports have emerged as intermediary transhipment hubs that connect other continents with northern European ports (Notteboom, 2010). These ports concentrate cargo flows from the hinterland and from feeder ports. They also serve northern European ports, including Atlantic ports, and ports in North America, South America and Africa. So, containerized general cargo is relatively important in Valencia, Algeciras and Barcelona, with percentages larger than 35% ((Núñez-Sánchez, Coto-Millán, 2012).

Even If Spain has some ports on the Atlantic Ocean, according to the government agency Puertos del Estado, the container traffic is highly dominated by the Mediterranean basin which was accounting for more than 90% of the total throughput in 2018 (Cf. Figure 2).
Figure 2. Main Spanish ports’ share in the total container traffic in 2018.


Nowadays, container ports are competing to become transhipment hubs as part of major shipping lines and feeder networks, while greater inland transport accessibility has allowed ports to spread further inland (Felicio et al, 2014). In reality, the basin of the Mediterranean Sea has become a significant focus of container traffic. Two functions are represented by this activity: one, the transhipment of containers involved in global networks; and, subsequently the intra-regional distribution of containers. This trade is revitalising port activity in many parts of the basin. Most striking has been the emergence of new hub ports, many of which now eclipse old-established port cities. The revitalisation offers prospects for a third function: the possibility of becoming the southern gateway of Europe (Ridolfi, 1999).

1.2. TRAFFIC CONCENTRATION IN SOME MEDITERRANEAN PORTS

In the paper, we decided to focus on the main Spanish container ports which top 6 is composed of three Mediterranean ports (Valencia, Algeciras and Barcelona) and three Atlantic ones (Las Palmas, Bilbao and Tenerife) (Cf. Figure 3). But, throughput volumes of Barcelona, Algeciras and Valencia dominate the market, while Las Palmas, Bilbao or Tenerife Port lag much behind.
Located on the Bilbao Abra bay in Biscay, in the North Atlantic Ocean, the Port of Bilbao is currently the 5th busiest port in Spain for the container traffic with 619 000 TEU’s in 2018. In 2019, Bilbao port has completed a project for the expansion of its container terminal, which has involved an investment of €10 million by CSP Iberian Bilbao Terminal. But, as we can see in figure 4, its traffic remains quite small compared to Spanish Mediterranean container ports. The main problem for Bilbao is its lack of connectivity and very often, transhipment is needed via ports in Northwest Europe (Veldmann, Garcia-Alonso, Vallejo-Pinto, 2013).
Las Palmas Port (located in Gran Canaria) is fourth in Spanish container port classification and the main ports in the Canary Islands (1.1 million TEU’s), with S.C. Tenerife Port (located in Tenerife). They are managed by different Port Authorities. Cargo transported in these ports, summed up to more than 88% of the Canary Islands total freight. Las Palmas is using its good port connectivity to become a major logistic platform between Europe, Africa and America and it offers many advantages to ocean-going vessels such as a recognized technical and commercial maritime community and competitiveness in supplies and repair services. Its location between main commercial trade routes makes it a cargo hub (over 19 million tons from loading, unloading and transhipments) (Tichavska, Tovar, 2015).

In 2018, the port of Valencia Spain's second-busiest port (76 millions of tons), overtaking the other Spanish port for the container traffic (5,182 million TEU’s). It also appeared at the fifth raw in the European container port ranking. Like Rotterdam and Antwerp, Valencia, the largest container port in the Mediterranean, present a healthy throughput increase (Notteboom, 2019). Its importance is mainly due to the fact that about 50% of the Spanish’s GDP is generated within a 350-km radius of the port, as is half of the country's employment. So the port of Valencia is strongly connected to the national economy. The hinterland of Valencia port has experienced the best evolution over the last decade in comparison with the other main Spanish container ports (Martínez-Pardo, Garcia-Alonso, 2014). Moreover, the port of Valencia is the first and last port of call for some shipping routes between the Western Mediterranean and the Atlantic. So, Valencia, is combining its gateway function with relevant transhipment flows (Cardoso Alves, 2016). From a transhipment incidence of almost 20% in 2004, Valencia, achieved in 2012, a transhipment incidence of 50% (Notteboom, Parola, et Satta, 2014).

Due to its locational characteristics, Algeciras placed itself as the western gateway to the Mediterranean basin (Ridolfi, 1999). In 2018, Algeciras was the largest port in Spain (107
millions of tons) and the third largest on the Mediterranean, but it was the behind the port of Valencia for the container traffic (4,773 million TEU’s). Algeciras get benefits from being chosen by Maersk as a global hub. But, the monopolistic situation of the port of Algeciras for container traffic was disrupted by the arrival of a strong competitor on the other bank of the Strait of Gibraltar, the Moroccan port of Tangier-Med, and by a situation of saturation of the Andalusian port's infrastructure (Marei, 2012). With new container terminal capacity becoming operational, Tanger Med is a major competitor for European hubs in the region around the Straits of Gibraltar, such as Algeciras or Valencia (Notteboom, 2019). Tangier-Med and Algeciras are similar ports, which can be classified as hubs. They are characterized by an extremely high transshipment rate: more than 88% in 2018 for the port of Algeciras (source: government agency Puertos del Estado, 2020) and almost 96% for the port of Tangier-Med (Marei, 2012).

In fact, competition is omnipresent in the region and five container ports, near the Strait of Gibraltar can be identified in a transshipment traffic map for the Mediterranean container ports: Sines and Valencia (transshipment share in 2018 was about 55%); Algeciras, Malaga and Tangier (transshipment share is around than 90%) (Monteiro, 2013).

The port of Barcelona is Spain's third-largest port, managing 67 million tons of cargo each year, the port handles four different types of cargo, of which containers is the most important with a share of more than 40%. So, Barcelona is, after Valencia and Algeciras, the third largest container port in Spain (3,182 million TEU’s).

Barcelona is the largest port in the region of Catalonia, which produces 18% of the country's GDP. Barcelona is well located to serve other parts of Spain as well as the South of France. However, traditionally the port community and the port authority focused on Catalonia (Van den Berg Peter, De Langen, 2011). In fact, Barcelona’s immediate hinterland has reduced its importance (Garcia-Alonso, 2017) and has been going down in the national container port ranking since the beginning of the 80’s (Cf. Figure 4).

The case of Spanish container ports illustrates one recent trend of maritime industry evolution: the integration and specialization of several routes with feeder ships converging at major maritime intermediate hubs. We can see that the most dynamics ports in Spain are those connected to this trend: Valencia and Algeciras but also Las Palmas.

2. CASE STUDY: SPANISH CONTAINER PORTS IN 2019 USING AIS DATA

Thanks to the AIS data and in relationship with external databases, we determined all container ships that called at Spanish port in 2019.

2.1. METHODOLOGY

This part of the analyse 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.

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,
2.2. SHIPS ET OPERATORS

The results of AIS data analysis concern different types of studies like port performance analysis (duration of call and ship size...), shipping companies’ strategies, maritime network study or regional markets analysis.

At first, we can analyse the number of port calls in 2019 (Cf. Figure 5). The three leading container ports are clearly more often touched by containerships and the gap with the other Spanish ports is important as there are 4 less port calls in Bilbao (rank 4 in the classification) than in Barcelona (rank 3 in the qualification).
Those results clearly show the hierarchy in the port system dominated by the ports located near the Strait of Gibraltar and Barcelona while the other ports with a lower container traffic are less connected to the maritime network.

Secondly, we can have a look to containerships’ size in the ports of Spain (Cf. Figure 6). In that field, the situation is similar to the number of port calls but the impact of Gibraltar Strait’s proximity seems to be stronger as we can see that Malaga also attract biggest ships. Gibraltar is one of the two points of entry the Mediterranean Sea which have significant transhipment activity (Rodrique, 2020).
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Even if vessels deployed in the Mediterranean region tend to be smaller than is some smaller areas, it is in part due to draft restrictions at some of these ports. But, some of the Spanish ports like Valencia, Barcelona and Algeciras are accommodating large container vessels (Van Hassel et al., 2016).

We can also use AIS data to study shipping companies and operators’ strategies. There is an evident correlation between the container traffic, the number of calls and the number of operators present in the ports: the biggest ports are interesting more shipping companies (Cf. Figure 7).
In 2019, 95 different operators were offering services to the Spanish ports and three major shipping companies, *Maersk*, *MSC* and *CMA CGM*, were dominating the markets. At the fourth and fifth places, *X-Press Feeders* and *WEC Lines* are showing the transhipment activity in the region and the role of companies specialised in feeder services.

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The figure 8 shows that stakeholders are different in the ports. For instance, Algeciras is strongly connected to Maersk when MSC is the leading company in Valencia, Barcelona and in Las Palmas. Once again, the role of transhipment hub of Algeciras is lightened by the position of X-Press Feeders. We can also state the absence of COSCO shipping in Spanish ports which can be explained by its alliance with CMA CGM which is present in the leading container ports in Spain (Cf. Figure 8). The French shipping company is toughly active in the smaller ports like Bilbao which, like Tenerife, is often included in services offered by shipping companies specialised in feeder services. At least, in these smaller ports, there is less hierarchy between the different shipping companies.
2.3. MARITIME NETWORK ANALYSIS

As seen previously, the main Spanish container ports are Valencia, Barcelona and Algeciras and all 3 together, they account for 77% of Spanish container traffic. So they are the main Spanish nodes of the international maritime network.

To analyze the integration of these ports into the global maritime network, we focus on container ships with a capacity over 15,000 TEU’s. These container ships, giants of the seas, are exclusively positioned on the Europe-Asia trade connecting the major Chinese commercial ports to the European consumption markets. The ports of Valencia, Barcelona and Algeciras receive this type of containerships but they are not served in the same way.

2.3.1. THE MARITIME NETWORK OF THE PORTS OF VALENCIA AND BARCELONA

The ports of Valencia and Barcelona have many similarities. Indeed, these two ports belong to the same maritime service. Thus, in 2019, the same 27 containerships over 15,000 TEU’S called at Barcelona and Valencia ports.

In 2019, for this category of containerships, both ports were exclusively touched by the 2M alliance ships consisting of MSC and Maersk. For instance, 5 ships from Maersk and 22 from MSC called in both ports for 48 and 45 stops respectively for Barcelona and Valencia. They belong, therefore, to the same maritime service for which the rotation of port of call in the Mediterranean Sea for previously identified vessels respects a well-defined loop (Cf. Figure 9).

Dominant connections can be stated, mainly in connection with the port of Gioia Tauro (Italy). Thus, in Barcelona, 71% of the containerships came from Gioia-Tauro when 40 container ships (83 %) went directly to Valencia. These containerships were then returned mainly to Gioia Tauro (33 of the 44 calls in Valencia). Then, the ships leaved this Mediterranean loop via Port Said and the Suez Canal.

Figure 9. Typical Mediterranean loop calling in the Spanish.

![Figure 9](source: IHS Maritime, 2020)

The ports of Barcelona and Valencia are therefore served by a single maritime service of the 2M alliance. This service is the "AE11 Eastbound" which provides a maritime connection from Spain to Chinese ports (Ningbo, Yantian, Qingdao, ...) and with the port of Singapore. This organization clearly appears in the scheme below (Cf. Figure 10). It is representing the maritime network of the 27 previously identified container ships with at least 10 relations and permits to visualize the place of the ports of Valencia and Barcelona.
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Figure 9. Typical Mediterranean loop calling in the Spanish ports.


2.3.2. ALGECIRAS: A DIFFERENT PORT, IN A DIFFERENT NETWORK

The port of Algeciras is not part of the same maritime network as the ports of Valencia and Barcelona. In 2019, 68 different containerships over 15,000 TEU’s called Algeciras for a total of 164 calls.

In 2019, the insertion of the port of Algeciras into the global maritime network is more important than for other Spanish ports. This is largely justified by its hub function. One indicator confirms this situation: it is the highest diversity of maritime shipping companies serving the port of Algeciras with the CMA CGM (62 calls), APL (9 calls), MSC (22 calls) and Maersk (71 calls).

The direct origins and destinations to and from Algeciras are also very diverse (Cf. Figure 11). We can see some maritime links with northern European ports (Southampton, Bermerhaven, Antwerp...).
Rotterdam, Le Havre, ...), Asia (Pasir Panjang, Tanjung, ...) or Even Mediterranean ports (Port Said).

Figure 11. Direct connections between Algeciras and some other ports.


Algeciras is thus strongly integrated in the global maritime network positioning itself as a major node in the organization of the shipping lines of the major operators. However, this position as a hub at the intersection of the Mediterranean and the Atlantic is threatened by the development of the port of Tangier-Med, which saw a 38% growth of its containerized traffic in 2019 and is now approaching the 5 million TEU’s per year.

2.4. APPROACH OF PORT EFFICIENCY

AIS data allows us to analyze the efficiency of ports through the development of different indicators. By linking this AIS data with a ship database and port traffic, it is possible to calculate a theoretical handling rate per call (Cf. Figure 12). This rate means that, for example, for a container ship with a capacity of 10,000 EVP, an average of 3400 TEUs (loading and unloading) are handled.

Concerning the studied ports, we note that the three main ports that are Algeciras, Barcelona and Valencia have an identical handling rates of 34%. If we compare to western European ports this rate is better than in Le Havre where only 18 % of containers are loaded / unloaded but smaller than in Antwerp (46 %) and Hamburg (65 %) (Serry, 2018); it means that during one call, in average, less containers are handled in the studied ports than in northern European ports.

On the other hand, the port of Bilbao has the highest handling rate at 91%. That seems to show that Bilbao which is touched by smaller ships is in fact served by dedicated feeders.
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Figure 12. Port performance regarding container handling rate.

This handling is also including the average number of containers loaded and unloaded during a call in each port. Once again, the three main ports, Algeciras, Barcelona and Valencia, are very similar results, with respectively 1437, 1435 and 1570 TEU’s handled. Thanks to this figure, we can see that the position of hub for the port of Algeciras is all the more threatened. In fact, European hubs handle more containers during a stopover: in 2017, in Europe, they handled more than 2000 TEUs (Serry, Kerbiriou, Montier, Méjane, 2019).

Regarding the Spanish ports, we can furthermore analyse port efficiency using the duration of port calls offered by AIS data. By integrating the port traffic in the research process, it is also possible to estimate the average duration of handling operations of one TEU in each port (Cf. Figure 13). Such an analysis could be more precise with the number of cranes used in each terminal for instance. Despite these few restrictions, the results are remarkable and give an interesting order of magnitude (Serry, 2019).
Barcelona appears to be the most efficient port in Spain but the other leading ports in the container market offer similar speed even if handling operations in Las Palmas are slowest. The situation in Bilbao is quite different because it seems to take three times more times to operate one TEU in Bilbao than in Barcelona.

3. CONCLUSIONS

The competitiveness of the Spanish container ports is driven by both initiatives undertaken at a global level (for instance alliances between shipping companies) and by their relative position in comparison to other European port concentrations. The expansion of international trade has equally led to an increase in the container turnover in the Spanish ports. The competition between ports is obvious, as can be seen between Algeciras and Valencia (or Tangier-Med). In that case, calls of large container ships confirm the ability of ports in Spain, On the Mediterranean coast as well as in the Canaries islands, to compete as hubs in international transport networks. The competition between the ports on the Mediterranean side also consists of ports which can handle container ships and the distribution of goods to close markets.

In this paper, from a methodological point of view, the huge potential of AIS data has been exploited to set up a platform to integrate the data and to offer new possibilities of analyses of the Spanish container ports’ network.

Our study enhances that situation by presenting the strong differences between the Atlantic and the Mediterranean cost. It also shows the complementarity at the national levels between the main ports like Algeciras, Valencia or Barcelona and feeder ports playing at a regional or local level (Bilbao, Vigo…).
References:


TRAFFIC ANALYSIS OF YANGTZE RIVER DELTA MULTI-PORT SYSTEM (CHINA) USING HIERARCHICAL CLUSTERING


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Abstract:

This paper focuses on the container throughput of 15 ports in the Yangtze River Delta (YRD) multi-port system from 1992 to 2019 to explore the evolution of container traffic share using concentration indexes and hierarchical clustering. Compositional Data (CoDa) analysis techniques are used to investigate the similarity and linkage of data. Then hierarchical clustering is used to cluster the traffic data of the YRD multi-port system from 1992 to 2019 into five periods based on the similarity among the yearly data. The consistency of the analysis is verified by combining the concentration index with the ternary diagram. The periods obtained from hierarchical clustering exhibit different patterns in the composition of traffic shares and they are consistent with traffic fluctuations. The combination of these methods provides a good interpretation of the spatial and temporal evolution of the YRD multi-port system.

Keywords:

container ports; the YRD multi-port system; concentration index; CoDa.

INTRODUCTION

The Yangtze River Delta (YRD) is in the central region of China’s coastline and the middle and lower reaches of the Yangtze River, facing the East China Sea and the Yellow Sea (see Figure 1). The YRD region includes Shanghai, Jiangsu, Zhejiang and Anhui
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INTRODUCTION
The Yangtze River Delta (YRD) is in the central region of China’s coastline and the middle and lower reaches of the Yangtze River, facing the East China Sea and the Yellow Sea (see Figure 1). The YRD region includes Shanghai, Jiangsu, Zhejiang and Anhui provinces, covering an area of 359,000 square kilometers, with a permanent population of 220 million, accounting for 1/26 and 1/6 of the country respectively, and the total economic volume of 19.5 trillion yuan, accounting for nearly 1/4 of the country [1].

In the world, more than 90% of the volume of trade is done by sea transportation [2]. In 2018, the YRD multi-port system container throughput was 90.608 million TEU, accounting for 36.27% of China’s total container throughput (24.982 million TEU). Shanghai port (SH) and Ningbo port (NB) rank first and third respectively among the top ten container ports in the world in 2018, both of which are in the YRD multi-port system. Therefore, it is great significance to analyze the container traffic share of YRD multi-port system.

There have been many recent studies on the evolution of port systems, such as Norway [3], Italian [4], Greece [5], Spain [6], Mexico [7] and China [8], etc. Regarding China, more attention has been focused on the YRD multi-port system, as SH and NB have developed into China’s largest ports in recent years. SH has the advantage of space convenience and NB has the advantage of cost [9]. During recent years, NB and SH have shown a competitive situation to form a dual-hub port in the YRD multi-port system [10].

Figure 1. Overview of the YRD multi-port. The YRD multi-port system includes Shanghai port(SH), Suzhou port(SZ), Nantong port(NT), Nanjing port (NJ), Lianyungang port (LYG), Jiangyin port (JY), Taizhou port (Jiangsu Province, TZJ), Yangzhou port (YZ), Zhenjiang port(ZJ), Ningbo port (NB), Taizhou port (Zhejiang Province, TZZ), Wenzhou port(WZ), Jiaxing port(JX), Huzhou port(HZ) and Hangzhou port(HZH).
The development of economic geography provides many research methods for container traffic research. It consists mainly of Lorenz curves [11], Gini coefficients [12], Hirschman-Huffendahl indices (HHI) [13], Moran coefficients [14], Rosenbluth index, and Concentration Ratio (CR) [15], etc. CoDa is a complex set of metadata that reflects the relative information between the data [16]. CoDa is applied in various fields such as geography [17], economics [18], archaeometry [19], biology [20] and chemistry [21], etc.

The objective of this contribution is to analyze the container traffic share the YRD multi-port system considering concentration indexes, hierarchical clustering and ternary diagram.

1. METHODOLOGY

In this Section, two concentration indexes (Gini coefficient and HHI) and CoDa are introduced briefly.

2.1 CR (1)

CR (1) is the main method of measuring the concentration level of container traffic share in the YRD multi-port system, with a higher CR (1) implying a larger share in the largest ports. The CR (1) formula is as follows:

\[ CR(1) = \frac{TEU_1}{\sum_{i=1}^{n} TEU_i} \]  
(Eq. 1)

where \( i \) to \( n \) is the port number in the multi-port system, and \( TEU_1 \) is the throughput of the largest port. When the value of CR(1) reaches 50%, the share is regarded as an oligopoly in the multi-port system [22] [23].

2.2 HERFINDAHL-HIRSCHMAN NORMALIZED INDEX (NHHI)

The NHHI is commonly used in regional economics to illustrate the degree of market concentration, which is expressed by the formula:

\[ NHHI = \frac{\sum_{i=1}^{n} \frac{TEU_i^2}{\sum_{i=1}^{n} TEU_i}}{\sum_{i=1}^{n} TEU_i^2} \]  
(Eq. 2)

where \( i \) to \( n \) is the port number in the multi-port system. NHHI ranges within \([0, 1]\), when the market is occupied 100% by a port, the value of NHHI is equal to 1. On the other hand, when NHHI approaches 0, it means the market is divided equally among all the ports.
SHIPS AND PORTS SAFETY AND SECURITY

The development of economic geography provides many research methods for container traffic research. It consists mainly of Lorenz curves [11], Gini coefficients [12], Hirschman-Hufendahl indices (HHI) [13], Moran coefficients [14], Rosenbluth index, and Concentration Ratio (CR) [15], etc. CoDa is a complex set of metadata that reflects the relative information between the data [16]. CoDa is applied in various fields such as geography [17], economics [18], archaeometry [19], biology [20] and chemistry [21], etc.

The objective of this contribution is to analyze the container traffic share the YRD multi-port system considering concentration indexes, hierarchical clustering and ternary diagram.

1. METHODOLOGY

In this Section, two concentration indexes (Gini coefficient and HHI) and CoDa are introduced briefly.

2. RESULTS

This article selects the data of the YRD multi-port system from 1992 to 2019. During this period, the development of the ports in the YRD multi-port system is distinct. The data of the YRD multi-port system from 1992 to 2019 are clustered based on clr transformed coordinates, and the development of the YRD multi-port system is divided into five stages, 1992-1995, 1996-2000, 2001-2007, 2008-2013, 2013-2018 (see Figure 2).

Figure 3 (left) shows the NHHI and CR (1) for the YRD multi-port system. NHHI and CR (1) decreased from 0.47 and 0.76 to 0.42 and 0.71 respectively in the period 1992-1995. After 1995, concentration ratio in the YRD multi-port system began to increase. NHHI and CR (1) increased to 0.49 and 0.76 respectively in 2000. During 2001 to 2013, NHHI and CR (1) decreased from 0.47 and 0.74 to 0.23 and 0.49, respectively. NHHI and CR (1) decreased by 50.95% and 34.22% respectively, which is considered an indication

2.3 CoDa

Compositional data is usually expressed as a vector of proportion, percentage, concentration or frequency. When proportions are expressed as a real number, it is easy to interpret it as real multivariate data [16]. The sample space of CoDa is the simplex, expressed as:

\[ S^D = \{ x = [x_1, x_2, \ldots, x_n] : x_1 > 0, x_2 > 0, \ldots, x_n > 0; \sum_{i=1}^{D} x_i = k \} \]  (Eq. 3)

A (row) vector, \( x = [x_1, x_2, \ldots, x_n] \), is a D-part composition when all its components are strictly positive real numbers and only carry relative information [24][16]. The constant is any positive real number, where the \( k \) the closure, which depends on the unit of measurement, usually 1 or 100.

CoDa analysis should satisfy scale invariance, permutation invariance, and subcompositional coherence [25]. For the research of CoDa, there are generally two ideas. One is to directly study on the simplex according to the unique calculation and metric structure of the CoDa. The second method is to obtain the logarithmic ratio coordinates first and then use traditional statistical methods. Several transformations based on log-ratios have been defined in the literature, the additive logratio (alr), the centered log-ratio (clr) and isometric log-ratio transformation (ilr) [26]. The clr transformation of a composition \( x = [x_1, x_2, \ldots, x_n] \) is

\[ \text{clr}(x) = \left[ \ln \frac{x_1}{g_m(x)}, \ln \frac{x_2}{g_m(x)}, \ldots, \ln \frac{x_D}{g_m(x)} \right] \]  (Eq. 4)

Where

\[ g_i(x) = (\prod_{i=1}^{D} x_i)^{1/D} \]  (Eq. 5)

2. RESULTS

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of a gradual deconcentration. The temporal evolution of the NHHI and \( CR (I) \) reveal consistent periods with hierarchical clustering obtained using \( clr \)-transformation. For instance, the period clustered 1992-1995 is characterized by a stable \( CR (I) \) and NHHI values. Then, the cluster 1996-2000 shows an increased concentration level, followed by a gentle decreasing during two clusters (i.e. 2001-2007 and 2008-2013 particularly accelerated during the later period). Finally, a stabilized period on concentration level is observed during the cluster 2014-2019.


![Year clusters of the YRD multi-port system from 1992 to 2019.](image)

**Figure 3.** (left) NHHI and \( CR (I) \) for the YRD multi-port system during 1992 to 2019. (right) Ternary diagram of the NB/SH/OTH (Other ports except SH and NB) traffic composition (The size of the points increases with the year).

![Ternary diagram of the NB/SH/OTH traffic composition.](image)
The ternary diagram was introduced by [27]. When the value of \( CR(1) \) reaches 0.5, the market is regarded as an oligopoly [13] [28]. In order to better represent the traffic share in ternary diagram, we divide the original big equilateral triangle into 4 smaller ones at the 50% parallel line (see Figure 3. (right)), the 3 smaller equilateral triangles around the corners are called as ‘NB Dominating’, ‘SH Dominating’ and ‘OTH Dominating’ respectively and the central one is called as ‘Efficient Competition’ [29]. For instance, in the ‘NB Dominating’ area, NB have the largest market share that is more than 50%, therefore the market is expected to be dominated by NB. However, in the ‘Efficient Competition’ area, market share of each port is less than 50%, and no port is able to dominate the competition absolutely. Figure 3. (right) shows that SH maintains the largest container traffic share, followed by NB in the YRD multi-port system. During the period 1992-2013 the container traffic share of the YRD multi-port system has been in the SH Dominating and since 2014 it has been moving into the ‘Efficient Competition’, which means SH has gradually lost its monopoly since 2001. \( CR(1) \) first dropped less than 0.5 also in 2014, which indicated the ternary diagram is coincident with \( CR(1) \).

3. CONCLUSIONS

The main conclusions derived from the analysis are the following: First, the overall throughput of the YRD multi-port system has achieved explosive growth from 1992 to 2019; Second, the conclusions drawn from the ternary diagram, concentration indexes and hierarchical clustering based on CoDa are consistent, thus confirming the reliability of this method. Third, the above analysis shows that before 2013, the traffic share of the YRD multi-port system was mainly concentrated in SH, and the tendency of concentration became stronger until 2000, after which the transport share gradually shifted from SH to NB and other marginal ports, and after 2013, it entered a “balanced situation”.

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STOCHASTIC REGRESSION MODELS ON THE SAFETY PERCEPTION ON BOARD CRUISE SHIPS

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Abstract:
The paper evaluates the perception of safety by cruise companies on board a ship and its organizational management. The approach on the probability of a negative event incurring on shipping companies, passengers and environment affecting safety and it requires adequate and well-timed procedures on board. The methodology is based on negative binomial regression model on cross sectional data observed in t period based on frequencies of the events. The variables considered are collision, death, gastrointestinal norovirus, mechanical problems, fire, wounded, and general accident as dependent variable. This model reflects the condition that the event happens not infrequently in a certain period of time.

Keywords:
Safety; cruise companies; perception accidents risk, negative binomial models.

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INTRODUCTION
Each year the cruise companies transport on board of their ships millions of passengers. Since 1970 the cruise industry is growing in the holiday market exceeding 27 million passengers estimated at the end of 2020. This strong increase induces the cruise companies to more investments in vessel of 517000 passenger capacity with a relevant economic and environmental impact.

The aim of the paper is the evaluation of safety perception on board cruise ships.

The sad story of the sinking of Costa Concordia, with the shortcomings pointed out by the chain
of command in emergency management, led all owners and institutions to reflect on the problems of the sector and, in particular, the safety of large cruise ships.

Currently companies and major international research centers are studying new methods and technologies to reduce the accidents risk improving safety conditions on board.

The strengthening of the safety conditions in the history of the worldwide navy after the sinking of the Titanic in 1912 with 1,852 deaths, induced to the improvement of the splashdown lifeboats; their equipment must be sufficient in number on both sides of the ship for the evacuation of all passengers and crew. Their fast positioning and stabilization must also be made in difficult conditions of rough sea.

In the sinking of Andrea Doria, in June of 1956, died 56 passengers and in the collision Costa Concordia, in January 2012, died 32 passengers. In these three disasters occurred different conditions of navigation, caused by human error.

Costa Concordia bumped into the rocks of Giglio Island and shortly it begun to founder. Passengers were disoriented and terrorized, there was widespread panic in evacuating the vessel, at the time of the collision it transported 4229 people on board: 3206 passengers and 1023 crew members. Safety exercises on board for 696 passengers boarded in the port of Civitavecchia, on impact moment had not yet been made, Baker, D. (2013).

The paper considers the safety management on board cruise ships in dealing with new technologies, some of which are lifeboats for 300 passengers’ capacity, advanced rafts systems, slides of great dimension.

Among the most advanced safety navigation systems on board ships, there are procedures for remote control of ships by monitoring and routing traceability and detection in real time of routes and technological and environmental engines on board. The availability of information on the nature of accidents on board, provided by the CDCP (2018) and IMO (2012) and companies have enabled us to develop a model of risk perception of cruise ships in case of accidents and evacuation troubles. www.Cruise ship death.com, www.Cruise Junkey. www.Cruise ship accidents (2017).

The risk of accidents can be classified into four macro events of study: collisions, mechanical errors, fire accident, gastrointestinal norovirus.

The methodology focuses on Poisson probability distribution and negative binomial model application. This analysis is based on the frequency of accidents and the likelihood of their occurrence in the short term.

1. SAFETY ON BOARD

The safety of human life at sea is a priority of the institutions required to ensure the navigation. Effectively, in the management on board, the evacuation step in case of accident is an absolute necessity as well as a civil duty. In terms of efficiency and rapidity of the handling of the event there are significant differences in procedures intervention.
The shipping companies have the possibility of monitoring the location of each passenger on board in case of emergency; moreover, the last generation ships have a better control of stability in cases of grounding or collision. There is also the possibility the remote control of the routes even if located thousands of kilometers away from the command bridge. All this evidences the increasing of safety on board. Although the cruise ships have those systems supporting the chain of command, the accidents at sea still happen.

The routing is immediate and highlights the dangers along the way but human error is lurking and the behavioral one is unacceptable.

Errors like Costa Concordia cannot be accepted and therefore we must ensure that these will be no more! In effect it is necessary to invest on the safety management avoiding errors such as helmsman inexperienced not able to properly understand the orders of the officer in charge, or communication of alarm evacuation only bilingual, or slowness in declining the lifeboats, etc.

Although these negative events are well publicized, the number of accidents happened is low in respect to the total cruise passengers transported. The Concordia tragedy reinforced attention on the safety and security operative standards of the cruise ship industry.

Nowadays all companies are able to operate quickly with appropriate instrumentation to ensure the safety of navigation. These are: a detection system of the ship (QPS) by monitoring in real time all emergencies of the case; the monitoring systems (VP & MS) that allow the routes traceability of every ship with a high update frequency of a second refresh rate and a precision of less than five meters.

On the web there are the routing of all types of ships and is it is also possible to see the route followed by Concordia to the point of sinking. The figure 1 shows the phases of Concordia accident, the monitoring routing on board MSC and new life rats.

Figure 1. Safety management.

The modern cruise ships have usually technological equipment as computerized nautical cartography, bathymetry and engines data controlling from a shore department. Moreover, in MSC cruise vessels it is possible monitoring the emergency in real-time fire control system in remote.

So, the management of the safety needs more and more the presence on board of a highly qualified staff that can accompany or even replace the captain in charge of the evacuation
process. Today the seas around the world are navigated about three hundred cruise ships, especially at certain times of the year, creating congestion in traffic especially in access to more scaled ports with serious safety issues during the maneuvers to dock at the cruise terminal.

It goes without saying that the state of alert for safety is high.

2. IMO SAFETY RULES AND MAIN FATALITY CAUSES

The regulatory framework of the International Maritime Organization (IMO 2007) ensures the minimum standards of the safety and security of cruise passengers and the environment within which they operate.

According to the Cruise Lines International Association, the cruise ship demand is increasing on time at a rate of 7% per year, CLIA (2018) nevertheless many efforts on cruise safety the accidents at sea and on board show no sign of decreasing.

The International Convention for Safety of Life at Sea (SOLAS) (IMO 2011), defines the most important of all international treaties concerning the human life safety at sea. The SOLAS Convention was created in London on 17 June 1960.

One of the main safety rules is to have sufficient lifeboats for all passengers and the crew with adequate training in loading and lowering the lifeboats. Under SOLAS, all passengers’ ships must reach rapidly lifeboats location, some of them can be integrated by life rafts and slides. Flag States are responsible for ensuring that ships under their flag respect requirements.


The Safety Management System (SMS) code ensuring the safety of ships as a risk management activity it determines also the appropriated measures for prevention. The risk assessment matrix must be made in each particular case.

The purpose of the codes is to provide a standard framework for risk evaluating, enabling Governments to change threats with less vulnerability for ships improving also facilities port through appropriate safety rules. The safety pass also by clear messages and easy communication among command chain, passengers and safe guard operators. In the figure 2 it is possible to see the main maritime navigation IMO rules.
SOLAS = Safety of life of sea  
ISM    = International Safety Management  
AIS    = Automatic Identification Ship  
LSA    = Life Saving Appliance  
SMS    = Safety Management System  
NSR    = National Safety Regulation  
VDR    = Voyage Data Recording

The data base used in the analysis consists of MSC data and other sources (G.P.Wild 2015, CDPC 2015) and focuses its attention on accidents involving cruise ships operating over world.

The main accidents that represent safety serious problems are gastrointestinal diseases (norovirus), fire, mechanical and technical failures, and collisions.

Considering the data of the total accidents, their number is increasing with an obvious and negative impact on ship companies anyway.
Improvement of all safety procedures, from the moment that the passengers get on board until their permanence is a priority of companies even if the safety must achieve standards of efficiency and efficacy much higher than at present.

Accidents prevention must also be extended to those areas particularly vulnerable as cruise terminal providing efficient gangways loading - unloading passengers operation. In many home ports there is a lot of local attractiveness and so an overcrowded traffic: in one day can dock also a dozen of cruise ships.

In these urban ports, there is a large flow of giant cruises, with grave polluting in terms of visual intrusion and environmental impact.

The checks and inspections of ships during approach to the coast should verify the use of fuels with low sulfur fuels content. But the protection of the landscape and the ecosystem is achieved by banning even risk maneuvers as longitudinal tilt of the ship, with the prow plunges as a greeting (bowing). These operations can lead to the relevant damages to the seabed and to the ship control (Costa Concordia). Among these delicate areas we can include Caribbean, Venice lagoon, Alaska and Arctic to the Antarctic ramifications.

3. THE SAFETY EVACUATION SYSTEM

The evacuation system of a large ship is very complex. The ability to manage the evacuation of thousands of passengers involves a series of steps to achieve life boats and saving rats such as: evaluating time of passenger’s reaction from alarm to abandon the ship, wearing life vests, identification of the path of grouping passengers in presence of obstacles, poor visibility for smoke and fire, declivity of the ship and panic.

Under an analytical point of view, the mass evacuation, in rough sea conditions, is a problem that raises difficulties of study and application of the procedures Lois, P. and Wang, J. and Wall, A. and Ruxton, T. (2004).

The evacuation was a priority within the International Maritime Organization (IMO) since 1999 when the SOLAS imposed the study, analysis, forecasting and management of evacuation programs included in the design phase of new cruise ship.

In this regard, IMO evacuation scenarios address issues related to the layout and the availability of the primary escape routes, at the time of distribution and reaction of the passengers. RINA (Italian Shipping Register) has developed and launched the first notation dedicated to operational aspects with help of the Center for Research of Stability of Ship (CRSS) implementing it on the class Spirit of Carnival Company’s.

The Evacuation Time considers the following elements:

- Time awareness (A): reaction time to the emergency situation that starts after warning alarm and it ends the passengers moving towards a point of meeting. 10 minutes awareness time for night scenario and 5 minutes for daytime
- Travel time (T): time required for the movement of people from where they are at the time of alarm to the assembly stations and then to the boarding area
The IMO rules of safety system provide the total Evacuation Time (ET) of cruise ship is equal 1 hour, as sum of three time above: ET = A + T + L = 1h.

In the case of the Concordia collision the total time of evacuation was 7 hours, a very high time that caused deaths and injuries and must therefore be significantly reduced. Unfortunately, very often there are significant differences between the rules and their practical implementation. The fact remains that the cruise ships are becoming larger and the companies need to invest more to improve the technology of evacuation systems to ensure greater safety for passengers.

The concept of "evacuation" reflects the ability to evacuate a "ship environment" within "interval time" (time to sink/capsize) Vassalos, D. (2009). Specifically, evacuation is a function of a set of initial conditions directly connected and resulting from a scenario of loss and that provide a direct measure of the environment. In fact, there are several advanced tools for simulation of the evacuation of the passengers, some of whom are able to take care of the design and operational issues. Including simulation tools, special mention should be made of that ENV, it is a software used to simulate the movement of pedestrians in any environment H.R. 1485, (111th) (2009). It has been widely used to model the circulation and evacuation of people on board ships, offshore structures and buildings. This simulation tool has several features that make it useful. Including its peculiarities, we find the ability of this software to provide 3D interactive simulation environments, the possibility to interact in real time for the different users that have access to the use of the program and also the evaluation of the impact resulting by critical events like a fire or flooding. See the successive figure 3.

Figure 3. ENV System.

Source: Vassalos 2009

- Life boats launching time (L).
The planning of Marine Evacuation System (MES) includes a series of activities linked to all critical events that ship has to handle. Below is an example of hazard situations that can be part of a MES figure 4.

![Figure 4. MES system.](image)

There are various MES for ship abandon. MES is technical safety tool currently adopted only a few passenger ships but are becoming more employed in the new vessels. They are located at the starboard sides. They are using as a replacement for davit launched of the life rafts as appliances for crew members, while lifeboats are the first life saving for the passengers. But the MES may be used also for passengers.

The MES allows the evacuation of a lot of passengers safely in the minimum time span as required by LSA code. It consists generally of 5 main components:

1. device for emergency launching
2. quick access and practicability of the stowage box
3. facilitate the boarding of passengers on the rafts by means the chute
4. suitable location of the rafts for emergency operations
5. check of the winch in the bowsing operations of the rafts at sea.

The management of safety systems should be organized as:

- security staff h24 located on each bridge to guide passengers in grouping areas towards the escape routes of ships
- away from danger footpath to reach the assigning post of evacuation
- possibility to advise with SMS the passengers
- security staff should ensure the availability of the seat on the rafts and life boats
• disabled passengers should have their own path towards escape routes.

The management in presence of the MES’s should be organized as:

• passengers should be informed about the its use
• allocation of seats during the evacuation phase must be respected
• disabled passengers must avoid to go down the MES chute
• possibility to advise with SMS the passengers
• safety proofs for crew must be done in rough sea and impracticable conditions.

4. NEGATIVE BINOMIAL DISCRETE RANDOM PARAMETERS DISTRIBUTION

The probabilistic analysis of event incurring on board with a significant risk for person and environment has been implemented. The application refers to disruptive events at sea such as fires, collisions, mechanical failure and other risks on board.

In the literature there are evidences as regards collision risk derived from different sources, such as experimental data or similar cases distributions, CMPT (1999), Dale, C. and Anderson, T. (2009).

The probability evaluation should be the base for safety management with strategies to prevent and to mitigate the risks on board, including also the navigation control systems to avoid the collisions.

If it occurs an accident, it is a result of a combination of human error (e.g. poor judgement, inattention, fatigue or workload), mechanical failure, and fire on board.

The method evaluates the risk perception of accidents by negative binomial regression estimate (NBR) and supported by accident review assessments and their frequency. The database consists of data provided from cruise companies. As primary causes of 142 cruise vessel accident on the last years (2012/18) as MSC Cruise, CDCP, Cruise Ship Accidents, Wild GP, subdivided per day, months and types. The variables considered with general accident as dependent variable, are:

- general collision
- accident
- norovirus
- mechanical problems
- fires on board
• wounded
• death.

The estimated probability, of navigation risks, based on empirical frequencies by hazards identification, and cruise leader companies.

The frequency of negative events as collision actually is lower than others in consideration of more efficiency systems of navigation. On the contrary, some others accidents as the mechanical failure with loss of control, norovirus gastrointestinal disease and wounded on board are higher.

The negative binomial application to discrete probability distribution applied to a number of events occurred or notating a sequence of independent and identically distributed (i.i.d.) as Bernoulli, Ahrens, J.H. Ulrich Dieter, U. (1974).

The probability mass function of the negative binomial distribution is:

\[ f(k; r, p) = \sum_{k=0}^{\infty} \binom{n}{k} x^k \alpha^{n-k} = \Pr(X = k) = \binom{k+r-1}{k} p^k (1 - p)^r \text{ for } k = 0, 1, 2 \ldots n \]

where "k" is the number of events occurred, "true" and "false" not occurred. The value in parenthesis is the binomial coefficient, and is equal to:

\[ \binom{k+r-1}{k} = \frac{(x + r - 1)!}{k! (r - 1)!} + \frac{(k + r - 1)(k + r - 2) \ldots r^2}{k!} + \frac{x^3}{3!} + \ldots, \]

This expression can be alternatively written in the following manner, explaining the name "negative binomial":

\[ \binom{k+r-1}{k} = (-1)^k \frac{(-r)(-r-1)(-r-2) \ldots (-r-k)x + r - 1)!}{k!} \]

Note that by the last expression and the binomial series, for every 0<p<1, hence the terms of the probability mass function as:

\[ (1 - p)^{-r} = \sum_{k=0}^{\infty} \binom{-r}{k} (-p)^k = \sum_{k=0}^{\infty} \binom{k+r-1}{k} p^k \]

Under certain conditions, the negative binomial model differing from normal distribution and gamma distribution (Greene W.H. (2004). The variables, in our application, are presented in the standard format, namely by reporting their estimates, their standard errors, T statistics and log likelihoods simulation function. The parameters distribution is synthesized below in figure 5.
5. RESULTS OF SIMULATION MODEL

The results of the calibration of application based on NBR model evidence the good fit of parameters, with coefficients, standard error and T statistics, and Mean of x, reported in figure 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>StE</th>
<th>b/St.Er.</th>
<th>Mean of X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>.709</td>
<td>.111</td>
<td>6.387</td>
<td></td>
</tr>
<tr>
<td>Collision</td>
<td>-.709</td>
<td>.587</td>
<td>-1.207</td>
<td>.023</td>
</tr>
<tr>
<td>Death</td>
<td>.054</td>
<td>.017</td>
<td>3.119</td>
<td>.564</td>
</tr>
<tr>
<td>Norovirus</td>
<td>.387</td>
<td>.137</td>
<td>2.812</td>
<td>.375</td>
</tr>
<tr>
<td>Mechanic</td>
<td>.675</td>
<td>.148</td>
<td>4.561</td>
<td>.195</td>
</tr>
<tr>
<td>Fire</td>
<td>.870</td>
<td>.181</td>
<td>4.801</td>
<td>.075</td>
</tr>
<tr>
<td>Wounded</td>
<td>.950</td>
<td>.003</td>
<td>.030</td>
<td>1.706</td>
</tr>
</tbody>
</table>

Source: our elaboration

The results of negative binomial regression model of variables distribution evidence for collision and fire a low value of T. The application reports a simulation log-likelihood -199.8.

The output reports for collision a low value of T statistics with the mean of x at lowest perception collision risk, but it is not a concern in terms of safety for shipping companies. This result does not reflect the gravity of the event since the collision is always a terrible and disastrous circumstance even if it happens rarely. The value of mean of x relating to the wounded variable appears very significant and it is a source of concern for shipping company.

The mean X for application evidences and reflects as a modest part of population (companies) is worry for the collision and fire on board, but this is implausible because they can induce a company to stop the cruise with evident economic and image damage for companies.

Major worries the companies have about norovirus, death and mechanical breakdown.

On the contrary, the wounded trouble is much perceived.

We believe that the companies are very sensitive to business and to all the economic and financial aspects that cruises create by satisfying the needs and desires of travellers, perhaps underestimating the dangers in which passengers on board the ship could directly incur during navigation and excursions to land. However, travellers’ risk perception of safety on board is undervalued, and so they may not confirm their loyalty to a specific cruise company.
Nowadays the cruise passenger, even habitual, not only pays attention to entertainment and good food, but he also considers potential dangers aboard and possible damage to the environment because he has become much more sensitive than in the past towards personal safety and the external environment.

6. CONCLUSIONS

The NBR model can be considered as experimental applications of cumulative probability distribution of the accidents. The application has been synthesized by a schematisation of the outcomes deriving from the simulations of the main phases of improvement the safety procedures on board a cruise ship.

Cruise companies must consider their perception risk of accidents without ever neglecting that millions of passengers because they are the first users of the cruise services, in this way will be possible to encourage the prevention of future accidents on modern cruise ships. The results of application model inform how the shipping companies and the passengers perceive the safety on board and the more significant variables which effect on the risk. Some of these, as collision probability perception, are statistically irrelevant with a lowest perception risk for the companies and the passengers but it can be due to the rare event.

As regards evacuation system, cruise companies operate in accordance with the strict requirements of the international maritime treaty under Safety of Life at Sea (SOLAS) Code, of International Maritime Organization (IMO). It may be insufficient because the management of the evacuation processes is the priority is the safety passengers and the companies must be equipped with sufficient lifeboats and life rafts, modern MES equipment with last generation slides to guarantee higher speed board evacuation.

Crews should undertake refresher trainings, certification and regular drills for emergency situations, including those more frequent and extensive ship evacuation. Safety must be improved and the new ships must consider the experience resulting from recent disasters. Pay attention also to the mechanical problems, fire on board and norovirus with adequate and severe rules of hygienic procedure to prevent epidemics on ship.

Further considerations can be done about safety ship management in presence of risk at sea and on board.

The environment safety in which a cruise ship operates is very complex and difficult to manage such as the control of great vessels and quantity passengers transported. The modern cruise ships must adopt advanced MES systems on board.

Accidents onboard can affect adversely on passenger’s satisfaction and public image about cruising but the considerations and solutions should not penalize or inflate the holiday. Even if the future of the cruise industry looks bright, the cruise companies have the duty to invest in safety by providing ships higher standards to ensure the protection of human life on the sea and the environment. It is clear that cruise passenger’s safety will depend on International Conventions, the design, layout and size of the ship, country of registry, crew training.

The results of this study reveal that the cruise supply chain is linked to safety but this aspect is not negatively affecting the entire cruise industry because the cruise represents always a
complete and fascinating holiday model in all seasons of the year.

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THE ROLE OF THE MALACCA STRAIT IN THE ONE BELT, ONE ROAD INITIATIVE

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Abstract:

The Strait of Malacca is a commercial step of utmost importance, where 60% of international maritime trade passes; it is crucial for global commerce but its geographic position makes it a dangerous chokepoint. In 2013 China unveiled its project of the One Belt, One Road Initiative (OBOR). This project is in part aimed to consolidate the Chinese strategic position in Southeast Asia, promoting alternative routes to secure the traffic of energy resources while reducing the Chinese dependence on the Strait of Malacca.

The main objective of this paper is to examine the geopolitical and economic impact of the OBOR Initiative in South East Asian Nation economies through an appraisal of the traffic in the Malacca Strait as well as highlight and justify why the One Belt, One Road Initiative is so crucial for the region. Even when China is actively seeking to reduce its dependence on the Strait, the calculations carried on this study show the Malacca Strait as the best route compared to its feasible alternatives.

Keywords:

Malacca Strait; chokepoint; energy security; alternative routes.

INTRODUCTION

Nowadays, over 90 percent of the world’s trade is carried by sea. Maritime industry is an important economic sector as it has a direct impact on the prosperity of a region, providing a source of income and employment for many developing countries.

The Southeast Asian region has played an important role in the development of global maritime economy and, at the same time, the sea has also played a pivotal role in the Southeast Asia’s economic and political development. Since the early days, the strategic position of Southeast Asia region favoured the boosting of its maritime trade as it is home to several international shipping lanes that straddle the territorial waters of numerous States.

The Malacca Straits was then already a critical trade route linking the Indian Ocean to the South China Sea and Pacific Ocean. Now, it is a commercial step of great importance and one of the main oil transportation routes. Among all the strategic routes that offer
entry into the South China Sea, the Strait of Malacca is by far the most widely used. It is the shortest and therefore most economical passageway between the Pacific and Indian Oceans. The high concentration of commercial goods flowing through it has raised concerns about its vulnerability as a strategic chokepoint.

Nowadays China accounts the 19% of global economic activity. Its economy is now so large that it pretty much determines the global price of a huge range of products. Even though its economy has been showing a slowdown after three decades of rapid growth, deepened by its trade war with U.S., its energy needs are expected to increase exponentially in the coming decades. Since more than 80% of the crude oil and almost 30% of the natural gas imports of China come through the Malacca Straits, that leaves China in a vulnerable position and with the need to decrease its dependency on the region and its littoral for supplying their energy needs.

In order to overcome this weakness, in 2013 Chinese President Xi Jinping unveiled plans for two massive infrastructure networks connecting East Asia with Europe: the “One Belt, One Road” (OBOR) Initiative, which comprises the Maritime Silk Road (MSR) and the Silk Road Economic Belt (SREB). The project is a system of roads, power grids, ports and other infrastructural projects destined to create a more connected trade and a commercial zone between the countries in East Asia, Southeast Asia and Africa. The 21 Century Maritime Silk Road is not the first maritime initiative that China has undertaken to consolidate its strategic position in the geopolitics of the Indian Ocean Region (IOR). Projects such as is China's trans-Myanmar oil and gas pipelines, the Pakistan-China Economic Corridor or the proposals to develop two land-bridges - including an oil pipeline and a railway - linking ports on the west and east coasts of the Malay Peninsula are aimed to bypass the Malacca Straits.

Despite the uncertain global political and economic environment, the ASEAN states and China have become, in the last decades, key partners regarding trade, investment, and infrastructure development. The prevalence of the Belt and Road Initiative as the only existing major integration initiative with a global framework, have increased the willingness of the countries and regions to cooperate in its economic alliance.

Recently, coverage of the OBOR Initiative in papers and mass media has been steadily expanding. To date, aside from providing background information, literature has largely examined the opportunities and the economic and political significance of China’s plans. However, many analyses are policy prescriptions and the facts exposed are distorted or biased by the public’s opinion of China and the motivations behind their initiative rather than showing the facts objectively. The truth is that China's OBOR Initiative is not fully understood from the international perspective, and it is not comprehensive enough to predict future development.

To address this subject objectively this paper focuses on the Strait of Malacca to make an early assessment of the impact of the OBOR Initiative on it. Despite considering the geopolitics, the foreign policy or the economic relationship between the states involved as important, this paper follows an analytical approach examining the traffic volume, the tendency of growth and other variables capable to give a more objective image of the effects of this project on the region. Furthermore, this paper wants to highlight and justify why the OBOR Initiative is so crucial for the region assessing the other feasible alternatives available at this moment, trying to judge its adequacy as well as its capacity to be enough in the future in conjunction with the Malacca Strait.
In order to do so, this paper contemplates, first, the data obtained with the STRAITREP and provided by the Marine Department of Malaysia, to study the growth tendency of the Malacca Strait in order to try to predict the risk of congestion on the Strait. After that, the estimated cost of rerouting the traffic from the Strait to the other two alternatives is calculated. Finally, through the Liner Shipping Connectivity Index, the impact of the OBOR Initiative in the ASEAN region is overviewed. The paper concludes with some remarks about the relevance of this project for the Strait of Malacca and ends outlining future lines of work to further the investigation.

1. METHODOLOGY

First, an assessment of the actual situation of the Malacca Strait was made by reviewing the number and type of vessel reporting to Klang VTS in 2018, which resulted in the following figure (Figure 1). With that information, its tendency of growth was studied.

![Figure 1. Type of vessel reporting Klang VTS in 2018.](image)

Also, to highlight the importance of the OBOR Initiative for the Malacca Strait an analysis of a case scenario was presented. Literature shows the Straits of Sunda and Lombok as feasible alternatives to the chokepoint\textsuperscript{14}. One of the objectives of this study was to check weather these two other routes where a feasible alternative by calculating the estimated cost of rerouting the traffic from the Strait of Malacca to them; the assessment of the real costs in the scenarios proposed are the same as the models established in literature by different authors such as Cullinane and Khanna (2000)\textsuperscript{15}, Stopford (2008)\textsuperscript{16} or Gkonis and Psaraftis (2010)\textsuperscript{17}.

In order to do so, a hypothetical Liner Company which sees one of its service schedules affected by the closure was proposed. In the assessment of the cost assumed by the Liner Company, six components of liner service costs were identified: service schedule, ship costs, port charges, container operations, container costs, and administration.

Regarding service schedule, it concerns the service frequency, the number of port calls and the distance, as well as the required number of ships in weekly string. The ship cost is usually expressed in terms of unit slot cost. Operating, capital and fuel costs are important elements, since fuel consumptions is a particularly important variable. Port charges are beyond the control of the ship-owner and vary around the world. Container
operations costs depend on the mix of container types, container turnaround time and empty containers that must be repositioned. Container costs include daily cost, maintenance, repair, and handling, among others. Administrations costs are related to management, logistics, financial, and commercial aspects of the business.

The object of study was a Container ship of 4,300 TEU as container vessels were the largest users of the strait in 2018. For cost calculation purposes, a characteristic ship was obtained from averaging data of some vessel with similar particulars and schedules and some assumptions were made. For instance:

1. In the calculations it was assumed that a year has 360 days.
2. The Bunker price was selected on 24th of May 2019 in Singapore (Shipandbunker.com) reaching for IFO380 the 413,5 $/ton.
3. It was assumed a 20% of inter-zone repositioning as an estimation of what industry demands nowadays.
4. It was assumed a 20% as the estimated amount the ship-owner would carry out the inland intermodal transport.
5. It was considered a 10% of cargo claims.
6. For administration cost, only were considered the employee costs, depreciating the other costs.

Due to that the major part of the costs remained constant, the time taken on the voyage and the distance travelled on that voyage were the two causal factors which had a strong effect on costs when considering a detour.

It is important to remark that for the sake of the comparison the total number of voyages per annum remained constant, even when a greater distance means more sailing time and consequently less voyage per year. It was assumed in that way to show what would suppose in terms of costs for the ship-owner to maintain the same conditions of service.

As this study also pretended to offer an early assessment of the impact of the OBOR Initiative in the ASEAN region, the Liner Shipping Connectivity Index for the different countries conforming it was studied and compared with the first top ranking countries, for instance, China and Singapore.

2. RESULTS

In the last four years, daily transit reports to Klang VTS increased from 222 vessels per day in 2015 to 233 vessels per day in 2018. This equates to nearly 10 vessels entering or leaving the straits every hour, or one vessel every six minutes.

In 2018, container vessels accounted for 30,8% (Figure 1) and remained the largest users of the strait despite rapid growth in the size of containers on the trade with lines.

Overall tanker traffic, including VLCCs, saw 28127 transits in 2018, an increase of 787 compared to 27340 transits in 2017, showing a continuous growth. Tankers alone accounted the second, with a 24,4% of the traffic. Bulk Carrier traffic in the strait saw a steady growth too reflecting East Asia’s import of raw materials such as iron, ore, and coal. On the other hand, LNG and LPG vessel traffic saw a small increase in transits too, showing a slow but constant growth.
As figure 2 shows, the Malacca Straits follows a tendency of continued growth, hitting an all-time high of 85030 transits in 2018. However, from 2012 to 2018 the average growth rate was of 2.67%; so, even when the tendency continuous being upwards, there has been a deceleration in the increase of the shipping traffic (figure 3).

![Figure 2. Tendency of the traffic in the Straits from 2011 to 2018.](image)

![Figure 3. Growth Rate of shipping traffic from 2012 to 2018.](image)

On the other hand, based on the difference in time between the minimum distance route, the one through the Strait of Malacca, and the other two feasible alternatives, Figure 4 shows the different costs due to the additional sailing time, the total cost (in Dollars and Euros) and the associated percentages.

![Figure 4. Costs assumed for the different scenarios.](image)

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<th>SUNDA</th>
<th>LOMBOK</th>
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<td>Additional fuel costs ($)</td>
<td>$7,827,430,39</td>
<td>$13,942,769,83</td>
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<tr>
<td>Additional container &amp; container handling costs ($)</td>
<td>$9,406,533,34</td>
<td>$16,925,576,03</td>
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<tr>
<td><strong>Total additional costs ($)</strong></td>
<td><strong>$17,230,485,81</strong></td>
<td><strong>$30,864,867,94</strong></td>
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Finally, regarding the Liner Shipping Connectivity Indexes for each ASEAN state member, the tendency is positive (figure 5). All the state members have observed a steady increase during the last decade, even though the crisis of 2008. Using China and Singapore, the two first top countries of the rank in 2018, as reference, it is clear that even when the ASEAN states are yet far from reach their same level, the tendency is clear upward. Furthermore, since 2013, the year when the Belt and Road Initiative was announced, it shows a further growth, following the path of China.

![Figure 5. China & ASEAN Liner Shipping Connectivity Index Comparison](image)

### 3. DISCUSSION

In 2006 the Maritime Institute of Malaysia (MIMA) conducted a study to enhance the safety of navigation in the Straits of Malacca. The basis of that study was determining the Carrying capacity of the Straits to make an appraisal for Risk Governance, resulting in 122640 vessels per year. MIMA forecasted this number of vessels for 2024, as well the World Bank predicted a similar number in 2025, while the Japan International Transport Institute projected 140000 vessels in 2020. These results implicate that congestion will start when the number of ships reach the Carrying Capacity of 122640 annually.

However, it must be considered that at the moment of the study, from 2000 to 2006, the growth rate of the Straits was about 6% per year. Nowadays, the figures have changed drastically. Even when the Malacca Strait has been following a tendency of continued growth, hitting an all-time high of 85030 transits in 2018, comparing this decade with the last one, growth rate shows a deceleration in the increase of shipping traffic.

It could be considered that both, the declining growth rate and the decrease in the accidents in the Straits, are consequence of the measures taken by the authorities to ensure the safety of navigation. However, a double reading can be derived from the data when considering the impact of the Belt and Road Initiative. The joint pursuit of the Belt and Road Initiative (BRI) aims to enhance connectivity and practical cooperation, and it has
put in place a general connectivity framework. The improved interconnectivity has had an impact on the Malacca Strait, as it was intended, and that is being shown in the constant deceleration in the increase of shipping traffic.

That affirmation is also corroborated by the comparison of the Liner Shipping Connectivity Indexes (LSCI) for each ASEAN state member (Figure 4). As the LSCI shows, all the ASEAN states members have observed a steady increase during the last decade, even though the crisis of 2008. ASEAN region is improving accessibility to the global trade, despite being yet far from reach the same level as China and the tendency is clearly upwards for the years to come.

On the other hand, even when the Sunda and Lombok Strait are physical viable alternatives, the extra cost of detour makes them inadequate as a long-term solution as it supposes an increase of distance as well as fuel consumption; calculations made show that for a Liner Shipping Company with a line service in the Southeast Asian Region, the added costs of rerouting would increase from a 10%, in the Sunda Strait, to a 17%, in Lombok Strait. The delays as well as the cost that ship-owners would need to assume surely could have far-ranging economic consequences for the global marketplace.

4. CONCLUSIONS

There is not yet a satisfying solution to the Malacca dilemma, and it seems that this situation would not change in the near future. However, China has not stopped here and is looking to ensure a more viable long-term energy security policy.

Climate change, in particular the melting ice, has opened new sea routes through the North Pole. The Arctic awakens commercial interests in many large companies and coastal and non-coastal states, given their natural resources and the savings they entail in the transport of goods between continents. China has also expressed interest in Arctic shipping routes along the Northern Sea Route and through the Northwest Passage. The shortest route from China to Rotterdam for example, is by using the Northern Sea Route, which can save up to 13 days. This translates into cost savings due to transport efficiency and considerable fuel savings. But other aspects as safety, security or legal requirements for ships sailing in those waters are not assessed.

The Arctic route reduces the risk of oil disruption for China, Japan and South Korea. The capacity to ship oil and gas from ports along the Northern Sea Route also reduces the need to build costly pipelines across the tundra for land-based energy transport. The fact that rivers in Russian Siberia flow north to the Arctic Ocean also allows these waterways to be used to ship oil and other resources to coastal ports. Using the Northern Sea Route that connects Northern Europe with China, Taiwan, South Korea and Japan will suppose a 40% reduction in sailing distance, and a 20% cut in fuel, compared with the Suez Canal route via the Middle East.

Even though analysts say that the transit will be increasingly easy to navigate for bulk carriers, even during winter months when ice levels are highest, navigating these routes will always involve a series of limitations and risks. The draft due to the shallowness in some navigation areas, the fact that they are only navigable for 3-5 months of the year, the lack of infrastructure and rescue, due to the long distances to supply and lack of investments, and communication problems due to high latitudes difficult the navigation.
A further route, still under discussion, is the proposal to build a canal across the Isthmus of Kra in southern Thailand. The canal would allow shortening maritime traffic by approximately 1,000 nautical miles. Although the channel project has not been officially part of the Belt and Road initiative and there has been political resistance, there have been unconfirmed talks between commercial parties in China and their counterparts in Thailand.

No one knows exactly how much oil and gas will go through the alternative routes and how much time will they take their final destinations. Other question marks include insurance charges and storage facilities. It would remain to be seen if the relative economic costs, even when the physical distance is reduced, would be competitive compared with the Malacca Straits. The accurate determination of the economic benefit considering these other alternatives is considered as future works.

The China-proposed and funded Belt and Road projects will undoubtedly alter the traditional trading routes in the region. However, just as in ancient times, the Malacca Straits will continue to remain a key focus for China in the near future.

Notes and References:


SESSION 2. AUTONOMOUS VESSELS
RISK MANAGEMENT, MARINE INSURANCE AND CHARTERPARTIES – FORMULATING THE RESEARCH NEEDS FOR AUTONOMOUS VESSELS IN MARITIME UNIVERSITIES

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Abstract:
The article describes work in Finland in forming international research group/network on activities relating to autonomous and remotely operated vessels, which concentrates in tackling marine business related obstacles and solutions especially for risk management, marine insurance and charter parties legal issues. Comparative approach to these issues connects national and international experts to network and future research alliance in MET. The purpose of the activities is to create a network of experts which will seek funding for future work to enhance Nordic model of risk management for autonomous vessels. The Nordic Marine insurance Plan already has a relevant market share in marine insurance worldwide, but the specific research area is promoting applications for research activities which lead to the Nordic solution to be the market leader in marine insurance for autonomous and remotely operated vessels worldwide. The article describes the benefits of this approach in relation to other jurisdictions. This approach will also concentrate on facilitating the maritime transport by renewing the charter party clauses for the benefit of those operators who use the Nordic Marine insurance plan for the basis of their risk management strategy and possibilities to use cost effective Nordic Offshore and Maritime arbitration (NOMA). The article is part of promoting research activities in forming research alliance and networking of experts internationally for international maritime transportation.

Keywords:
autonomous and remotely operated vessel, marine insurance, charterparties, risk management, research in MET.

INTRODUCTION
Nordic countries are leading the technological development of autonomous shipping and they are in forefront of the testing of the commercial solutions. The technology itself is mainly based on existing solutions with new applications for the maritime industry. However these solutions will have a huge impact on maritime industry in future. How this future is formed in different parts of the world depends much on the economical pressure to gain benefits of replacing crew both partly by transferring crew work to technological solution step by step and in some cases
creating vessels which are fully autonomous. For example countries with sheltered waters, like Norway with its fjords and high salary cost have much to gain. Finland with its large archipelago also can benefit fully autonomous vessels to cut cost. Another example in Europe with large archipelago is Croatia. Japan is a good example of a country with ambitious strategy for autonomous vessels due to lack of seafarers and it’s policy not import foreign seafarers – They need to invest in technology first to support the crew and then by 2030 to build fully autonomous vessels as the ageing Masters will finally retire.

This article describes work in Finland in forming international research group/network on activities relating to autonomous and remotely operated vessels, which concentrates in tackling marine business related obstacles and solutions especially for risk management, marine insurance and charter parties legal issues. Comparative approach to these issues connects national and international experts to network and future research alliance in MET. The purpose of the activities is to create a network of experts which will seek funding for future work to enhance Nordic model of risk management for autonomous vessels. The Nordic Marine insurance Plan already has a relevant market share in marine insurance worldwide, but the specific research area is promoting applications for research activities which lead to the Nordic solution to be the market leader in marine insurance for autonomous and remotely operated vessels worldwide.

1. DEVELOPMENT OF AUTONOMOUS SHIPPING

The technological development of autonomous shipping in Nordic countries has been fast during the last decade and especially Finland and Norway are in forefront of the testing of the commercial solutions. The projects of fully autonomous ferries have already been introduced in Finland and a commercial cargo vessel will start operating in Norway 2022. Japan invest heavily in replacing crew with already existing technical solutions to minimize crew and to replace the crew entirely in next decade in most new-buildings that carry cargo.

The global regulatory body for shipping - the International Maritime Organization’s (IMO’s) senior technical body, the Maritime Safety Committee (MSC) has agreed a framework for a regulatory scoping exercises, “Maritime Autonomous Surface Ship (MASS)” to find the solutions how to implement autonomous shipping in IMO instruments. MASS defines a ship which “to a varying degree, can operate independently of human interaction”. The categories of autonomy in this regulatory exercise are defined as follows:

- Automated processes are used on ship and decision making is supported. Systems and functions are controlled onboard by the ship crews which are sailing with the ship. There are certain operations on the vessel which may be automated.
- Ship is sailing with seafarers onboard, but the vessel is controlled remotely and operated distant from another location.
- Ship is operating without the crew onboard and remotely controlled and operated from another location.
- Ship is operating fully autonomously with the help of operating system which makes decisions and actions by itself.
The scoping exercise which is currently ongoing identifies current provisions in a list of IMO instruments, (SOLAS, COLREG, Load Lines, STCW, STCW-F, SAR, Tonnage Convention and special trade passenger ship) and determines how they may or may not be feasible to vessels with various levels of autonomy and of they may prevent MASS operations. The IMO legal Committee is finalizing its own scoping exercise on the Conventions under its auspices in its next meeting when the Covid-19 is over. The author nr.1 of this article has been nominated to participate that Legal Committee meeting as a legal expert of the Finnish delegation.

2. RESEARCH NEEDS AND RAAS

Research Alliance for Autonomous Systems (RAAS) has been put up to achieve innovation platform that would be internationally known network for industry, research institutions and educational institutes.

The basic idea according to RAAS internalisation plan is to link RAAS internationalisation activities together with national interests, ecosystems, platforms, testbeds etc. regarding autonomous systems development in selected application domains (drones, mobile work machines, autonomous driving and maritime). For each application domain, the aim is to find 1 - 3 main autonomous innovation ecosystems/entities, where the need and driving force for systemic innovative solution stems from the global market change, which represents a great business opportunity for several Finnish companies. In some cases, a remarkable opportunity to find pathways to make Finnish society more efficient are also created at the same time.

RAAS internationalization activities are linked to boost these innovation ecosystems/entities to build their success story in international markets. RAAS group has been formed to help the parties to find the best international scientific experts, the most skilful company partners, start-ups with the greatest novel ideas and the most innovation-friendly public authorities to get the job done. At the same time, through the preferred Public-Private-People-Partnership (4P) approach, the goal is to greatly improve RAAS community’s own scientific excellence and ability to serve the stakeholder groups.

RAAS participants have identified several this kind of innovation ecosystems/entities to be used as target innovation efforts for RAAS internationalization planning. None of these entities is ready-made concept to be publicly announced and described in detail, but in several cases some activities are already under way and plans for taking activities into world-class level are under preparation. This is why the innovation ecosystems/entities are described only at general level.

RAAS’s internationalization involves building of international joint projects and arranging expert/researcher exchange etc. traditional activities. From strategic point of view, the options are (suitable strategy selected for each ecosystem/entity):

1. Building multinational autonomous system innovation hub/testbed/platform, which effectively is a network of interconnected national innovation hubs sharing common target. Linking heavily research projects and partners to this hub. (Multinational Hub strategy)

2. Building innovation hubs/testbeds/platforms with Finnish International Growth Ecosystems. Boosting Invest-In activities (foreign companies investing on development (and production) activities in Finland because of attractive innovation environment) in
autonomous system development around these hubs. Linking research projects and partners to these hubs. (Invest-In strategy)

3. Actively networking with and exploiting appropriate existing foreign autonomous systems hubs/testbeds/platforms. Linking research projects and partners to these hubs. (International Hub strategy).iii (RAAS internalisation Plan)

One of the selected innovation ecosystems/entities in RAAS Maritime: Baltic Sea area as a pioneering area in autonomous shipping and multimodal logistics. This is called “The Sea of Opportunities.” Finland and some other European countries deliver a significant amount of high-technology products to the global marine market. The recent megatrend of increasing ships’ autonomy levels and decreasing their emissions is a historical opportunity for the Finnish industry to secure a strategic position in maritime business – regardless of the country of manufacture for future ships. Technologies related to autonomous and carbon-free ships are scalable like any other areas of digitalisation. This highlights the ability to rapidly expand the target market for finnish industry.

These opportunities can be fully utilised through collaborative effort that combine companies’ business interests and research organizations’ expertise to national and European sustainable growth strategies. This will require long-term collaboration and commitment of private and public sector actors across national borders.

Developing and taking into use technologies for autonomous and carbon-free shipping for maritime industry and research require real-life test environments. These should include: (1) closed test areas in the national waters, (2) maritime routes between two or more countries, (3) harbours that connect the maritime and land logistics and (4) land-based remote control centers.iv As part of the legal task force Satakunta University of Applied Sciences (SAMK) is leading co-operation between Nordic and European Maritime educational institutions in promoting common syllabus development relating to autonomous shipping in Bachelor level STCW Convention based education. The specific targets groups/companions are SIMAC (Danish Maritime Academy with test areas in Denmark) and University of Split in Croatia. Both Institutions have existing research and education in this field and have already shown interest for this co-operation. University of Split has interests to co-operate with Finland specially in relation to developing automated traffic in the Croatian archipelago.

Main areas in RAAS Legal task force by SAMK is to form research group/network on legal activities relating to autonomous vessels which concentrates in tackling business related obstacles and solutions especially for risk management, marine insurance and charter parties legal issues. Comparative law approach to these issues connects national and international experts to network and future research alliance. At the starting point where the projects is at the moment SAMK participants are participating, presenting and publishing articles (legal) and promoting RAAS in international conferences while forming the alliance and networking internationally. In order to be attractive concentration for development of autonomous maritime systems for international we need to employ high skilled specialist from the research organizations and the industry to the future projects.
The idea of RAAS is also to build national education network for maritime industry and to combine research activities strongly to the education devilment. A part of the activities is Doctoral school which offers a possiblity for graduating Master students to continue to doctoral studies in the network in Aalto University´s doctoral School that has already been established. Main focus however is to serve the maritime industry players through the expert network and to find solutions that enhance the development of autonomous shipping and to tackle the legal barriers for the industry in this development together with the partners and to offer Nordic model as the solution of the problems the industry is facing. In the following chapters we will present some basic features of problems of the industry relating to autonomous vessels and why the Nordic solution is used as a starting point to solve these problems.

3. NORDIC MARINE INSURANCE PLAN

Norwegian/Nordic Marine Insurance Plan (NMIP) has been commercial success in international insurance market since 1996 when the rules were revised broadly. Until 2013 the Plan Rules were known as Norwegian Marine Insurance Plan 1996. The Rules became “Nordic” 2013 when they had been further revised and they had become broadly used in Nordic countries and a consensus was reached in Nordic insurance market that their name would be Nordic Marine Insurance Plan.\(^v\)

The Nordic Marine Insurance Plan had practically replaced the national Hull clauses, especially in Sweden and Finland, used before in other Nordic countries as they had been used less and less when Norwegian plan had gained most of their market shares.\(^vi\) In this article the Rules are referred as Nordic Marine Insurance Plan (later NMIP) even though they have existed as “Nordic” only since 2013.

The Nordic Marine Insurance Plan as all risk cover has gained remarkable market share internationally also outside Nordic countries. It has been estimated in August 2019 that the NMIP-conditions market share is approximately 21 percent worldwide. It gives effective protection and is found to be assured friendly on both “full terms”-insurance cover and limited cover. NMIP is also especially popular on Loss of Hire -insurance market\(^vii\). Nordic plan has become more and more popular as a basis for cover since the conditions of cover are quite straightforward and fair for the owners who play fair and maintain their vessels well. Nordic marine Insurance Plan has several benefits and competitive advantages. It is stable when it has been formed on the basis of Norwegian Marine Insurance Plan, which has a legislative history that goes back more than 100 years and case law collected in one single collection from Scandinavian Maritime courts and Arbitration Tribunals. The Nordic Marine insurance is based on the all risks -principle with exceptions listed, which will not be covered. The most important is war risk, which can also be separately covered by taking out a separate war risk insurance under the Nordic Marine Insurance Plan. If the person effecting the insurance has also obtained
such cover, there will be relatively few caps in the shipowner insurances insofar as the perils are concerned.

In principle the Nordic Marine Insurance Plan seems to suit well for remote controlled vessels and autonomous shipping. It is clear, however, that the rules need adjustment at least regarding the Commentary of the conditions to explain clearly the rules and exceptions when applied to remote controlled or autonomous vessels. It is possible, in principle, for the person effecting the insurance and for the insurer to assess the Hull insurance risks in general with the NMIP clauses. The Nordic Plan has detailed rules on causation and duty of disclosure as well as highly developed system of safety regulations, unlike the English system.

The English law on marine insurance is heavily based on case law, such as the Marine Insurance Act 1906 is made on basis of existing case law. The difficulty with remote controlled and autonomous vessels is clear. The existing clauses with named perils were not made with the kind of problems in mind that can arise with such vessels. It is unclear how they would suit the purpose without major changes or additions. A specifically problematic area of English marine insurance law is the warranties and especially warranty of seaworthiness, which will be especially problematic area of law connected to autonomous or remote-controlled vessels. Adjusting existing case law to suit the needs and risks associated with autonomous and remote controlled vessels will be a difficult assignment and it will take some time before the interpretations of courts will be available.

The Nordic Marine Insurance Plan has a rule that in order to be covered by the Hull insurance (as well as other shipowner’s insurances under the Plan) the assured needs to follow the safety regulations. The system of safety regulations as described in NMIP does not exist in English legal system. In NMIP The assured can risk losing his cover in connection with the breach of safety regulations but since 2007 there is no longer requirement of vessel being seaworthy.

Safety regulations have been described in the clause 3-22 of NMIP. A safety regulation is a rule concerning measures for the prevention of loss issued by public authorities, stipulated in the insurance conditions, prescribed by the insurer pursuant to the insurance contract or issued by the classification society. The safety regulation is a flexible requirement as in order for a rule to have the status as of a safety regulation, it only needs to include the purpose to prevent loss, but it does not require that the sole purpose of the regulation is to prevent loss. If the rule has several purposes it is enough that one of the purposes is to mitigate the effect of loss or prevent loss. In relation to autonomous and remote controlled vessels, it is expected that the class rules in the beginning will form an important source of safety regulations and classification societies simulation standards for software will also be crucial for the industry’s risk assessment. Therefore these will be important sources of safety regulations for autonomous and remote controlled vessels.

The insurer has a right to inspect the ship when he suspects that safety regulations have not been met. Breach of safety regulation can lead to the insurer not being liable for the casualty
if there is a causal connection between the breach of the safety regulation and the casualty and the breach has been culpable.

Before 2007 NMIP contained a separate clause on unseaworthiness. This clause has been abolished as the rules on safety regulations and unseaworthiness more or less covered the same issues and the Norwegian Seaworthiness Act had also been abolished. This abolishment of unseaworthiness rule from the NMIP was already considered when the plan was modified largely in 1996. This development gives a clear benefit for the owners who have good maintenance systems and who follow the safety regulations strictly, as in relation to the insurer there are no grey areas where the insurer, despite the fact that the safety regulations have been followed, can no longer claim the ship being unseaworthy. In future, relating to remote controlled and autonomous vessels this can give a clear benefit for the NMIP clauses in relation to the other markets where unseaworthiness in relation to these vessels needs to be determined by courts as there is no existing case law for autonomous vessels in the field.

The safety regulation in this respect is a Nordic solution. As the safety regulations can be described widely, this gives also flexibility for the insurers to meet the demands of the industry in insuring the vessels with different levels of autonomy. The risk management with safety regulation approach will be much easier considering 4-6 different levels of autonomy in shipping in future. IMO has started its work by using four different categories. It is a demanding task for the industry to create this regulation, but as it will at the same time create the basis for risk evaluation for the insurance industry as safety regulations to be followed, it will give a clear benefit for “the Nordic approach” in relation to the English marine insurance system.

The NMIP rules are easier to be adjusted to autonomous and remote controlled shipping than the common law rules of law. It can therefore be expected that the NMIP and NOMA will be lucrative solution for those shipowners who enter the autonomous and remote controlled shipping market in 2020’s. Several reasons for this development can already be highlighted. The response for insuring autonomous or remotely controlled vessels will be immediate in the industries and maritime clusters which are in forefront of the development. These are at the moment the Nordic countries like Finland and Norway where technology is already highly developed and experiments and prototypes are already being tested. Nordic Marine insurers are expected to have commercial insurance documents based on NMIP conditions in place when the first commercial vessels will be operating in beginning of 2020’s.

Nordic Marine Insurance Plan is already well known to international markets. English market -According to statistics - already offers 30 % of its marine insurances with NMIP when ITCH conditions share in its own market is 56 %. The Market share of NMIP conditions in London has been growing steadily. As the NMIP conditions have a relevant market share also in Far East Asia (15 %) and North America (10 %) it is highly probable that their share of the market will grow when the autonomous and remotely operated solutions will increase also in these markets.
When referring to cost of arbitration in London arbitration and comparing it to ad hoc arbitration cost in Norway during this millennium, it is easy to predict that the vessel owners or operators of future autonomous or remote controlled vessels will look to both cost of arbitration and expertise in the field of this changing field of shipping when they decide where the insurance arbitrations will take place. As the NMIP conditions can be expected to be ready for the market when more autonomy will take place in shipping, it is probable that these conditions of cover will be increasingly used and trusted by the industry together with Nordic jurisdiction.xiv

4. NORDIC OFFSHORE AND MARITIME ARBITRATION

Effective, highly skilled and especially cost effective ad hoc arbitration in Norway has also been one of the benefits of NMIP. As a tool with updated Commentary, it is also possible for foreign arbitrators to understand it. Mainly arbitrated in Norway it has offered cost effective and smooth ad hoc arbitration near the main financial markets in Europe.

Nordic Offshore and Maritime Arbitration (NOMA) was founded in November 2017 by the initiative of Nordic countries maritime law associations. It can be seen as part of continuous development started by creation of Nordic Marine Insurance Plan and creation of strong common judicial market for Marine and offshore industry. The Nordic countries have long traditions for settling disputes within the maritime- and offshore industry by arbitration. Traditionally, ad hoc arbitration has been dominant in the Nordics, particularly in Norway and Denmark, while Sweden and Finland have stronger traditions for institutional arbitration.

NOMA will unify this Nordic arbitration market in following years and form a strong alternative to London market.

The NOMA arbitration rules were incorporated to NMIP rules 2019. The NOMA associations arbitration clause has also already been used in offshore/chartering contracts. In combination NMIP conditions and NOMA Rules they give the assured a client friendly insurance and cost-effective arbitration in Nordic countries in jurisdiction preferred by clients and chosen language. The NOMA rules have raised interest and attracted potential users also outside Nordic countries as Nordic countries are generally known for highly skilled arbitration for commercial disputes in general. The Board of directors is currently guiding the work on creating the Fast Tract procedure rules and Mediation rules to be implemented in practice of NOMA in 2020. After this has been done the Associations Rules will cover the same procedures that the London maritime arbitration covers.

When Nordic Offshore and Maritime Arbitration Associations Mediation and arbitration rules are in effective use in 2020’s, they will offer an economically lucrative, legally firm and speedy solution for the industry for commercial arbitration based on NMIP conditions. NOMA can provide arbitrators who have strong background in interpreting Nordic Marine Insurance Plan Conditions based on Nordic law. This can have a positive effect that future shipping arbitrations
will be divided more equally between England and Nordic countries when shipping will be more and more automated industry.

5. AUTONOMOUS SHIPPING AND CHARTERPARTIES

As autonomous shipping is still in experimental phrase, there is still no standard charterparties available. One of the reasons is that there is a lot of work still to be done with the international conventions so that fully autonomous can operate commercially. IMO Maritime Safety Committee and Legal Committee are preparing a scoping exercise which defines the needs of changes in international regulations before the international operation is possible. As the needs of risk management have already been started in the maritime insurance industry, it is expected that when the IMO has proceeded with the conventions the charterparties will be drawn up for the autonomous shipping. This will probably take place under the auspices of BIMCO. National solutions will probably be made for national traffic already before that as they are less affected by the international development. As a part of the RAAS project these national solutions will be developed and the target of the projects legal task force is to offer its expertise and assistance later to international development when BIMCO will start to plan the standard charterparty development in the area. The jurisdiction and arbitration clauses have already been developed by NOMA in order to existing vessels to use the service of the association. those clauses can be used also with the autonomous shipping.

6. CONCLUSION

The Nordic model of managing legal obstacles for autonomous shipping can influence shipping also internationally. The idea is to serve the industry development to tackle the the problems which arise by increasing automation to maritime legal issues, risk management and charterparties. The process will take years and the SAMK research group is prepared to continue with the issues with international partners and experts from the partner universities and industry. The research targets developed under the RAAS project are a starting point for creation of competitive entity of solutions which can be applied as a whole by the industry. Combining the risk management issues and charterparty issues to effective arbitration model offers a lucrative entity for the autonomous maritime industry in future. The idea of RAAS is also to build national education network for maritime industry and to combine research activities strongly to the education. Formulating the research needs for autonomous vessels in Maritime Universities has been in progress for one year since SAMK received a major part of funding (80 percent of the Legal Task Force funding). Master of Maritime management students knowledge and abilities to apply the information received in relation legal issues, risk management and charterparties has been tested throughout the year as a part of the Master programs studies and applied industry experiments and assignments.

The research results by August 2020 are promising – The four stages of autonomy (Now basis for scoping exercise, becoming standard when confirmed as standard in the next IMO Legal
Committee session 107) will create huge challenges for the studies, and needs research activities to enhance the level of assignments to be connected to both Bachelor and Master Programmes. Research needs to be based on differences of four levels of autonomy vessels operating simultaneously in the same environment and concentrating legal, risk management and charterparty issues applied on different levels of autonomy and changes when level of autonomy is different in relation to others in the area. Comparative approach to multiple levels of autonomy by adding legal regulation, risk management by varying insurance rules, and different charterparty clauses under which the vessels are operating will change the regulatory environment and make it dramatically more complex.

Responsibility for RAAS projects educational part in Maritime field in Finland will be transferred to Universities of Applied Sciences in the next stage of the project starting Autumn 2020. This will based on the existing work described in this paper but hopefully more closely coordinated also with international partners than what Covid-19 situation has allowed us to do 2020. Formulating the needs in the final form at the moment awaits the decisions of IMO LEG 107.

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ADVANTAGES AND DISADVANTAGES OF SOME UNMANNED AERIAL VEHICLES DEPLOYED IN MARITIME SURVEILLANCE

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Abstract:

The paper discusses the advantages and disadvantages of some unmanned aerial vehicles used for maritime surveillance. As examples, the Zephyr pseudo-satellite, as well as the AR5 and the AR3 medium altitude unmanned aircraft have been presented. A high-level Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is applied in this regard, as a tool to help assess the potential benefits of UAVs in the current maritime surveillance context. Strengths as lightness, possibility of manual launching, low energy consumption, lower price in comparison to satellites, high seeing, sensing and communication features, capacity of both line of sight (LoS) and beyond line of sight (BLoS) operations, large coverage, and durability of flight and like are highlighted. Threats such as high risk to operations due to severe weather conditions, loss of human control over the systems due to their high degree of autonomy, potential users’ reluctance to accept high-risk innovation and similar are argued, as well. In addition, weaknesses as complexity of the systems and the requirement of highly skilled personnel for these aircraft design, production, operation and maintenance, along with opportunities like lower costs, lower ecological and logistics footprints and higher efficiency are also taken into consideration. The appropriateness of these advanced aerial vehicles for monitoring and securing sea borders has been intertwined within the context.

Key words:

Unmanned aerial vehicles, Zephyr, AR5, AR3, maritime surveillance, SWOT.

Acknowledgment:

This article should contribute to the dissemination of the COMPASS2020 Project (Grant Agreement No: 833650) goals and assets with emphasis on the UAVs, which the project has been including and developing within the specific European maritime safety, security and environmental protection requirements. At the same time, research work on the article has been supported by the same Project.
INTRODUCTION

Unmanned aerial vehicles (UAVs) are being increasingly used for numerous purposes in both military and civilian domains. For instance, current applications of this kind of systems include surveillance, reconnaissance, remote sensing, target acquisition, border and maritime patrol, infrastructure monitoring, communications support, aerial imaging, industrial inspection, as well as emergency medical support, among others. The UAVs have capacities of sensing and perceiving the environment, processing the sensed information, communicating, planning and decision making, as well as acting using control algorithms and actuators [1]. Although these systems have historically found their main technological drive and applications in the military domain, their capabilities, alongside an increasing dissemination and consequent accessibility of this kind of technology, have attracted the interest of the civilian markets for several applications. As a result, the integration of UAVs in civil (non-segregated) airspace commonly used by conventional manned aircraft has been subject of intense study in recent years, with many initiatives currently approaching the initial implementation stages (e.g. the U-space initiative from the European Union’s SESAR Joint Undertaking (JU) [2]). In addition to applications such as agriculture and infrastructure monitoring, this has also paved the way to a growing use of unmanned aircraft in support of civil security missions, with particular emphasis in border and maritime surveillance.

Considering the context described above, this research paper has the main goal of providing an overview of the potential impact of deploying specific types of unmanned aerial systems in support of maritime surveillance missions and adjacent roles. As such, this paper describes the main features of the Zephyr High Altitude Pseudo-Satellite (HAPS), as well as the AR5 and the AR3 UAVs, which are part of a broader maritime surveillance and reconnaissance system for monitoring and control of the European sea borders, being developed within the context of the COMPASS2020 (Coordination Of Maritime assets for Persistent And Systemic Surveillance 2020) Project. The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the above mentioned UAVs will be conducted and presented, as well.

The question of motivation for developing and implementing the COMPASS2020 project logically arises in this context. The project has as overarching goal the deployment of unmanned aerial, sea surface and underwater vehicles, in operational coordination with manned oceanic patrol vessels used by EU Maritime Authorities, to enhance current maritime border surveillance operations, with a particular focus on the detection, monitoring and control of irregular migration and narcotics smuggling. The project aims at setting up a solution to ensure long range and persistent surveillance, increasing the situational awareness of maritime authorities, as well as to upraising the cost-effectiveness, availability and reliability of related operations. It has been conceived to help authorities handle the pressure put on European external borders by the vast amount of irregular border crossings observed in recent years, through improving coordinated actions supported by both manned and unmanned vehicles. Besides struggling with irregular migrants, Europe has a problem with other incidents of the most disperse nature, such as the long lasting issue of narcotics trafficking [3]. Consequently, COMPASS2020 has also been conceived to help address this issue. In order to address these two big challenges, the project proposes the development of a unified system based on open standards that will enable the combined operation of multiple unmanned assets, manned...
platforms currently used for marine surveillance and the future accommodation of other platforms and services with minor integration efforts. The project contributes to improve the situational awareness beyond coastal waters in different environmental conditions, ranges and altitudes. In addition, pollution monitoring is also an increasingly important part of maritime safety, as global commerce increases from and towards Europe, leading to a growth of vessels and cargos crossing European sea borders. Marine traffic of high density results in a higher probability of occurrence of pollution incidents, such as oil spills, as well as an increase in ships sulfur emissions. Those incidents, especially the ones that occur due to severe weather conditions such as strong winds and high sea state, can lead to high negative impacts to the environment [4]. The capability to establish a persistent maritime surveillance infrastructure such as proposed in the project will allow a better monitoring, control and management of these and other threats, and allow for better decision making to ensure the safety and security of European maritime borders.

As it is stated afore, the paper deals with unmanned aerial vehicles (UAVs) deployed within the project. Accordingly, the rest of the paper is organized as follows: the second, third and fourth sections comprise the description and high level analysis of the Zephyr, the AR5 and the AR3 UAVs crucial technical features and operational capacities, respectively; the fifth section contains the SWOT analysis of the considered UAVs; while the last section contains some conclusion remarks along with the directions for further research work in the field.

2. THE ZEPHYR: KEY FEATURES

The Zephyr 7 has been invented in 2000 at the Flemish Institute for Technical Research in the context of the Pegasus project. This solar airplane has been later transferred to Airbus in 2013. The only solar-powered airplane has demonstrated a unique mission of 14 days duration at more than 21 km flight altitude carrying a payload of 5 kg [5]. In 2014, work on Zephyr 8 began. The Zephyr S is a new variant of Zephyr family developed upon an agreement settled between the UK Ministry of Defense and Airbus Defense and Space. It is the first unmanned aircraft capable to fly in the stratosphere, harnessing the sun’s rays and running on a combination of solar cells and high-power lithium sulphur batteries (i.e., on solar-electric power), above the weather and conventional air traffic. It is a High Altitude Pseudo-Satellite (HAPS) [6], able to fly for a month at a time, combining the persistence of a satellite with the flexibility of an unmanned aerial vehicle (UAV). As HAPS, the Zephyr uses high-definition electro-optical and infrared cameras to produce real-time visuals in any lighting (Figure 1). The Zephyr unit costs around 5 million $, while an orbital satellite costs between 50 and 400 million $ [7]. Airbus now possesses two types of the Zephyr, designed to accommodate a variety of payloads. The production model Zephyr S has a wingspan of 25 m and weighs less than 75 kg. It is able to carry see, sense and connect payloads. Briefly, Zephyr S is capable to:

- **See** with clarity (facilitate disaster management, e.g., wildfires and oil spills);
- **Sense** with efficiency (trace environmental changes; monitor and secure borders);
- **Connect** with precision (connect securely across the globe; connect the isolated, since four billion people in the world do not have Internet access, etc.).

Presently, the larger Zephyr T, which is under development, has a wingspan of 33 m and a Maximum Take-off Weight (MTOW) of 140 kg [8]. The Zephyr’s main features include, but they are not limited to:

- **Flexibility** - The Zephyr’s launch requirements are simple compared to traditional aviation.
  - It requires no runway and no airport. It is launched manually. After taking-off and reaching
the stratosphere, the Zephyr navigates to the desired location, which may be hundreds or thousands of kilometers away. It transmits real-time imagery, voice and data in the perimeter of around 1000 km². The Zephyr can be controlled from ground control stations anywhere in the world deploying both line-of-sight (LoS) and beyond line of sight (BLoS) operations.

- **Safe and secure** - The Zephyr has both civil and military applications, which include maritime surveillance, border patrol, intelligence, reconnaissance, navigation, satellite communications, missile detection, environmental surveillance, continuous photo capturing, humanitarian and disaster relief, among others [9].
- **Persistence** - The Zephyr’s persistent flight is unmatched. It uses solar-electric power, with secondary batteries charged in daylight powering overnight flight.
- **Revolutionary** - the first unmanned aircraft capable to fly the stratosphere, the Zephyr might upgrade defense, humanitarian, and environmental missions all over the world.

**Figure 1. Zephyr.**


The Airbus’ Zephyr S has been firstly launched on 11th July 2018 in Yuma, Arizona, USA. Previously, it has been transported from Farnborough, UK. It used to have a small ground infrastructure. It was a historical take-off, when after eight hours Zephyr reached the stratosphere. Its lower altitude was 18 km, and the highest was 23 km. This was, at the time, the longest flight without refueling, lasting 25 days, 23 hours and 57 minutes [10]. Unfortunately, on 15th March 2019 the Zephyr aircraft with 25 m wingspan and mass of less than 75 kg has crashed near its launch site in Wyndham, Western Australia. This was caused by severe adverse weather. Luckily, it happened in an extremely remote location and caused no injuries or property damage. Work on the Zephyr improvements is continued and it is to be expected that the Zephyr’s mechanical launcher will be tested in 2020 [11].

The Zephyr was conceptually integrated in the proposed COMPASS2020 architecture, as a valuable asset for future concepts of operation. More specifically, due to its potential of acting as a high altitude platform capable of performing early detections and providing the respective warnings to the system, this platform is considered to bring added value to the solution, by providing persistent surveillance means and the first detection of potential events of interest. The goal of the project is to develop the solution in such a way that it will be possible and simple to integrate the Zephyr (both physically and in terms of data processing) within the overall system.
3. THE AR5: KEY FEATURES

The AR5 Life Ray Evolution (EVO) was chosen by the European Maritime Safety Agency (EMSA) in an international tender to be the first Unmanned Aerial System to act as a European wide marine patroller (Figure 2). It is a medium-endurance and medium-altitude fixed wing Unmanned Aerial System (UAS). This medium-endurance and medium-altitude fixed wing UAS is designed for wide area land and maritime surveillance, pollution monitoring, fisheries inspection and communication relay [12]. The AR5 has advanced on board capacities in terms of data processing. It can simultaneously process Electro-Optical/Infra-Red (EO/IR), radar and AIS data. Since EO/IR systems are less known in sea surveillance and navigation than radar and AIS, they will be shortly described below [13].

The EO/IR systems are imaging systems used for military, airborne homeland security, combat, patrol, surveillance, reconnaissance, and search and rescue programs, which include both visible and infrared sensors. Because they span both visible and infrared wavelengths, the EO/IR systems provide total situational awareness both day and night and in low light conditions. Critical features of EO/IR systems are long-range imaging abilities and image stabilization. The EO/IR sensors are usually mounted on aircraft or vehicles, used at sea, and must be able to identify targets, track them, and assess threats from a distance and in challenging environmental conditions. The EO/IR technology is being fit to smaller payloads, including traditional commercial drones and reconnaissance UAVs, and allow for transmitting live video and high-definition (HD) images back to the operator to improve their awareness and reduce risk to ground forces.

Figure 2. AR5 EVO Unmanned Aerial Vehicle.

Source: Tekever.

The AR5 Life Ray Evolution is sub-tactical UAS ranging up to 180 kg MTOW. It allows high-speed BLoS satellite communications. More precisely, it fully manages LoS and BLoS datalink handover. It also provides high precision video, imagery and sensor data in real time. Its features include, for instance, a flexible architecture, supporting multiple types of payloads and datalinks. Moreover, this platform complies with the highest production standards as the first European-wide UAS-based maritime surveillance system, which is International Traffic in Arms Regulations (ITAR) free [14]. As a UAV that requires a runway for take-off and landing, its automatic take-off and landing capabilities, as well as the fact that it can use short and
unpaved airstrips, are great advantages. The AR5 EVO has a cruise speed of 100 km/h and a standard endurance of 16 hours (its endurance is mission and payload dependent, being able to reach up to 20 hours). The available payload capacity is up to 50 kg, wingspan 7.3 m and length 4.0 m.

The AR5 EVO is suitable for both wide area surveillance as well as near shore and maritime missions. Among its main applications are [15]:

- Autonomous surveillance of large maritime and land areas, with onboard multi-sensor pattern detection;
- Use of both LoS and BLoS datalink to maximize performance and minimize operational costs;
- Multi-mission support, including border protection, fire surveillance and infrastructure monitoring;
- Optimized onboard and ground algorithms for oil spill detection;
- Multi-sensor fusion and specialized support to Search and Rescue (SAR) operations;
- Anti-piracy and traffic control missions;
- Support to fisheries using high precision sensors.

The AR5 EVO is equipped with a three-axis multi-sensor gyro-stabilized gimbal, capable of supporting the integration of multiple types of payloads. This includes, for example, AIS transceiver, multiple EO/IR sensors, Emergency Position Indicating Radio Beacon (EPIRB), maritime radar, among others. It uses the following communication packages [16;17]:

**Line of Sight (LoS)**
- Configurable control and non-payload communication software-defined radio datalink between 400 MHz and 1.2 GHz;
- Configurable control and non-payload communication software-defined radio back-up datalink between 400 MHz and 1.2 GHz;
- Configurable payload datalink between 1.2 GHz and 6 GHz.

**Beyond Line of Sight (BLoS)**
- Configurable control and non-payload communication datalink over commercial Satcom service at 1.5-1.6 GHz (L-Band);
- Payload datalink over commercial Satcom service at 1.5-1.6 GHz (L-Band shared).

Within COMPASS2020, the AR5 EVO UAV plays an important role as a middle layer platform, which is able to provide wide maritime area surveillance, complementing the operational gap between the wider coverage but lower resolution capabilities of the Zephyr, and the lower altitude and more localized situation monitoring provided by the AR3 UAV described in the next section.

4. THE AR3: KEY FEATURES

The AR3 Net Ray is a ship-borne UAS designed to carry out several types of maritime and land-based missions (Figure 3). These missions include intelligence, surveillance, target acquisition, reconnaissance (ISTAR) actions, pollution monitoring, infrastructure surveillance, communication support operations and like. This UAS is capable of delivering an endurance up to 10 hours (depending on the mission), which makes it an ideal solution to carry out both maritime and land based missions. The payload capacity is 4 kg and it includes multiple options for EO/IR sensors, near infrared to long-wave infrared (LWIR) sensors, laser illuminators,
communication relay systems, AIS transceivers, EPIRB, etc. Therefore, it can provide real time collection, processing and transmission of high definition video. Its communication range is up to 80 km within Radio Line of Sight; cruise speed is 85 km/h; MTOW is 23 kg; launch is conveyed via catapult; recovery via parachute and airbags (for land based operations) or a net system (for maritime based, ship-borne operations). The AR3 dimensions are 3.5 m of wingspan and a length of 1.7 m [18]. The AR3 missions include both wide area surveillance and near shore and maritime surveillance, comprising the following:
- Autonomous surveillance of large maritime and land areas, with onboard multi-sensor pattern detection;
- Multi-mission support, including border protection, fire surveillance and infrastructure monitoring;
- Environmental monitoring, including heat-tracking;
- Fire prevention;
- Anti-piracy and traffic control missions;
- Support to fisheries inspection using high precision sensors;
- Long range monitoring of large infrastructures, like pipelines or aerial electricity networks;
- Support for “over the hill” or beyond radio line of sight missions, etc.

Figure 3. The AR3 Net Ray taking-off.

Source: Tekever.

The AR3 Net Ray UAV will be included in the COMPASS2020 surveillance ecosystem as an organic asset of the oceanic patrol vessels operated by the maritime authorities. This UAV will be operated (launched, piloted and recovered) from the vessel to provide the tactical teams with enhanced real time information to help decision-making. The AR3 will cover a surveillance level below the AR5, providing a more localized monitoring of events and situations of interest.

5. THE UAVs SWOT ANALYSIS

In this subsection, some indicative positive and negative factors connected with the above presented UAVs are given. These factors are organized in the form of the SWOT analysis (Figure 4). After the strengths and weaknesses, the authors identified the main threats and opportunities of the considered UAVs [19].
Figure 4. The SWOT concept.

Source: Own.

**Strengths:**
- Lightness;
- Manual launching or reduced logistics footprint;
- Low energy consumption;
- Lower acquisition price in comparison to satellites;
- Better quality of information in comparison to satellites;
- Lower operational costs in comparison to manned aircraft used for the same mission profiles;
- Ability to fly for more hours continuously in comparison to manned aircraft, as there is no need for aircraft downtime for pilot rendition;
- High seeing, sensing and communication capacities;
- Capacity of both LoS and BLoS operations;
- Large coverage and durability of flight without recharging;
- High level of automation;
- Resistance to environmental disturbances;
- Possibility to be safely integrated with commercial aviation;
- Capacity to support high risk activities;
- Capacity to reach areas inaccessible for humans, etc.

**Weaknesses:**
- Complexity of the UAVs makes them more vulnerable;
- Requirements for highly skilled personnel for designing, creating, operating-controlling, maintaining and upgrading the UAVs;
- Lack of law regulations at a wider scale;
- Lack of management and operational knowledge at different levels of the UAVs operation;
- Lack of common communication capacities between the UAVs and other vehicles within integrated traffic and transportation system;
- The link between the UAVs and ground control stations;
- Maneuvering and obstacles’ avoidance algorithms are under development;
- Computer vision is also still until development, etc.

**Opportunities:**
- Increasing safety and security at sea and in general;
- Reduction of traffic congestion in areas with high density traffic;
- Approaching up to now inapproachable areas;
- Approaching areas of high risk for humans;
- Gathering more information on distance areas, entities, constructions, etc.;
- Lower ecological footprint;
- Developing 3D path planning with obstacle avoidance;
- Developing potentials of autonomous systems;
- Further development of artificial super-complex UAV systems, etc.

**Threats:**
- Collapse of the UAVs due to severe weather conditions/harsh environments;
- Negative effects of external factors as natural forces and cosmic impacts;
- Losing human control over the craft;
- Unsafe landing and recovering;
- Internal disturbances and faults in the systems as super-complex ones;
- Over-reliance on technology, i.e., UAVs in the analyzed context;
- Unauthorized malicious intrusion into the system (hacking);
- Scarcity of the cost-benefit analysis;
- High investment risks;
- The lack of readiness of entrepreneurs to support further development of UAVs;
- Uncertain revenue of investments;
- Users’ reluctance to accept high risk investments in the UAVs innovations;
- Questionable innovation acceptance success, etc.

The efficiency of the UAVs is always at the expense of their robustness. Therefore, there should be a balance between the efficiency and robustness of these systems [20]. Besides, it is well known from the theory of automated systems that the more complex the system, the greater the possibility of errors and its disturbance [21]. A way to make the UAVs more reliable is to make them layered, while the communication between layers and maintaining efficiency should be boosted.

6. CONCLUSIONS

A review of the UAVs within the context of the COMPASS2020 project has been presented in this article. The Zephyr, the AR5 and the AR3 UAVs have been described through highlighting their key features. Based on the findings from secondary literature resources and experiences from the project up to now, some strengths, weaknesses, opportunities and threats of the considered UAVs have been identified and highlighted.

The future research in this area should provide a deeper insight of compatibility of the UAV systems with the existing and well-established manned and unmanned craft used for the same or similar purposes. In addition, harmonizing and rationalizing communication among all assets involved within the considered project should be taken into more depth consideration.

There is a strong argument in favor of increasing initiatives for testing, validating and integrating unmanned systems within current surveillance infrastructures (both land and maritime based), as these assets can help enhance current surveillance and monitoring
capabilities of authorities in a cost-effective way. However, the so-called “blind-belief” in technology, including the analyzed UAVs, should be interrogated. The willingness of various stakeholders to implement and adopt these advantageous systems should be investigated, as well, with the aim to provide the innovation implementation success in both military and civil traffic and surveillance missions.

References:


A SURVEY OF MACHINE LEARNING APPROACHES FOR SURFACE MARITIME NAVIGATION


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Abstract:

In this article we present the state of the art in the field of autonomous surface ship navigation using machine learning. We discuss the main challenges towards the development of fully autonomous navigation systems with the International Regulations for Preventing Collisions at Sea (COLREGs). Finally, we propose two alternative approaches that are based on machine learning. Existing COLREGs-based navigation and collision avoidance algorithms are based on traditional search-based planning and optimization algorithms. We consider that these approaches are suitable when the problem space is defined completely and rigorously. However, experts believe that is not the case for COLREGs since it leaves many aspects open to the interpretation of the captain. For example, COLREGs expects that any collision avoidance action shall be taken with due regard to the observance of good seamanship, a concept not defined in the convention. Furthermore, many rules are defined using undefined concepts like safe distance, or keywords like early, or substantial, without giving any definition. COLREGs even allow for the rules to be broken to avoid an accident. Due to this, traditional planning approaches may not be able to handle complex scenarios that are underspecified according to COLREGs.

An alternative is the use of machine learning (ML), reinforcement learning (RL) and imitation learning (IL) at the core of autonomous navigation systems. Machine learning is known to succeed and outperform traditional approaches specially in vaguely defined problem domains, where it is difficult, if not impossible, to create a full formal specification of the phenomenon under study. We consider this to be the case for COLREGs-based navigation and we conjecture that a ML-based navigation approach can outperform existing search-based and optimization algorithms.

Keywords:

Autonomous navigation; surface ship navigation; machine learning.
INTRODUCTION

Autonomy as a way to increase safety, improve the logistics, decrease the operational costs, maximize profitability and reduce the carbon-footprint of traffic, has gained a lot of interest worldwide, and is mainly focusing, in Europe and the US, in the automotive area. Maritime Autonomous Surface Ships (MASS) of the future are expected to contain functionality that handle an increasing range of self-sufficiency. Autonomous capabilities include relieving the vessel operator from constant supervision by taking over certain responsibilities of the vessels using partial or complete remote operation of vessels, or partial or complete unsupervised navigation.

Technological advances in the field of big data, data analytics and processing, cloud computing, sensor technology and improved communication infrastructures open the doors to a future where ships will sail the seas autonomously. According to the Norwegian Forum for Autonomous Ships (NFAS), an autonomous vessel, whether manned or unmanned, is a ship with a certain level of automation and self-governance. These vessels will be equipped with systems having the ability to self-initiate actions. These actions rely on sensor-based detection and analysis using algorithms guiding the automated decision-making. The level of autonomy (LoA) defines the level of engagement that is expected of a human operator and the level of performance conducted by automation. LoA will depend on the vessel and its operational purpose and objectives. Some vessels may contain maintenance crew, others operated from the shore by the remote operation center crew and some might even be fully manned with intelligent automated support systems for decision-making. The level of autonomy can vary from ship to ship raising the need for successful interaction with humans.

Parasuraman, et al. (2000), and referred by Veritas (2017), divide maritime vessel functionalities into four levels of automation: Information acquisition; Information analysis; Decision and action selection and Action implementation.

The maritime industry is already leveraging various vessel-dependent levels of automation. Shipping has always been a fore runner in acquiring modern technology. For example, first electric navigation solutions emerged in the 1930s and vessels were the first civilian user of satellite navigation technology. Further, the anti-collision radar became mandatory onboard vessels from 1974 and automatic identification transponders from 2002, [33]. The vessels of today can be equipped with an autopilot following a pre-planned route in a track-following mode executing independently turns while the officer on watch (OOW) mainly monitors the proceedings and ensures safe navigation.

Today’s unmanned vessels are mainly small crafts engaged in research and scientific activities, like for example marine environment exploration or deep ocean surveys. Some vessels perform underwater operations such as mine seeking and military has some autonomous surveillance vessels, e.g. US Navy’s Sea Hunter Drone Ship. Although, at the moment, there is no fully functional autonomous maritime vessels in operation, there have been various attempts in that direction. Regarding the merchant vessels, the Yara Birkeland vessel is under development and is stated to be the world's first autonomous container ship sailing in the near future. Its design is mainly motivated by environmental factors. Also, some autonomous small passenger ferries have been tested such as NTNU’s Autoferry and autonomous passenger ferries are expected to sail sometimes soon. Successful test runs have been done within the project SVAN by Rolls-Royce (currently Kongsberg Maritime Finland Ltd.) and Finnferries,
where they successfully demonstrated the world’s first fully autonomous ferry in the Finnish Archipelago. Similar tests have been done also by ABB (remote control of Suomenlinna ferry) and Wärtsilä (successful tests with the Norwegian ferry Folgefonn).

The operational environment of a ship can vary from open sea navigation without traffic to highly complex dense traffic areas. Prevailing circumstances like weather conditions have also an impact on collision avoidance. Collision avoidance is very situationally bound, where concepts like “safe distance” or “in ample time” change according to the prevailing circumstances. Machine learning is known to succeed and outperform traditional approaches specially in vaguely defined problem domain, where it is difficult, if not impossible, to create a full formal specification of the phenomenon under study. We consider this is the case for COLREGs-based navigation and we conjecture that a ML-based navigation approach can outperform existing search-based and optimization algorithms.

1. THE DRIVING FORCES OF AUTONOMOUS SHIPPING

Maritime Autonomous Surface Ships of the future are expected to contain functionalities that handle an increasing range of self-sufficiency. Autonomous capabilities include relieving the vessel operator from constant supervision by taking over certain responsibilities of the vessels using partial or complete remote operation of vessels, or partial or complete unsupervised navigation.

An important motivation for autonomous functions in ships is to avoid human errors resulting from distraction, tiredness, lack of focus, etc. Despite the advances in technologies and the high level of reliability found in navigational equipment on a vessel, ship safety is still considered as one of the major issues in the maritime shipping industry. Several studies have shown a predominant impact of human behavior in maritime accidents and casualties, with an estimated 89% to 96% of ship collisions directly due to human error [2]. In 2017 alone, 3301 accidents were reported by the European Maritime Safety Agency and over 53% of all reported accidents were collisions, contacts or grounding occurrences, all due to navigational error [10]. The development of autonomous navigational capabilities is seen as a possible solution to dramatically reduce the number of accidents due to navigational error.

Several researchers have tackled this problem by proposing automatic COLREGs-based navigation algorithms and even complete systems [45, 13]. COLREGs prescribes a set of rules that all ships should follow to ensure safe navigations.

The origin of COLREGs goes back to the ending of Age of Sail in mid-19th century. The appearance of steam ships raised the concern about shipping safety and rules of the road at sea started to evolve. For decades the rules have been evolved according to the needs of maritime traffic and COLREGs were published in modern form in 1972. Now the maritime traffic is facing a new revolution, the autonomous vessels to which the traditional rules are challenging to apply. The COLREGs have been written to humans while in interaction with other humans in a qualitative format. Due to complex maritime domain, they also are general in nature to make them applicable to as many situations as possible [32]. The qualitative nature of COLREGs poses challenges for algorithm creation used for collision avoidance as the creation of anti-collision software requires the rules to be transformed into quantitative format. Definitions like “good seamanship” guiding the decision making of seafarers or changing
concept of safe speed that is dependent on situational circumstances pose challenges for quantification. Further, the rules change according to weather conditions like restricted visibility or signals of the counter vessel such as restricted maneuverability. Therefore, COLREGs needs to be interpreted always in the context of prevailing navigational conditions and the correct application of the rules can vary from one situation to the next as the prevailing conditions change.

Porathe [31, 32], discusses the matter in his articles and raises the question for new set of rules for autonomous vessels. Although the question cannot be answered yet, he points out that if the autonomous vessels need to interact with humans, the actions of an autonomous vessel need to be transparent and understandable by human mariners. Endsley [11] states that poor understanding of the functioning of an autonomous system leads to inappropriate interaction with automation, resulting in poor situational awareness. Therefore, autonomous vessels do need to operate within the context of COLREGs to ensure that their actions are understood. Research on human behavior in various, specified circumstances and navigational areas can be the way to overcome challenges posed by quantification of COLREGs.

Maritime traffic has been coordinated in dense traffic areas by Traffic Separation Lanes, but these lanes do not cover all areas. Complex traffic situations with multiple vessels entering from various directions is just an ordinary day at sea for professional seafarers. Belcher [6] studied COLREGs from a societal point of view giving an example of complex traffic situations where the rules of COLREGs conflict with each other leaving the decision making and courses of action for individual interpretations of officers. Similar example was given by Porathe [32] pointing out that the actions of one ship in a complex situation will affect the decision making and actions of others. In addition, a collision avoidance situation can be solved with various solutions e.g. course change, speed change or both. These decisions also have an impact on which rule to apply as one rule can change to another dynamically in the same collision avoidance situation between vessels depending on the chosen courses of action.

2. STATE OF THE ART IN AUTONOMOUS NAVIGATION SYSTEMS

Maneuvering a ship is composed of three fundamental tasks: navigation, guidance and control [42]. The navigation task aims at estimating the state of the ship motion, which can be done with the help of a variety of sensors (for example inertial measurement unit, compass, global position system). The guidance of a ship is the task in charge of determining the desired ship state motion and is usually based on a set of input values related to physical environment of the ship, the ship mission or goals and associated costs (for example time, energy, and risk). The control task is implementing the required actuator commands to reach the desired ship state motion. A possible composition of tasks for an autonomous ship manoeuvring architecture is illustrated in Figure 1.

Understanding the vessel’s environment, i.e., situational awareness is the corner stone for the guidance task. It includes components on several levels, level 1: perceive all environmental elements defining the current situation (for example, weather environment, type, location and speed of other vessels, etc.), level 2: comprehend the current situation (for example, understand and quantify a risk of collision), and level 3: project the future state of the ship (for example predict the near-future way points of the ship). The existing works for autonomous ships put a
focus on the situation awareness components of the guidance task. Specifically, collision avoidance or path planning approaches have attracted attention through the past few years.

**Figure 1. A decision-making architecture for an autonomous ship.**

Recently, Zhou, et. al. [46] proposed a quantitative model of situational awareness based on the system safety control structure of remotely controlled vessel. This study provides a theoretical ground for further work in the area of situational awareness. The model developed in this study considers a high level of abstraction while using probabilistic approaches to provide guidelines for evaluating the navigation safety of autonomous ships. In another study, Murray and Perera [25], proposed an approach to facilitate situational awareness by predicting the other vessels’ trajectories accurately. They used a data-driven approach taking advantage of the information collectable from historical AIS data. They employed a clustering based Single Point Neighbor Search Method along with a Multiple Trajectory Extraction Method. Endsley [12] proposed a three levels situational awareness model defined as Level 1: perception of element of the environment within a volume of time and space; Level 2: the comprehension of the current situation and Level 3 projection of the status in the near future.

Xu, et.al. [44] proposed an autonomous collision avoidance method which is designed based on the visual technique similar to the human’s visual system. They used the recorded navigational manoeuvres for pre-defined scenarios performed on a simulator to train a deep convolutional neural network. The model is used to predict the collision avoidance manoeuvres based on the image scenes fed to the model as the input. During the same year, Xidias and Zissis [43] proposed an optimization approach to identify an optimum collision free path, based on the input obtained by the visibility graphs. Their optimization model is designed in such a way that the optimum path (1) should be minimal, (2) should respect the three COLREGs rules and (3) should avoid collisions with both static and moving obstacles. Target detection is another area of study that contributes in designing of collision avoidance approaches. For example, Stateczny, et. al. [37] provided an empirical analysis of the maritime surface target detection approaches, which could be utilised for the design of tracking and anti-collision systems for autonomous surface vehicles (ASV). Their research focused on identifying the field of views in which different surface targets could be detected. Their analysis included the objects that are typically detectable in the water environment, including a boat and other floating objects.

Path planning is also another area of interest. A popular choice is to develop Kalman filter-based algorithms for path planning. For example, Liu, et. al. [24] proposed a Kalman filter-based predictive path planning designed to predict the trajectories of moving ships, and the
maritime vessel’s own position in real time. Based on this information, this method, evaluates the potential collision risk of the vessels of interest. Allotta, et. al. [3, 4] conducted two studies to compare the efficiency of two different Kalman filter-based algorithms, namely, Extended Kalman filter (EKF) and Unscented Kalman filter (UKF). Kuwata, et. al. [22] took an algorithmic view towards solving the problem of identifying optimal path for the maritime vessels. As the input they consider the near-term waypoint, a reference speed, and a list of contacts representing moving and static hazards. The objective of their algorithm is to find the optimal velocity command in which the surface ship could avoid the hazards and follow the COLREGs. The algorithm computes the closest point of approach with the current position and velocity of the vessel and other traffic vessels and evaluates if any COLREGs rules need to be applied at all and change the current route based on the identified COLREGs rule. Later, Jeong, Lee, and Lee [20] developed a technique to devise a motion planning approach using real-time data. This is a risk analysis method which assesses and visualizes maritime traffic risk as the foundation for the route planning of an Autonomous Surface Vehicles (ASV). The optimal route that matches the desired objectives is identified using the risk contour map and the ASV’s data processing.

Tan, et. al. [40] presented a different approach to path planning which joins AIS locations of the same vessel at different times and locations in a region into a route. Next, it automatically computes navigation plans using nearest neighbor-based path retrieval relying on two representations, Ship Feature and Navigation Feature. Then, it utilizes the available AIS data, including ship properties, and the preprocessed corresponding route which are accessible from the form of Ship and Navigation Feature. This approach considers the available navigational constrains in the form of a vector data, then identifies the nearest neighbor to this query vector in the space under investigation and eventually points out the recommended navigational path as the output. Taking into account the importance of respecting COLREGs, the path planning approach developed by Park, Choi, and Choi [29] is based on defining all potential trajectories’ uncertainty. In this approach, the authors utilize a tracking filter that estimates the motion information. They use the error covariance if this filter as the basis of their modelling. Furthermore, based on this developed model, a probabilistic approach, they identify a considered collision risk zone (CRZ) for the predicted trajectory. Finally, considering the dynamic characteristics of the vessel and in order to avoid the identified CRZ, an optimal path is proposed. In another study, Bibuli, et. al. [7] developed a two layered approach in order to devise a multiple unmanned surface vehicles navigation framework. In the top layer of the architecture, a robust path planner is adopted to generate optimal waypoints, which are later smoothed using the polyfitting operation. This smoothed trajectory is given as an input to the bottom layer of the guidance system based on virtual target approach integrated with a swarm aggregation algorithm based on attraction-repulsion strategy.

Later, Hinostroza, Xu, and Soares [16] focused on designing a motion-planning unit, which is based on the angle-guidance fast-marching square method, which is specially developed for operation in dynamic and static environments. The collision avoidance unit is based on fuzzy-logic formulation, the guidance unit uses the vector-field guidance formulation and the control unit is composed by a PID heading controller and a speed controller.
3. MACHINE LEARNING APPROACHES FOR THE GUIDANCE TASK

Several ML-based navigation algorithms have been successfully employed in other application domains, like aerospace and automotive. Reinforcement learning, imitation learning and generative adversarial imitation learning are the most relevant approaches for autonomous navigation.

3.1 REINFORCEMENT LEARNING

Reinforcement learning (RL) models identify the main elements of the problem understudy by analyzing how an agent interacts with its environment to reach a maximum reward while pursuing an ultimate goal, see Sutton and Barto [38]. In an RL model, the agent is defined to derive useful information from the environment in order to perform actions which have influence on the environment based on a predefined reward function. The goal in an RL model is to formulate different steps from collecting information to taking action and achieving goal in such a way that they are simple as well as efficient and non-trivialized. One of the main obstacles in implementing an RL model is its reliance on the reward function. As designing a reward function requires involved and complex experiments to imitate the behaviors close to the natural one, many RL models tend to settle for a local minima rather than a global one, [27].

3.2 IMITATION LEARNING

Imitation learning (IL) models are designed to learn a policy based on the data collected from humans’ demonstration to imitate an expert behavior. The policies learned by an IL model typically is captured through an expressive model such as neural networks [21] IL have been widely adopted when it comes to learning car navigation. One of such adoptions is Behavioral Cloning (BC) [30]. BC is a supervised learning approach in which the driver’s behaviors is learned via building a regression model based on the dataset including tuples of state and actions recorded from human experts’ demonstrations. The shortcoming of BC is using a regression model on the existing data and any deviation from the data could dramatically reduce the accuracy of the model. Such a shortcoming leads to the model being unstable, for example, Ross and Bagnell [34], argue that as the dataset of experts’ demonstration lack the careless driver behavior and thus lacks recovery actions, the BC model could lead to errors and undesirable driving decisions. Ross et al [35] argues that a BC model, by nature, violates the independent and identically distributed random variables (i.i.d) assumption as the future behavior heavily relies on the previous actions. Thus, the BC model could potentially showcase poor performance.

Apprenticeship learning (AL) [1] is another IL method that learns an unknown reward function which is the basis of the expert demonstration. AL could be considered superior to BC, as it focuses on learning the reward function rather than the behavior from the dataset which could potentially include non-optimal demonstrations. Syed and Schapire [39], proposed a new AL approach based on the work of Abbeel and Ng [1], where they consider the unknown reward function to be the combination of a set of known and observable features. They claim that their approach has the potential to produce a policy, in times, better than the expert’s. In contrast to
Syed and Schapire [39] approach, Levine et al. [23], assumes the reward function to be a non-linear one and use Gaussian processes to learn it. They argue that such an assumption, makes it feasible to capture more complex behaviors. As such, it is worth considering that AL is computationally expensive and it could only be utilized when the resources are available [17].

### 3.3 Generative Adversarial Imitation Learning (GAIL)

As mentioned in the previous section, the implementation of the BC and AL algorithms is not always feasible. Several different approaches have been proposed to overcome the aforementioned issues. Inverse reinforcement learning (IRL) is one of such approaches, where the goal is to find a cost function which facilitates the expert’s uniquely optimal behavior. However, IRL is also a computationally expensive approach as it has a middle RL loop. To alleviate this issue, Ho and Ermon [17], proposed a new approach called Generative Adversarial Imitation Learning (GAIL). GAIL tends to learn the policy directly from the data without the need for the middle RL loop. GAIL uses Generative Adversarial Networks (GAN) [15] to fit distributions of states and actions leading to identifying the expert’s behavior. GAN consists of two main components: 1) a generator (producing new data samples and 2) a discriminator (evaluating whether the new sample belongs to the actual training dataset or not). GAN the generator and discriminator are learned by a gradient. In contrast to GAIL which is a model-free approach, Baram et al. [5], used a model-based approach and reparameterization techniques to identify the gradient of the discriminator based on the state and action information. Finally, similar to the study by Baram et al. [5], Blondé and Kalousis [8], proposed a new approach to deduce the gradient of the discriminator. Rather than using intermediary approaches, they directly deduce it based on the actions using a deterministic policy.

Taking into account the specific considerations related to the maritime domain, mainly the need of safety requirements and lack of training data, specific approaches need to be developed for the autonomous maritime domain. As such, we propose the development and evaluation of the following approaches: Safe Reinforcement Learning and Simulation-based Multi-agent Imitation Learning.

### 3.4 Safe Reinforcement Learning

The overall goal of Reinforcement Learning is to learn a decision-making policy to maximize a reward-based objective function. The reward function can be defined in terms of the mission objectives, for example arriving to the next way point of a previously planned route. However, Reinforcement Learning does not take into account possible risks or actions to avoid even if they would contribute to achieve the goal.

Constrained Reinforcement Learning [9] can be considered an extension of Reinforcement Learning where only policies that abide a given set of constraints are considered. We can introduce the concept of Safe Reinforcement Learning as an application of Constrained Reinforcement Learning where the constraints represent the safety requirements of our problem domain.
The safety constraints are formulated in terms of cost functions that represent states to avoid. In the case of autonomous navigation, one cost function can be used to estimate the risk of collision. This, in turn, can be quantified using the Velocity Obstacles approach [22] or the risk assessment function presented by Hu et al. [19]. Once we are able to quantify the risk of collision as a real function, we can define a constraint limiting what is the maximum risk that we are able to allow during the training of the agent. In this way, the policy implemented by the autonomous agent must find a balance over maximizing the reward function, i.e. achieving the mission objective, while abiding the constraints imposed by the cost function, i.e. bounding the risks of unsafe operation to an acceptable risk.

Safe Reinforcement Learning has the potential to combine the benefits of Reinforcement Learning while taking into account safety requirements. However, there are some challenges to this approach. The first one is the actual definition of the reward and cost functions. As discussed, different authors have proposed methods to calculate the estimated time and distance to a possible collision between two vessels, but often these models are rather simplistic and often assume that the ships are following a straight line. Finally, these models require a precise estimation of parameters such as the position and speed vector of the own and other vessels, and this task can also be challenging in case of equipment malfunction or failure.

3.5 SIMULATION-BASED MULTI-AGENT IMITATION LEARNING

The use of simulation platforms to create and test traffic patterns is a common approach used in development of autonomous land vehicles. Augmenting the simulator with real world inputs promises to provide richer and more authentic environment to test the reliability and safety of automatic navigational technology. However, unlike autonomous land vehicles, maritime traffic is sparser with rarer occurrence of navigationally complex events. In addition, unlike navigational guidelines for land vehicles, maritime navigational guidelines are intentionally vague due to a large permutation of possible scenarios, making it difficult to rely only on sets of expert-written rules and interpretations of maritime navigation regulations. The situation calls for a reliable dataset of various vessel, environment and traffic scenarios with data quality ideally from real-world measurements or mimics the real-world as close as possible.

The main challenge in multi-agent imitation learning lays in preparing the simulation environment, which is highly dependent on the task to be performed. The model has to figure out how to avoid a collision in a safe environment. The first step to build such a model, a dataset is to be constructed by directly recording the state as human experts navigates a ship, to facilitate making multiple renders of both the environment and data with varied environmental conditions, other vessels specifications and positions, and different routes. Two main components need to be introduced to build the required dataset: a set of sequential decision-making environments in the simulator and a corresponding public large-scale dataset of human demonstrations. In order to facilitate the training of multi-agent imitation learning models, simulations run by multiple users on the same scenario on different simulator bridges must be recorded.

The aim of the approach is to learn multiple parametrized policies that imitate the behavior of all experts. As the data are collected from multiple players in the same scenario, the model would consider interactions among all the vessels and reflects individual differences. This
approach has an adversarial component, called a critic, to compute the difference between the off-course trajectories and true trajectories. During training, the algorithm iteratively updates the policy to minimize the difference and updates the critic to maximize the difference. When the algorithm converges, the critic cannot distinguish between the true trajectory and the roll-out trajectory, which implies point-wise convergence of the policy.

4. CONCLUSION

The fundamental challenge for the maritime industry is to achieve safety for the IT systems that are being deployed. A substantial amount of research has been done for the automotive area, but these results do not easily transfer to the maritime area. This is due to differences in the physics of the vessel’s vs that of a car, differences in weather conditions leading to different sensing needs, and differences in traffic conditions making the datasets collected for the automotive area pretty useless in the maritime area.

There is a need to find an approach to address the general problem of autonomy for maritime vessels, by establishing a model of "good seamanship" using modern machine learning techniques like safe reinforcement learning, and multi-agent imitation learning.

In this paper we surveyed the field of algorithms for autonomous navigation for maritime vessels. It is clear that although there have been several attempts to find a solution to design surface ship autonomous navigation system, there is a need to explore new ways to learn the behaviors of actual humans. In this paper we proposed the development and evaluation of the following approaches: Safe Reinforcement Learning and Simulation-based Multi-agent Imitation Learning.

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STCW-CONVENTION AND FUTURE OF JOINT CURRICULUMS FOR AUTONOMOUS AND REMOTELY OPERATED VESSELS IN MARITIME EDUCATION AND TRAINING (MET)

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Abstract:

The article describes UAS and University co-operation between Nordic and European Maritime educational institutions in promoting common syllabus work relating to autonomous shipping in Bachelor level STCW Convention based education and examines possibilities for co-operative use of test beds in STCW convention determined topics in selected parts of Europe where test areas have already been established. Content development in existing Master education syllabus in UAS SAMK Finland for the benefit of autonomous and remotely operated shipping in following issues: 1) international treaty obligations, 2) risk management and marine insurance, 3) charter parties and shipbroking. One of the aims is connecting the Finnish and foreign students and their employers/shipowners to future of MET in relation to IAMU (International Association of Maritime Universities) defined “Global Maritime Professional” is described and analyzed.

Technological advancement in the area is progressing fast and need for development of seafarers’ education needs to adjust in this development. Professional targets/standards, determining the research targets and needs for development projects in the field of autonomous and remotely operated seafaring in future co-operation between Universities in Master of Maritime Management programs is analyzed. Bachelor level education for persons working at sea (Captains and Chief engineers) is closely regulated in STCW-convention. In addition to this, MET will need to add resources and focus to the change in the working environment of seafarers. Analysis how this work should be addressed to both bachelor and master level education is presented.

Keywords:
autonomous vessels, joint curriculums, STCW, MET.
INTRODUCTION

The global maritime trade has reached amount of 11 billion tons by the year 2018 with the fleet capacity of 1.97 billion dead-weight tons. It is predicted by UNCTAD that international maritime trade will continue growing with the rate of 3.5 per cent over the 2019-2024 period even though there are certain risk factors that may have influence on predicted growth. [1]

Technical development and innovations have gone hand in hand with the transport development and have benefit the industrialization and globalization. The growing global maritime trade and developing world economy are continuously trying to find improvements for economic benefits, efficiency in operations, improvements in safety and lately, acknowledging the environmental issues. Nowadays a quicker flow of information is now possible and provides actual situation awareness to various operators at sea and onshore thanks to improved communication equipment and technical solutions.

A new innovations and development of logistics at sea and ashore changes inevitably the nature of work and requires new skill for the people and will change the working routines. [2] However, the various stages of development of countries and different developmental needs have an influence how new technologies are implemented and what kind of priorities there are from investment perspective in the near future. [3]

Despite of increasing technology and variable level of automation, human resources are needed onboard the ships until further notice. The developing maritime industry requires educated and skilful work force for its needs also in the future. Currently, maritime sector and maritime education and training institutions are estimating the direction for future education and what skills are vital for modern mariners. As a result of this, a joint project called Global Maritime Professional (GMP) Body of Knowledge which was published by the Nippon Foundation and the International Association of Maritime Universities (IAMU) in 2019. Also, a lot of other projects and research which are related to maritime technological development and innovation ecosystems/entities are active at the moment. One example of these research projects is Research Alliance for Autonomous Systems (RAAS) which aims to find best possible scientific knowhow and innovation ecosystems among autonomous maritime industry.

1. DEVELOPMENT OF MARITIME INDUSTRY

The worldwide shipping has developed enormously during the decades due to trends of globalized production and markets as well as logistic chain requirements of just-in-time deliveries (JIT). This logistic strategy has brought reduced costs at receiver’s end when need for warehousing is decreased. On the other hand, this leads to increased requirements of lower shipping expenses and need for monitoring the continuously the planned production processes. Transport costs have lowered with the influence of economic scale in the ship size and due to the trend where traders prefer to buy transported goods timely instead of paying for inventory holding. Also, the containerization of goods has had a revolutionary impact on more fluent shipments and cost savings. [4]

In the area of technology and automation, the progress of shipping has continued quickly. Innovations of automation can be seen already all around in everyday life, like drones, self-
driving cars and in various solutions of autonomously operated cargo handling systems. Currently, maritime stakeholders’ interests have wakened by the first vessels which can be remotely controlled, and the level of automation is highly developed. However, even though the maritime industry has got the first tastes of modern technological solutions, the implementation of these innovations in maritime transport have proceeded quite slow steps thanks to various obstacles and regulative limitations. [2] Like earlier mentioned, also different developmental needs in every country have an impact on technological progress globally. A new business models and economic advantages are looked for with help of different levels of automation and implementation of new technologies but in the other hand, the high expenses at the beginning of technological development can slow down the willingness to invest into these systems. In the ports, infrastructure systems for controlling and supervising will demand new structures which also requires high investments and anew kind of shore-side support. [2]

2. RESEARCH ALLIANCE FOR AUTONOMOUS SYSTEMS (RAAS)

Autonomous systems are one of the most important industrial application sites for artificial intelligence and robotics. Their research and development combine a number of rapidly evolving technology areas and industries. The market for autonomous systems is growing rapidly, creating growth opportunities for both technology producers and providers of global systems. Many Finnish companies and research institutes are at the head of development related to among the others, maritime transport, automation of ports, automated cargo handling machinery and with various automated processes in logistic chain. There a wide range of export companies which are committed to regional development. However, the international competition requires accelerating the development and commercialization of the results and the full exploitation of synergies between different operator in the industry. [5]

To create an innovation ecosystem, a research alliance for autonomous systems (RAAS) has been build up in Finland which purpose is to be internationally recognized network for industry, research and educational institutes. The different interest groups have recognized the importance of enhancing synergies between the autonomous solutions of various application sectors in terms of accelerating innovations. The best international scientific experts, the innovative company partners and public authorities are gathered by RAAS to boost the development and implementation of modern technological ideas. The aim is to significantly improve RAAS alliance’s scientific excellence and possibilities to help the stakeholder groups. [5]

It has been thought that RAAS would primarily serve and help with increasing the level of autonomy of mobile machinery and in logistical chain because innovation activities are in that area the fastest. The main idea is to connect RAAS internalization activities with national interests, ecosystems, different kind of platforms and testbeds etc. related to development of autonomous systems in certain application areas of transport and logistics. For these application areas, the goal is to find 1-3 autonomous innovation ecosystem/entities where innovative solutions are needed and the pressure for change is coming from the international markets and in addition, Finnish companies can open new possibilities for business. [5]

The preparatory team of RAAS has worked on an overall R&D framework for autonomous solutions which consists of seven main topics:
1) ethics and acceptability,
2) rules, responsibilities and legal issues,
3) change of business activities,
4) operational planning,
5) technical abilities,
6) artificial intelligence and data utilization and
7) assessment of effectiveness. Most of these levels are divided also into sub-themes.

RAAS, among others, seeks to be a platform that highlights the best talent and competences, irrespective of organizations, and develops the knowledge capital in a long term. RAAS focuses on the systemic, multidisciplinary challenge and its phenomena, rather than on individual technology or business challenges.

Satakunta University of Applied Sciences (SAMK) is actively participating this alliance among the others in legal task force which aims to form a research group and network on legal activities related to autonomous ships and concentrates on resolving the business-related obstacles and challenges particularly in charter parties, risk management and marine insurance.

3. MARITIME EDUCATION

Originally, the careers that have been connected to maritime transport, have developed by on-the-job based learning and also on different extent by shore-based education. In countries where transportation via sea is possible, the combination of shore-based education and practical onboard training has taken place. The International Convention on Standards on Training, Certification and Watchkeeping for Seafarers (STCW) which sets the minimum level for seafarers’ education and has guided globally the education of seafarers from 1984 when it entered into force. The Convention and Code have been updated several times after that due to its limitations and the latest revision Manilla amendments were adopted in 2010 to enable them to address issues are expected to arise in the near future. [4] There are various different educational system in different countries which makes possible career paths in maritime industry multifold. The curriculums in maritime education and training (MET) institutions are built individually in each country and controlled under local jurisdictions. The education must respond and adapt to the coming changes in the industry and due to that the attention maritime sector stakeholders have engaged the importance of right skills which is needed in the near future in the maritime industry. [6]

Nevertheless, the further education i.e. the master level programs for seafarers improves the possibilities to build the career paths from sea to shore after seafaring period. Often many managerial positions in land-based organizations demand a higher degree from their employers and the further educational systems have offered solutions to industry´s needs. [3]

Currently, as part of the legal task force of RAAS, SAMK is the leader in co-operation between the Nordic and European maritime educational institutions in progressing common syllabus development relating to autonomous shipping in Bachelor level STCW Conventions based
education. Also, SAMK master level program is linked into close co-operation with other maritime universities to creating opportunities to put to good use the scientific and industry experts experience and the contents of the master program courses are in connection to autonomous shipping. In existing Master education syllabus in SAMK the content development for the benefit of autonomous and remotely operated shipping is done in following subjects: 1) international treaty obligations, 2) risk management and marine insurance and 3) charter parties and shipbroking.

4. THE FUTURE MARITIME PROFESSIONALS

It is predicted that technology would increase new high-tech jobs. In the report “Transport 2040 – Automation Technology Employment – The future work” published by World Maritime University (WMU) and International Transport Worker’s Federation (ITF), it was estimated that highly automated vessel would decrease the growth rate in call of mariners with possible reduction rate 22 per cent by year 2040. This report states that the demand for new types of workers, such as remotely working operators, maintenance crews and mobility-as-a service producers would increase. [2]

In IAMU’s report, Global Maritime Professional, it is intended to meet the envisaged needs of maritime industry and evolve educational and career context while catering for the professional development aspirations of individual seafarers. The information has gathered through a comprehensive survey designed and administered to the membership of IAMU and to the other stakeholders in the maritime industry. [7]

The new concept of a Global Maritime Professional has been defined in the report as:

”An individual who is a professional in the maritime industry and who is equipped with all the relevant technical competencies relevant to their specific operational role in the industry and as required by international requirements, which high level academic skills including logical and critical thinking and who - in attention to their technical competency - exhibits a high level of professionalism and ethical behavior, human relations skills, emotional intelligence and multicultural/diversity awareness and sensitivity. Such an individual exhibits significant leadership skill and is able to optimally work with teams and also take personal initiative. They additionally exhibit a high sense of environmental consciousness and the need for sustainable practices and have an excellent grasp of contemporary issues affecting the maritime industry.” [8]

5. CONCLUSIONS

The fourth industrial revolution (4IR) has driven the world towards new ways of doing business and force us to renew our way of operating the systems rather rapidly. This revolution is shaping the operational environment in many sectors worldwide but also in national levels. The maritime industry which has reacted previously quite slowly to changes, is now strongly forced adapt to technological development and chance the way of its activities which sets new challenges and but also new opportunities.
It is acknowledged that education of seafarers must adapt to the changing maritime industry even though, the skills we need now, are not disappearing completely, not at least in the next 20-30 years. The most ships that currently are build and designed are still made for traditional shipping. This doesn’t still mean that educational institutes should not renew planning of the syllabuses and take into account of industry’s needs. MET institutions must have a strategic objective to serve the maritime industry and offer high quality research to benefit the maritime stakeholders now and in the future so that the maritime transport be executed in safe, secure and efficiently at the same time respecting the nature.

References:


SESSION 3. SHIPS AND NAVIGATION
COMPASS ADJUSTMENT BY GPS AND TWO LEADING LINES

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Abstract:

The deviation card of a magnetic compass previously adjusted on two leading lines was created using a GPS receiver.

During compass adjustment, the vessel follows magnetic courses using a gyroscopic compass and taking into account magnetic declination and gyro error. A satellite compass may also be used for the same purpose. However, some vessels are equipped with neither gyroscopic nor satellite compass. In these cases, a minimum of five leading lines must be considered, or a minimum of five bearings of conspicuous and distant points or sun’s azimuths must be taken. This renders adjustment and creation of the deviation card more laborious and time consuming. In order to expedite this process, a reliable and practical method was developed to create the deviation card with courses over ground given by a GPS receiver instead of the headings provided by a gyroscopic or satellite compass. For this purpose, the stream factor, which, as in the ECDIS, also includes other factors such as wind and waves, was considered. The method is valid for all vessels, but is primarily intended for ships equipped with only magnetic compasses to indicate the heading. Actual compass adjustment is carried out following two leadings lines that coincide with or are close to magnetic cardinal courses separated by 90°. Subsequently, courses over ground are taken when the vessel follows the main (four cardinal and four quadrantal) compass headings to create the table of residual deviations.

Keywords:

compass, adjustment, magnetic.
INTRODUCTION

The objective of this paper is the proper creation of the deviation card of a magnetic compass previously adjusted on two leading lines using a GPS receiver.

Compass adjustment is necessary for the proper working of the magnetic compass, i.e. the first nautical equipment mentioned in SOLAS V19. For many years, this procedure has remained stagnant. However, with the emergence of new technologies, magnetic compass applications and its adjustment techniques have once again become subjects of research. In Spain, for example, there are four doctoral thesis focused on the improvement of magnetic compass performance: Gaztelu-Iturri, 1999; Gea, 2003; Martinez-Lozares, 2009; Arribalzaga, 2016. This article follows this line of research in an attempt to simplify the process of compass adjustment as well as enhance efficiency, focused in small crafts that have a magnetic heading indicator only.

The paper is divided in seven sections. In section 1, the compass adjustment of small crafts is explained. In sections 2, 3 and 4, the proposed method is approached, developed and discussed respectively. In section 5, the application of the method is exposed, according to the obtained results in section 4. Section 6 is focused on the determination of necessary leading lines for the method’s application, taking as example, the fieldwork carried out in the Barcelona harbour. Finally, in section 7, conclusions are drawn.

1. INTRODUCTION TO COMPASS ADJUSTMENT

The process of compass adjustment has two phases: actual compass adjustment or compensation, and creation of the table of residual deviations or deviation card. The present work is mainly concerned with the latter. However, before this method is presented, the following sub-sections explain how compensation is carried out in vessels with only magnetic compasses to indicate heading.

1.1. DEVIATION EQUATION [2] [6]

The deviation equation commonly applied is

\[ \Delta = A + B \cdot \sin \zeta + C \cdot \cos \zeta + D \cdot \sin 2\zeta + E \cdot \cos 2\zeta \] [i],

where

\( \Delta \) is the deviation, \( \zeta \) is the compass course (\( \zeta \) indicates the magnetic course; see section 2) and A, B, C, D, E are the approximate coefficients, with the exact coefficients being the sines of the approximate ones.

Course deviation consists of three parts: constant deviation, A, which does not depend on the course; semicircular deviation, B \( \cdot \sin \zeta \) + C \( \cdot \cos \zeta \), which depends on the course, and quadrantal deviation, D \( \cdot \sin 2\zeta \) + E \( \cdot \cos 2\zeta \), which depends on twice the course. These deviations are called semicircular and quadrantal deviations because they are repeated with different sign every 180º and 90º, respectively, where 180º corresponds to half a circle (semicircle) and 90º to a quarter of a circle (quadrant).

The semicircular deviation depends mainly on the hard irons of the ship (which have permanent magnetism) and is corrected with magnets. On the other hand, the constant
and quadrantal deviations depend solely on and are corrected with the soft irons, which do not have permanent magnetism but are induced according to their orientation within the earth's magnetic field.

Considering $\zeta' = 0^\circ, 90^\circ, 180^\circ, 270^\circ$, the expressions of the deviations on the cardinal courses are obtained as follows:

\[
\Delta_n = A + C + E \\
\Delta_e = A + B - E \\
\Delta_s = A - C + E \\
\Delta_w = A - B - E
\]

Therefore, the deviations on the cardinal headings depend on the constant (coefficient A), semicircular (coefficients B, C) and part of the quadrantal (coefficient E) deviation, with the semicircular one being the main deviation.

1.2. COMPENSATION DEVICES

The semicircular deviation of compasses in small crafts is compensated with a device that fits the position of longitudinal and transversal magnets by turning one screw for the longitudinal magnets and one for the transversal ones with an anti-magnetic screwdriver. The polarity of magnets is indicated with colors: red for the north pole ends and blue or green for the south pole ends.

As an example, Figures 1 and 2 show a small binnacle comprising a longitudinal magnet (LM) on the port side with its north (red) end to aft and a transversal magnet (TM) on the fore side with its north (red) end to starboard. In addition, there are two magnets arranged in V-shape in the diametrically opposite position to the LM, and two more in the opposite position to the TM; that is, opposite poles are located at the apex and ends of the V, meaning that the latter form a magnet (V magnet). By adjusting the distance between the V ends with a screwdriver-operated device, the magnetic moment of the V magnet is changed because the distance between its poles is varied [1] [2]. Next, the magnets are arranged in such a way that each V magnet and its corresponding simple magnet have opposite polarities, and the magnetic moment of the V magnet at maximum distance between its ends is twice that of the simple magnet, such that

i) For no distance between ends of the V magnet, the resulting magnet is the simple magnet.

ii) For the maximum distance between ends of the V magnet, a magnet with the magnetic moment of the simple magnet but the polarity of the V magnet is obtained.

iii) For the middle distance between the ends of the V magnet, the resulting magnet is null.

iv) For intermediate distances, magnets with magnetic moments lower than that of the simple magnet and polarities depending on the distance from the midpoint between ends are obtained.

The quadrantal deviation can be compensated by installing soft iron correctors, such as small spheres or cylinders, or boxes where several soft iron plates can be placed. However, as this is not a common practice, this paper does not consider the compensation of this deviation. It must be remembered, though, that the effect of the quadrantal deviation is always included in the residual deviations.
Another very common device consists in placing one (or two) longitudinal and one (or two) transversal magnets that can rotate around their centers, as shown in Figure 3. In this case, the horizontal component of the magnetic moment of the magnets is used to compensate.

Figure 3. Compensating device with rotating magnets.

Source: The authors.
Notice that the longitudinal magnets are inside the transversal rotating cylinder and the transversal magnets are inside the longitudinal rotating cylinder.

1.3. COMPENSATION METHOD WITH TWO LEADING LINES

The ship follows a leading line that matches the magnetic east or west, or that is close to one of these headings, and the position of the resulting longitudinal magnet is fitted by turning the starboard screw to nullify the deviation, making the compass heading coincide with the magnetic course of the leading line.

Analogously, the ship follows a leading line that matches or is close to the magnetic north or south, and the position of the resulting transversal magnet is fitted by turning the fore screw to make the compass heading be the magnetic course of the leading line.

1.4. RESIDUAL DEVIATIONS

According to sub-section 1.3, when the deviations on two magnetic cardinal courses separated by 90° are nullified, the effect of hard irons (reflected in coefficients B, C) is minimized. However, this effect is not completely eliminated because the deviations on the cardinal courses also depend on the constant deviation (coefficient A) and part of the quadrantal one (coefficient E) (see sub-section 1.1). In addition, the effect of soft irons is not compensated, either. Consequently, residual magnetic effects remain after the compensation. [2] [6]

In small vessels, the procedure exposed in section 1.3 is usually enough to comply with the requirement in [3], i.e. the deviation on any course must not exceed 4° for ships with a length less than 82.5 m.

However, the residual deviations must be determined and reflected on the table (deviation card) attached to the compass adjustment certificate, which must also be checked regularly on board [4]. The proposed method is used to create this table, avoiding following more leading lines and/or taking bearings of conspicuous and distant points of land or sun’s azimuths, as indicated in [2] and [6], respectively.

2. APPROACH OF THE METHOD

Coefficients A, B, C, D, E of the deviation equation [i], as well as the set and drift of the current, are determined from the courses over ground indicated by the GPS when following the eight main compass courses (the four cardinal and the four quadrantal ones).

The method is based on the triangle of speeds and types of courses, as shown in Figure 4. References TN, MN, CN correspond to the true, magnetic and compass north, which are the origins of the true (TC), magnetic (ζ) and compass course (ζ’), respectively; δ is the magnetic declination; Δ, the deviation, and S, the vessel’s speed through the water. The parameters of the current are set (α) and drift (d), where α is expressed as a magnetic course. Also, β is the course difference due to the current: β = COG − TC.
3. DEVELOPMENT OF THE METHOD

According to Figure 4, by the law of sines,

\[ \frac{S}{\sin \gamma} = \frac{d}{\sin \beta} \Rightarrow \sin \beta = \frac{d}{S} \cdot \sin \gamma \]

But \( \beta + \gamma = \alpha - \zeta \), since they are opposite angles of a parallelogram. Then,

\[ \sin \beta = \frac{d}{S} \cdot \sin(\alpha - \zeta - \beta) \]

Developing,

\[ \sin \beta = \frac{d}{S} \cdot \sin(\alpha - \zeta) \cdot \cos \beta - \frac{d}{S} \cdot \cos(\alpha - \zeta) \cdot \sin \beta \]
\[
\sin \beta \left[ 1 + \frac{d}{S} \cdot \cos(\alpha - \zeta) \right] = \frac{d}{S} \cdot \sin(\alpha - \zeta) \cdot \cos \beta \Rightarrow \tan \beta = \frac{\frac{d}{S} \cdot \sin(\alpha - \zeta)}{1 + \frac{d}{S} \cdot \cos(\alpha - \zeta)}
\]

Since \((a + b) \cdot (a - b) = a^2 - b^2\), multiplying the numerator and denominator by \(- \frac{d}{S} \cdot \cos(\alpha - \zeta)\), we obtain

\[
\tan \beta = \frac{\frac{d}{S} \cdot \sin(\alpha - \zeta) \cdot \left[ 1 - \frac{d}{S} \cdot \cos(\alpha - \zeta) \right]}{1 - \frac{d^2}{S^2} \cdot \cos^2(\alpha - \zeta)}
\]

Because \(d^2\) is much smaller than \(S^2\), the denominator can be considered 1. Also, since \(\beta\) is a small angle, its tangent can be replaced by its sine, which in turn can be replaced by \(\beta \cdot \sin 1^\circ\). Thus,

\[
\beta \cdot \sin 1^\circ = \frac{d}{S} \cdot \sin(\alpha - \zeta) - \frac{d^2}{S^2} \cdot \sin(\alpha - \zeta) \cdot \cos(\alpha - \zeta)
\]

Let \(\omega = \frac{d}{S} \cdot \csc 1^\circ\),

\[
\beta = \omega \cdot \sin(\alpha - \zeta) - \omega^2 \cdot \sin(\alpha - \zeta) \cdot \cos(\alpha - \zeta)
\]

where

\[
\sin(\alpha - \zeta) = \sin \alpha \cdot \cos \zeta - \cos \alpha \cdot \sin \zeta
\]

\[
\cos(\alpha - \zeta) = \cos \alpha \cdot \cos \zeta + \sin \alpha \cdot \sin \zeta
\]

Now let

\[
\left\{ \begin{array}{l}
\omega \cdot \cos \alpha = x \\
\omega \cdot \sin \alpha = y
\end{array} \right\} \Rightarrow \left\{ \begin{array}{l}
\omega \cdot \sin(\alpha - \zeta) = -x \cdot \sin \zeta + y \cdot \cos \zeta \\
\omega \cdot \cos(\alpha - \zeta) = x \cdot \cos \zeta + y \cdot \sin \zeta
\end{array} \right.
\]

Consequently,

\[
\omega^2 \cdot \sin(\alpha - \zeta) \cdot \cos(\alpha - \zeta) = (-x \cdot \sin \zeta + y \cdot \cos \zeta) \cdot (x \cdot \cos \zeta + y \cdot \sin \zeta) =
\]

\[
= -x^2 \cdot \sin \zeta \cdot \cos \zeta - x \cdot y \cdot \sin^2 \zeta + x \cdot y \cdot \cos^2 \zeta + y^2 \cdot \sin \zeta \cdot \cos \zeta =
\]

\[
= x \cdot y \cdot \cos 2\zeta - \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin 2\zeta
\]

Then,

\[
\beta = -x \cdot \sin \zeta + y \cdot \cos \zeta - x \cdot y \cdot \sin 1^\circ \cdot \cos 2\zeta - \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin 1^\circ \cdot \sin 2\zeta
\]

Substituting \(\zeta\) by \(\zeta'\),

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\[
\beta = -x \cdot \sin \zeta' + y \cdot \cos \zeta' - x \cdot y \cdot \sin 1^\circ \cdot \cos 2\zeta' - \frac{1}{2}(x^2 - y^2) \cdot \sin 1^\circ \cdot \sin 2\zeta'
\]

The deviation is the difference between the magnetic course and the compass course, i.e. \(\Delta = \zeta - \zeta'\). Likewise, the magnetic course is the difference between the true course and the magnetic declination, i.e. \(\zeta = TC - \delta\). Hence, \(\Delta = TC - \delta - \zeta'\), and TC is the difference between the course over ground and \(\beta\): \(TC = COG - \beta\). Therefore,

\[\Delta = COG - \beta - \delta - \zeta'\]

And the deviation equation is

\[\Delta = A + B \cdot \sin \zeta' + C \cdot \cos \zeta' + D \cdot \sin 2\zeta' + E \cdot \cos 2\zeta'\]

Thus,

\[COG - \beta - \delta - \zeta' = A + B \cdot \sin \zeta' + C \cdot \cos \zeta' + D \cdot \sin 2\zeta' + E \cdot \cos 2\zeta'\]

Now let the pseudo-deviation (\(\Psi\)) be defined as the difference between the course over ground and the compass course: \(\Psi = COG - \zeta'\). Then,

\[\Psi = A + B \cdot \sin \zeta' + C \cdot \cos \zeta' + D \cdot \sin 2\zeta' + E \cdot \cos 2\zeta' + \beta + \delta\]

\[\Psi = A + B \cdot \sin \zeta' + C \cdot \cos \zeta' + D \cdot \sin 2\zeta' + E \cdot \cos 2\zeta' + x \cdot \sin \zeta' + y \cdot \cos \zeta' - x \cdot y \cdot \sin 1^\circ \cdot \cos 2\zeta' - \frac{1}{2}(x^2 - y^2) \cdot \sin 1^\circ \cdot \sin 2\zeta' + \delta\]

Particularizing for the four cardinal compass courses, we obtain

\[\Psi_n = A + C + E + y \cdot x \cdot y \cdot \sin 1^\circ + \delta \quad [\text{ii}]
\]

\[\Psi_e = A + B - E - x + x \cdot y \cdot \sin 1^\circ + \delta \quad [\text{iii}]
\]

\[\Psi_s = A - C + E - y - x \cdot y \cdot \sin 1^\circ + \delta \quad [\text{iv}]
\]

\[\Psi_w = A - B - E + x + x \cdot y \cdot \sin 1^\circ + \delta \quad [\text{v}]
\]

Consequently,

\[[\text{i}] + [\text{ii}] + [\text{iii}] + [\text{iv}] \Rightarrow \Psi_n + \Psi_e + \Psi_s + \Psi_w = 4A + 4\delta
\]

\[A = \frac{1}{4}(\Psi_n + \Psi_e + \Psi_s + \Psi_w) - \delta \quad [\text{vi}]
\]

\[[\text{ii}] - [\text{iv}] \Rightarrow \Psi_e - \Psi_w = 2B - 2x \Rightarrow B = \frac{1}{2}(\Psi_e - \Psi_w) + x \quad [\text{vii}]
\]

\[[\text{i}] - [\text{iii}] \Rightarrow \Psi_n - \Psi_s = 2C + 2y \Rightarrow C = \frac{1}{2}(\Psi_n - \Psi_s) - y \quad [\text{viii}]
\]

\[[\text{i}] + [\text{iii}] - [\text{ii}] - [\text{iv}] \Rightarrow \Psi_n + \Psi_s - \Psi_e - \Psi_w = 4E - 4 \cdot x \cdot y \cdot \sin 1^\circ
\]

\[E = \frac{1}{4}(\Psi_n + \Psi_s - \Psi_e - \Psi_w) + x \cdot y \cdot \sin 1^\circ \quad [\text{ix}]
\]

And particularizing for the four quadrantal compass courses, we obtain
\[ \Psi_{ne} = A + B \cdot \frac{\sqrt{2}}{2} + C \cdot \frac{\sqrt{2}}{2} + D - x \cdot \frac{\sqrt{2}}{2} + y \cdot \frac{\sqrt{2}}{2} - \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin l^\circ + \delta \]  
[x]

\[ \Psi_{se} = A + B \cdot \frac{\sqrt{2}}{2} - C \cdot \frac{\sqrt{2}}{2} - D - x \cdot \frac{\sqrt{2}}{2} - y \cdot \frac{\sqrt{2}}{2} + \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin l^\circ + \delta \]  
[xi]

\[ \Psi_{sw} = A - B \cdot \frac{\sqrt{2}}{2} - C \cdot \frac{\sqrt{2}}{2} + D + x \cdot \frac{\sqrt{2}}{2} - y \cdot \frac{\sqrt{2}}{2} - \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin l^\circ + \delta \]  
[xii]

\[ \Psi_{nw} = A - B \cdot \frac{\sqrt{2}}{2} + C \cdot \frac{\sqrt{2}}{2} - D + x \cdot \frac{\sqrt{2}}{2} + y \cdot \frac{\sqrt{2}}{2} + \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin l^\circ + \delta \]  
[xiii]

Therefore,

\[ [x] - [xii] \Rightarrow \Psi_{ne} - \Psi_{sw} = (B + C - x + y) \cdot \sqrt{2} \]  
[xiv]

\[ [x] + [xii] \Rightarrow \Psi_{ne} + \Psi_{sw} = 2A + 2D - \left( x^2 - y^2 \right) \cdot \sin l^\circ + 2\delta \]  
[xv]

\[ [xi] - [xiii] \Rightarrow \Psi_{se} - \Psi_{nw} = (B - C - x - y) \cdot \sqrt{2} \]  
[xvi]

\[ [xi] + [xiii] \Rightarrow \Psi_{se} + \Psi_{nw} = 2A - 2D + \left( x^2 - y^2 \right) \cdot \sin l^\circ + 2\delta \]  
[xvii]

\[ [xv] - [xvii] \Rightarrow \Psi_{ne} + \Psi_{sw} - \Psi_{se} - \Psi_{sw} = 4D - 2 \left( x^2 - y^2 \right) \cdot \sin l^\circ \]  
[xviii]

\[ D = \frac{1}{4} \left( \Psi_{ne} + \Psi_{sw} - \Psi_{se} - \Psi_{sw} \right) - \frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin l^\circ \]  
[xvii]

\[ [xv] + [xvii] \Rightarrow \Psi_{ne} + \Psi_{sw} + \Psi_{se} + \Psi_{nw} = 4A + 4\delta \]  
[xv]

\[ A = \frac{1}{4} \left( \Psi_{ne} + \Psi_{se} + \Psi_{sw} + \Psi_{nw} \right) - \delta \]  
[xix]

\[ [xiv] + [xv] \Rightarrow \Psi_{ne} - \Psi_{sw} = 2(B - x) \cdot \sqrt{2} \]  
[xiv]

\[ B = \frac{1}{2\sqrt{2}} \left( \Psi_{ne} + \Psi_{se} - \Psi_{sw} - \Psi_{nw} \right) + x \]  
[xx]

\[ [xiv] - [xvi] \Rightarrow C = \frac{1}{2\sqrt{2}} \left( \Psi_{ne} + \Psi_{nw} - \Psi_{se} - \Psi_{sw} \right) - y \]  
[xxi]

\[ [xv] + [xx] \Rightarrow 2B = \frac{1}{2} \left[ \Psi_{e} - \Psi_{w} + \frac{\sqrt{2}}{2} \left( \Psi_{ne} + \Psi_{se} - \Psi_{sw} - \Psi_{nw} \right) \right] + 2x \]  
[xxii]

\[ B = \frac{1}{4} \left[ \Psi_{e} - \Psi_{w} + \frac{\sqrt{2}}{2} \left( \Psi_{ne} + \Psi_{se} - \Psi_{sw} - \Psi_{nw} \right) \right] + x \]  
[xiii]

\[ [xvii] + [xxi] \Rightarrow C = \frac{1}{4} \left[ \Psi_{n} - \Psi_{s} + \frac{\sqrt{2}}{2} \left( \Psi_{ne} + \Psi_{se} - \Psi_{sw} - \Psi_{nw} \right) \right] - y \]  
[xxiii]

\[ [vi] + [xix] \Rightarrow A = \frac{1}{8} \left( \Psi_{n} + \Psi_{ne} + \Psi_{e} + \Psi_{se} + \Psi_{s} + \Psi_{sw} + \Psi_{w} + \Psi_{nw} \right) - \delta \]  
[xxiv]

It is observed that unknowns \( x, y \) cannot be found. Hence, it is only possible to determine coefficients \( B, \ldots, E \) if \( d, \alpha \), on which \( x, y \) depend, are known previously. Therefore, it is convenient to express \( B, \ldots, E \) as a function of the current parameters:

\[ x = \omega \cdot \cos \alpha = \frac{d}{S} \cdot \csc l^\circ \cdot \cos \alpha \cong 57.3 \cdot \frac{d}{S} \cdot \cos \alpha \]  
[xxv]
y = ω · sin α = \frac{d}{S} \cdot \csc 1^\circ \cdot \sin α \approx 57.3 \cdot \frac{d}{S} \cdot \sin α \quad [xxvi] \\
x \cdot y \cdot \sin 1^\circ = \frac{d^2}{S^2} \cdot \csc^2 1^\circ \cdot \cos \alpha \cdot \sin \alpha \cdot \sin 1^\circ = \frac{d^2}{S^2} \cdot \csc 1^\circ \cdot \frac{1}{2} \sin 2\alpha \approx 28.65 \cdot \frac{d^2}{S^2} \cdot \sin 2\alpha \\
\frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin 1^\circ = \frac{1}{2} \left( \frac{d^2}{S^2} \cdot \csc^2 1^\circ \cdot \cos^2 \alpha - \frac{d^2}{S^2} \cdot \csc^2 1^\circ \cdot \sin^2 \alpha \right) \cdot \sin 1^\circ \\
\frac{1}{2} \left( x^2 - y^2 \right) \cdot \sin 1^\circ = \frac{1}{2} \cdot \frac{d^2}{S^2} \cdot \csc 1^\circ \left( \cos^2 \alpha - \sin^2 \alpha \right) \approx 28.65 \cdot \frac{d^2}{S^2} \cdot \cos 2\alpha \quad [xxviii] 

Then, substituting the expressions of x, y, x·y·sin 1^\circ, \frac{1}{2}(x^2 - y^2)·\sin 1^\circ according to [xxv], [xxvi], [xxviii], [xxvii] in expressions [xxii], [xxiii], [xxviii], [ix], respectively, we have 

B = \frac{1}{4} \left( \Psi e - \Psi w + \frac{\sqrt{2}}{2} \cdot \left( \Psi ne + \Psi se - \Psi sw - \Psi nw \right) \right) + 57.3 \cdot \frac{d}{S} \cdot \cos \alpha \quad [xxix] \\
C = \frac{1}{4} \left( \Psi n - \Psi s + \frac{\sqrt{2}}{2} \cdot \left( \Psi ne + \Psi nw - \Psi se - \Psi sw \right) \right) - 57.3 \cdot \frac{d}{S} \cdot \sin \alpha \quad [xxx] 

D = \frac{1}{4} \left( \Psi ne + \Psi sw - \Psi se - \Psi nw \right) - 28.65 \cdot \frac{d^2}{S^2} \cdot \cos 2\alpha \quad [xxxi] \\
E = \frac{1}{2} \left( \Psi n + \Psi s - \Psi e - \Psi w \right) + 28.65 \cdot \frac{d^2}{S^2} \cdot \sin 2\alpha \quad [xxxii] 

Coefficients B, C can also be obtained by substituting the expressions of x, y according to [xxv], [xxvi] in the expressions [vii], [xx] and [viii], [xxi], respectively:

B = \frac{1}{2} \left( \Psi e - \Psi w \right) + 57.3 \cdot \frac{d}{S} \cdot \cos \alpha \quad [xxxiii] \\
B = \frac{1}{2} \sqrt{2} \cdot \left( \Psi ne + \Psi se - \Psi sw - \Psi nw \right) + x \\
B = 0.3536 \cdot \left( \Psi ne + \Psi se - \Psi sw - \Psi nw \right) + 57.3 \cdot \frac{d}{S} \cdot \cos \alpha \quad [xxxiv] \\
C = \frac{1}{2} \left( \Psi n - \Psi s \right) - 57.3 \cdot \frac{d}{S} \cdot \sin \alpha \quad [xxv] \\
C = 0.3536 \cdot \left( \Psi ne + \Psi nw - \Psi se - \Psi sw \right) - 57.3 \cdot \frac{d}{S} \cdot \sin \alpha \quad [xxxvi]
4. DISCUSSION OF THE METHOD

Expressions [xxix], [xxx], [xxxiii], [xxxiv], [xxxv], [xxxvi] are not reliable for calculating coefficients B, C because not knowing with precision the d/S ratio can lead to a considerable error.

Nevertheless, it is observed that at a sufficient speed, the \( d^2/S^2 \) ratio is very small, and can therefore be neglected in expressions [xxxii], [xxxii]. For example, for an already quite critical ratio of \( S/d = 5 \) (i.e. a ship sailing at 5 knots with a 1 knot current, or a ship sailing at 10 knots with a 2 knot current), the maximum error in the calculation of coefficients D, E would be 1°. This maximum error is shown below for the S/d ratio:

**Figure 5. Maximum error of coefficients D, E for the S/d ratio.**

<table>
<thead>
<tr>
<th>S/d</th>
<th>Max. error: 28.65·d²/S²</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.1460</td>
</tr>
<tr>
<td>6</td>
<td>0.7958</td>
</tr>
<tr>
<td>7</td>
<td>0.5847</td>
</tr>
<tr>
<td>8</td>
<td>0.4477</td>
</tr>
<tr>
<td>9</td>
<td>0.3537</td>
</tr>
<tr>
<td>10</td>
<td>0.2865</td>
</tr>
<tr>
<td>11</td>
<td>0.2368</td>
</tr>
<tr>
<td>12</td>
<td>0.1990</td>
</tr>
</tbody>
</table>

Source: The authors.

These results show that the effect of the current can indeed be neglected in expressions [xxxii], [xxxii]. Therefore,

\[
\begin{align*}
D &= \frac{1}{4} (\Psi_n e + \Psi_s w - \Psi_s e - \Psi_n w) \quad [\text{xxxvii}] \\
E &= \frac{1}{4} (\Psi_n + \Psi s - \Psi e - \Psi w) \quad [\text{xxxviii}]
\end{align*}
\]

In summary:

i) Coefficient A can be determined from the pseudo-deviations without error. The magnetic declination must also be applied (see [vi], [xix], [xxiv]).

ii) Coefficients D, E can be determined solely from the pseudo-deviations but with a small error which is negligible for sufficiently high speeds, i.e. for a ratio of \( S/d \) equal or greater than 8, which causes an error less than 0.5° for each coefficient. Assuming a drift of 1 knot or less, the minimum speed is 8 knots, and assuming a drift of 0.5 knots or less, the minimum speed is 4 knots.

iii) Coefficients B, C cannot be calculated with the pseudo-deviations because a considerable error can be made.

On the other hand, coefficients B, C can be determined from coefficients A, E (calculated from the pseudo-deviations) because

\[
\Delta e, w = A \pm B - E \Rightarrow B = \pm (\Delta e, w - A + E) \quad [\text{xxxix}]
\]

\[
\Delta n, s = A \pm C + E \Rightarrow C = \pm (\Delta n, s - A - E) \quad [\text{xl}]
\]

where \( \Delta e, w \) and \( \Delta n, s \) can be considered the deviations on the leading lines which have been nullified. Therefore,
B = \pm (- A + E) \quad (+ \text{leading line towards E}; - \text{leading line towards W})
\[ C = \pm (- A - E) \quad (+ \text{leading line towards N}; - \text{leading line towards S}) \]

Simplifying,
\[
B = (-1)^{\lfloor TB_i/180 \rfloor + 1} \cdot (A - E) \quad \text{[xli]}
\]
\[
C = (-1)^{\lfloor TB_j/180 \rfloor + 1.5} \cdot (A + E) \quad \text{[xlii]}
\]

where

\([x]\) is the integer part of \(x\), and \(TB_1, TB_2\) are the true bearings, expressed in circular form (from 0º to 360º), of the leading line close to the E or W and the leading line close to the N or S, respectively.

5. APPLICATION OF THE METHOD

The complete procedure to compensate the compass and create its table of the residual deviations is as follows:

1. The vessel must follow a leading line coincident with or close to the magnetic east or west, and the deviation must be nullified. Next, the vessel must continue following the leading line, and the course over ground indicated by the GPS must be noted down to determine the pseudo-deviation, i.e. \(\Psi_{e,w} = \text{COG} - \zeta'\).

2. \text{Idem} on a leading line coincident with or close to the magnetic north or south.

3. The vessel must follow the other six main compass courses, and the course over ground indicated by the GPS must be noted down to determine the pseudo-deviations.

4. Coefficients A, D, E, B, C must be calculated using expressions [vi], [xxxvii], [xxxviii], [xli], [xlii], respectively. Coefficient A can also be obtained by using [xix], [xxiv].

5. The table of the residual deviations must be created by applying the deviation equation [i] to different compass courses, for example every 15º, as is the case of the deviation card model of the Spanish regulation [5].

6. DETERMINATION OF LEADING LINES

Two leading lines that coincide with or are as close as possible to magnetic cardinal courses separated by 90º must be found. However, these leading lines cannot always be determined on the chart (because one or both points are not on the chart), or if they can be, they may be at a considerable distance. Alternatively, points that determine the required leading lines can be selected despite not appearing on the chart, and then their positions can be obtained from Google Maps and verified in situ, as done by Moncunill and González La Flor in the outer northern area of the Barcelona harbour.
On January 16, 2020, the sailboat APHRODITE sailed the coastal waters between the Besòs river mouth and the northern entrance to the Barcelona harbour, corresponding to a distance of about 5 nautical miles. The voyage actually began and ended at El Masnou marina (where the sailboat has her mooring), about 6 miles NE of the Besòs river mouth. The meteorological conditions were as follows: on the way out, in the morning, predominant onshore wind of force 2 on the Beaufort scale and rippled sea with a 0.5 m swell from E; on the way back, in the afternoon, SW wind of force 3 and smooth sea; good visibility and almost clear sky throughout the day. We sailed all the time, with the occasional use of the engine.

The following leading lines, on which the points can be clearly distinguished, were observed:

i) Close to the W, southernmost chimney stack of former thermal power plant by the Besòs river (point A) with the Tibidabo church (point B): IMAGE 1 (Figure 6).

ii) Close to the W, second northernmost chimney stack of the Besòs combined cycle plant (Endesa towers) (point C) with the Tibidabo church (point B): IMAGE 2 (Figure 7).

iii) Close to the W, the Glòries tower (former Agbar tower) (point D) with the Collserola telecommunications tower (point E): IMAGE 3 (Figure 8).

iv) Close to the N, the Aigües del Besòs tower (point F) between two emblematic buildings: IMAGE 4 (Figure 9). A ship's position was taken as the second point when the ship was following the leading line (point G).

v) Close to the N, the La Catalana de Gas tower (point H) with the Glòries tower (point D): IMAGE 5 (Figure 10).

Figure 6. IMAGE 1: Leading line A–B, close to the W.
On January 16, 2020, the sailboat *APHRODITE* sailed the coastal waters between the Besòs river mouth and the northern entrance to the Barcelona harbour, corresponding to about 5 nautical miles. The voyage actually began and ended at El Masnou marina (where the sailboat has her mooring), about 6 miles NE of the Besòs river mouth.

The meteorological conditions were as follows: on the way out, in the morning, predominant onshore wind of force 2 on the Beaufort scale and rippled sea with a 0.5 m swell from E; on the way back, in the afternoon, SW wind of force 3 and smooth sea; good visibility and almost clear sky throughout the day. We sailed all the time, with the occasional use of the engine.

The following leading lines, on which the points can be clearly distinguished, were observed:

i) Close to the W, southernmost chimney stack of former thermal power plant by the Besòs river (point A) with the Tibidabo church (point B): 

![Figure 6. IMAGE 1: Leading line A–B, close to the W.](image)

Source: The authors.

ii) Close to the W, second northernmost chimney stack of the Besòs combined cycle plant (Endesa towers) (point C) with the Tibidabo church (point B):

![Figure 7. IMAGE 2: Leading line C–B, close to the W.](image)

Source: The authors.

iii) Close to the W, the Glòries tower (former Agbar tower) (point D) with the Collserola telecommunications tower (point E):

![Figure 8. IMAGE 3: Leading line D–E, close to the W.](image)

Source: The authors.

iv) Close to the N, the Angus del Besòs tower (point F) between two emblematic buildings: 

![Figure 9. IMAGE 4: Leading line F–G.](image)

Source: The authors.

v) Close to the N, the La Catalana de Gas tower (point H) with the Glòries tower (point D):

![Figure 10. IMAGE 5: Leading line D–E, close to the W.](image)

Source: The authors.
Figure 9. IMAGE 4: Leading line G–F, close to the N.

Source: The authors.

Figure 10. IMAGE 5: Leading line H–D, close to the N.

Source: The authors.
Since the sailboat has a magnetic heading indicator only, it was impossible to determine exactly the true bearing of each leading line. Therefore, the positions of points A,...,H, must be taken to obtain them.

These positions, which were taken from Google Maps and verified in situ, are shown in the table below. They were rounded to the fourth decimal place of sexagesimal degree (in latitude, 0.0001º corresponds to 11 m). Differences between both positions (Google Maps and verified in situ) are due to the impossibility to access the central point of the buildings. As for the position provided by the GPS (point G), it is shown as it appears on the screen, i.e. rounded to the third decimal place of sexagesimal minute (0.001′ = 1.852 m).

### Figure 11. Position of the points of the obtained leading lines.

<table>
<thead>
<tr>
<th>Point</th>
<th>Google Maps</th>
<th>In situ verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Three Besòs chimney stacks</td>
<td>41.4266° 2.2345°</td>
<td>41.4263° 2.2342°</td>
</tr>
<tr>
<td>B: Tibidabo church</td>
<td>41.4220° 2.1187°</td>
<td>41.4217° 2.1192°</td>
</tr>
<tr>
<td>C: Endesa towers</td>
<td>41.4191° 2.2296°</td>
<td>41.4185° 2.2303°</td>
</tr>
<tr>
<td>D: Glòries tower (Agbar tower)</td>
<td>41.4038° 2.1895°</td>
<td>41.4037° 2.1896°</td>
</tr>
<tr>
<td>E: Collserola tower</td>
<td>41.4170° 2.1143°</td>
<td>41.4180° 2.1151°</td>
</tr>
<tr>
<td>F: Aigües del Besòs tower</td>
<td>41.4060° 2.2117°</td>
<td>41.4061° 2.2119°</td>
</tr>
<tr>
<td>G: Sea, following the leading line</td>
<td>* * *</td>
<td>41°23.319′N 2°12.828′E</td>
</tr>
<tr>
<td>H: La Catalana de Gas tower</td>
<td>41.3838° 2.1926°</td>
<td>41.3837° 2.1925°</td>
</tr>
</tbody>
</table>

Source: The authors.

The true bearing (TB) of each leading line can be determined in three different ways:

i) Plotting the points on the chart and drawing the leading lines.

ii) Using dead reckoning formulae.

iii) Using the loxodrome equation.

With the help of a spreadsheet, it was finally decided to use the loxodrome equation, from which it follows that

\[
\cos \text{TB}_{\text{SEMICIRCULAR}} = \frac{M_2 - M_1}{\sqrt{(M_2 - M_1)^2 + (\lambda_2 - \lambda_1 + 360 \cdot k)^2}},
\]

where

\( \text{TB}_{\text{SEMICIRCULAR}} \), i.e. the arccosine provided by calculators and spreadsheets, is between 0° and 180°; \( M_1, M_2 \) are the meridional parts, expressed in sexagesimal degrees, of the closest point of the leading line and the furthest one, respectively; \( \lambda_1, \lambda_2 \) are the positive (E) or negative (W) longitude, expressed in sexagesimal degrees, of the closest point of
the leading line and the furthest one, respectively, and k is the integer (0, 1 or –1) such that the absolute value of \( \lambda_2 - \lambda_1 + 360 \cdot k \) is inferior or equal to 180º. In this case, \( k = 0 \).

Likewise, with \( \varphi \) being the latitude of a point, expressed in sexagesimal degrees, and positive or negative depending on whether it is N or S, respectively, its meridional part (M) is

\[
M = \frac{180^\circ}{\pi} \cdot \ln \tan \left(45^\circ + \frac{1}{2} \varphi \right)
\]

Finally, the true bearing expressed in circular form (from 0º to 360º) is TBSEMICIRCULAR if \( \lambda_2 - \lambda_1 + 360 \cdot k \) is positive, or 360º – TBSEMICIRCULAR if it is negative. TBSEMICIRCULAR was obtained from a cosine and not a tangent (using the most common formula in Navigation) because, unlike the tangent function, the cosine function is continuous such that errors in the spreadsheet are avoided with the arccosine.

The obtained true bearings, rounded to half sexagesimal degree, are shown in the following table:

**Figure 12. True bearings of the obtained leading lines.**

<table>
<thead>
<tr>
<th></th>
<th>A–B</th>
<th>C–B</th>
<th>D–E</th>
<th>G–F</th>
<th>H–D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>267</td>
<td>271.5</td>
<td>283</td>
<td>355</td>
<td>353.5</td>
</tr>
</tbody>
</table>

Source: The authors.

The practical value of the magnetic declination (i.e. rounded to half sexagesimal degree) for the indicated day, taking the breakwater end at the north mouth of the Barcelona harbour (41.3577, 2.1854, Google Maps) as the reference position, is 1º.

According to the *World Magnetic Model* WMM (2019-24), as used by NOAA ([https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml](https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml)), \( \delta = 1.23^\circ \pm 0.34^\circ \).


It is worth recalling that the magnetic declination varies very slowly, both in time and space (except near the geographical and magnetic poles), and therefore the value of 1º is valid for the entire area considered.

Hence, the magnetic bearings are

**Figure 13. Magnetic bearings of the obtained leading lines.**

<table>
<thead>
<tr>
<th></th>
<th>A–B</th>
<th>C–B</th>
<th>D–E</th>
<th>G–F</th>
<th>H–D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>266</td>
<td>270.5</td>
<td>282</td>
<td>354</td>
<td>352.5</td>
</tr>
</tbody>
</table>

Source: The authors.
The two closest to the magnetic bearings N and W are selected:

G–F: *Aigües del Besòs* tower between two emblematic buildings: IMAGE 4 (Figure 9)

C–B: second northernmost chimney stack of the Besòs combined cycle plant (Endesa towers) with the Tibidabo church: IMAGE 2 (Figure 7)

In addition, the leading line C–B has the advantage over A–B that it is closer to G–F.

7. CONCLUSIONS

The proposed method enables a rigorous and practical compensation to be carried out on vessels that have a magnetic heading indicator only. In order to perform the actual compass adjustment, two leading lines as close as possible to magnetic cardinal courses separated by 90° must be known, and to create the deviation card, a GPS receiver is used.

References:


CRUISE PORT IDENTITY MAPPING BY USING MULTI CRITERIA EVALUATION WITH GEOGRAPHIC INFORMATION SYSTEMS

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(II) Prof. Dr., Mugla SK University, Bodrum Maritime Vocational School, kulelituncay@gmail.com

Abstract:

Port identity is an important factor in the development of a cruise port destination. By definition, the port identity created by quantitative and qualitative components can be defined as a collection of meanings that a continuous process extending from the past to the future. The aim of this paper is to propose a method that shows how to digitalize the port identity. As digitalization, the port identity was mapped via Geographic Information based Multi-Criteria Evaluation (GIS-MCE) method. For mapping, the port identity GIS-MCE method was used. Before applying the GIS-MCE method, four basic input steps are needed to be completed: (i) data collection for quantitative criteria that defined the port identity; (ii) converting data for GIS usage; (iii) assigning of weights of each criterion using the pairwise comparison; (iv) spatial analysis in GIS toward mapping the port identity. In this study, the method for mapping was applied to a cruise port destination in Turkey, named Bodrum. By looking at the port identity distribution map which was created, for Bodrum, it has resulted that the geographic position of Bodrum Cruise Port reflects the identity at a level of 93%. Also, as a result of spatial analysis, it was observed that the port identity that is distributed across the whole destination at least a level of 53%. The results were achieved with 82.9% consensus accordingly a group decision-making process in defining weight factors of the criteria. In conclusion, the port identity distribution map, which was created in this paper, is proposed as a useful decision support tool for decision-makers on their local and regional spatial planning and cruise destination planning.

Key words:

Port identity, GIS-MCE, cruise tourism.

INTRODUCTION

Cruising has become more and more popular in the travel industry. Cruise activities are based on cruise ships and seaport-destinations. Therefore, so-called cruise industry is feed by two sides: maritime and leisure based economy. The cruise industry has become increasingly competitive in worldwide (Chen & Nijkamp, 2018). It has been growing significantly and continuously since 1980 (Dowling, 2006). Globally, it is one of the largest emerging ocean
industries considering its long-term potential for innovation, employment creation and economic growth (OECD, 2016). From a marketing point of view, cruise market is an oligopoly where a few global cruise operators dominated to a large part of the industry (Wood, 2000; Dowling, 2006; Da Cruz, 2017). Today, with a 29.5 million passenger capacity 423 cruise ships sail worldwide. Estimated revenues are based on the average revenue generated by each passenger for the major cruise operators over the past years, is approximately $1,675 per cruise (Gungor, 2020). The shares of the market are distributed geographically to the North America, Europe and Asia/Pacific. The cruise industry grew by an average of 7.5 % annually between 1980 and 2011. With new ship orders, global passenger capacity will increase by 32% by 2027 (Gungor, 2020).

World cruise fleet are much more diversified than ever regarding ship sizes and facilities onboard. Features of the ships create segmentation on the market. Cruise ships visit at least two port-destinations in order to provide a cruise rather than floating hotel experience. So, this unique experience as a mix of sea navigation and shore excursion that makes the cruise market very popular among travelers. Seaports facilitate maritime operations for cruise ships and passengers while port-destination have a big impact on overall cruise passenger satisfaction as well as cruise operators’ choices for planning itinerary (Rodrigue & Nottebom, 2012). According to Marti (1990), one of four components which set the bounds on cruise itineraries is the spatial pattern of port-destinations (Marti, 1990). Distinctiveness (uniqueness) is one of key principles of spatial planning and related policies for cruise port development (McCarthy & Romein, 2012). Several port visits including shore excursions in port-destinations are still the most influential factor as much as modernized cruise ships attracting cruise passengers (CLIA, 2014). Cruise port-destinations is a substantial component of cruise industry since cruise demand is affected by them especially by unique ones (Lee & Ramdeen, 2013; Vaggelas, 2016).

Although the largest share of cruise market are taken by cruise ship operators, cruise activities generate socio-economic benefits to the destinations (Dwyer & Forsyth, 1998; Braun et al., 2002; Dwyer et al., 2004; Fernández Guerrero et al., 2008; Vaggelas, 2016). There is a strong competition among cruise port-destinations because trends in demand side has been changing over the years. In addition to this, modern cruise ships have become self-sufficient systems, just like a holiday destination. So, the ports and destinations are became both competitors and complementary elements of ship operators.

From one side, modern cruise ships are introduced in the market as a destination in itself (Wood, 2000; Weaver, 2005; Rodrigue & Nottebom, 2012; Whyte, 2016; CLIA, 2017). On the other side, the developments in the industry have put the importance of the concept of port identity more crucial than ever. According to the Organization for Economic Co-operation and Development (OECD), maritime and port identity is a key issue in sustainable development of port-cities. The identity factor was ignored in many port development plans, however it is an important instrument for regional and global competitiveness of port-cities (OECD, 2015).

In this study, port identity concept was mapped by using GIS (Geographic Information System) based MCE (Multi Criteria Evaluation) as a decision support tool for cruise port-destination developers, managers or stakeholders. This paper consists of four main sections. In first section which is introduction basic information, literature about cruise market were given and the objective of the study were mentioned. The next is methodology section where data, method and techniques that used for mapping the port identity was explained. The mapping process was
applied in a research area so results were given for this application in the result section. Finally, evaluation of results, limitations of the study and recommendations were presented in the conclusion section.

1. METHODOLOGY

In this section, research area that was selected for the application of the method to map the port identity was given. Data and method where data types, methods and techniques to be used in mapping processes were given as the second sub-title. Results of the application of port identity mapping method to the research area were given in the results section.

1.1. RESEARCH AREA

The research area is a coastal distinct located near the Aegean Sea, Turkey. It has 30,224 sq. km of sea surface, including waterways among Greek Islands and 70,438 sq. km of land surface, including several touristic attractions. Bodrum was selected considering its potential to attract easily cruise ships as a result of its geostrategic position, natural sources and cultural heritage, also its social opportunities such as shopping and entertainments (Idikut & Edelman, 2003; Kiper, 2004). Research area boundaries were determined based on current and potential mobility of cruise passengers around the cruise port considering authors observations, interviews with local stakeholders during field study that was held in July-September, 2017 and June-August, 2018 in Bodrum (Figure 1).

Figure 1. The boundaries of research area (Bodrum Cruise Port-Destination) in the Bodrum (Turkey) Peninsula.
Studied area is a well-known touristic port-destination as well as an ancient city named Halicarnassus (modern name is Bodrum) where socio-economic activities have mainly been mainly depending on marine and coastal tourism. Current cruise port called as Bodrum Cruise Port is an artificial seaport that facilitates maritime transportation via the ease of approach to the destination.

1.2. DATA-METHOD

For mapping, GIS-MCE method was used. In the GIS-MCE for mapping the port identity, Saity’s Analytic Hierarchy Process (AHP) was combined with GIS. Although the AHP was developed outside the GIS software, different disciplines have integrated multi-criteria approach with GIS in order to aid decision process (Carver, 1991; Lin et al., 1997; Eastman et al., 1998; Atkinson et al., 2005; Gemitz et al., 2007; Aceves-Quesada et al., 2007; Wood & Dragicevic, 2007; Krois & Schulte 2014; Bagdanaviciute et al., 2018; Irina et al., 2019).

For applying the method, four basic input steps are needed to be completed: (i) data collection for quantitative criteria that defined the port identity; (ii) converting data for GIS usage; (iii) assigning of weights of each criterion using the pairwise comparison; (iv) Spatial analysis in GIS toward mapping the port identity.

(i) Data collection for quantitative criteria that defined the port identity

The method for mapping the port identity consists of processes, which begin with the data collection in order to prepare each port identity criterion map for further spatial analysis. The data about port related spatial criteria were obtained from different data sources as shown in the Table 1. Therefore, every data set was needed to be separated concerning data type (point, line and polygon) for GIS applications. Vector file formats were generated from collected data in GIS software. Spatial information collected from Openstreetmap and Google Earth were verified using 1/25.000 zone map of the Bodrum and field studies.

<table>
<thead>
<tr>
<th>Data set</th>
<th>Data Types</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port identity criteria</td>
<td>Point</td>
<td>Openstreet.mapper</td>
</tr>
<tr>
<td>Historical-cultural places</td>
<td>x</td>
<td>Topographic maps</td>
</tr>
<tr>
<td>Natural places</td>
<td>x</td>
<td>Google.Earth</td>
</tr>
<tr>
<td>Endemic places</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Places for local foods and beverages</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Coast and beaches</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sport facilities</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>City center</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
(ii) Converting data for GIS usage

TerrSet Geospatial Monitoring and Modelling System, IDRISI GIS software was used for GIS applications. Therefore, spatial data that gathered for the identity criteria were prepared for an appropriate file format and projection for creating criteria maps. In this step, initial maps converted to raster images, because raster images will be used as an input for next spatial analysis.

(iii) Assigning of weights of each criterion using the pairwise comparison.

For fulfilling MCE procedures in GIS, factor weights should be calculated. In this step, pairwise comparison technique of Saaty’s AHP was used (Saaty, 1980). Evaluations were taken from cruise experts, local stakeholders and decision makers in port destinations. Any data collection tool can be used such as surveys, interviews etc. In this study, individual evaluations were taken via face-to-face questionnaires carried out with local experts in the research area during summer season in 2018 (June, July, August). Questionnaire is a technique that was designed to take individual judgements of participants to give priority to each criterion comparing to other pair.

(iv) Spatial analysis in GIS toward mapping the port identity

Distance and fuzzy analysis run in GIS for obtaining port identity distribution map. The distance analysis for each criterion map is essential due to it is an input stage for MCE. The GIS run the two-dimensional Euclidean geometry for distance analysis. Toward MCE analysis all distance maps (raster) are needed to be standardized. Via distance analysis, distance maps of each criterion are obtained from raster images. Fuzzy set membership was used for standardization of raster images distance analysis. When considering distance for constructing port identity maps, the less the distance from any given cruise port to attractions, the better is. Therefore, “monotonically increasing” curves should be chosen.

After completing the four input stages that were detailed above, MCE was applied in GIS. Port identity criteria maps were combined with factor weights of each criterion by using MCE-WLC (weighted linear combination) function in GIS. Sea area was masked. For this study, to obtain a composite map using the port identity criteria, Boolean constraints was applied to mask out sea areas. As performing the WLC procedure following model as shown in Equation 1 was used for mapping the port identity. GIS software systems such as IDRISI provide an effective tool for performing of such function (Drobne & Lisec, 2009).

$$I = \sum W_i X_i \times \prod C_j$$  \hspace{1cm} (1)

Where,
I = Port Identity (percentage)

X = Standardized criteria image (formed by pixels)

W = Weights of each criterion (weight factors)

C = Criterion score of constraint (Seamask)

2. RESULTS

In this study, the port identity was digitized and visualized by combining factor weights of the port identity related spatial (quantitative) criteria with MCE in GIS. With the spatial data collected from different data sources, the criteria map as much as the number of criteria were obtained. Each criteria map represents the port identity in their weights which found by calculation 45 pairwise comparisons via AHP technique. Accordingly, each identity criterion has some substitutability (trade off) with each other in proportion to their weight in spatial decision making process covering the port identity (Table 2). Table 2 shows factor weights of each port identity criteria that will used for the application of MCE-GIS to create port identity map.

<table>
<thead>
<tr>
<th>The port identity criteria ranks</th>
<th>Normalized Factor weights principle eigenvector (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical-cultural places</td>
<td>25.15</td>
</tr>
<tr>
<td>Natural places</td>
<td>20.48</td>
</tr>
<tr>
<td>Endemic places</td>
<td>18.62</td>
</tr>
<tr>
<td>Places for local foods and beverages</td>
<td>8.0</td>
</tr>
<tr>
<td>Coast and beaches</td>
<td>7.6</td>
</tr>
<tr>
<td>Sport facilities</td>
<td>5.6</td>
</tr>
<tr>
<td>City centre</td>
<td>5.1</td>
</tr>
<tr>
<td>Touristic information desks</td>
<td>3.6</td>
</tr>
<tr>
<td>Bazaar market</td>
<td>3.6</td>
</tr>
<tr>
<td>Shopping malls</td>
<td>2.3</td>
</tr>
<tr>
<td>Connectivity (networks, roads/ways)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Weight factors were obtained from expert who live in Bodrum at least for 5 years via surveys. Factor weight for connectivity criterion is assumed as equal to “1” regardless of individual judgments of local experts. Because, without any connections among cruise port and land facilities the port identity criteria existence would not be a matter of discussion. As a result of the expert evaluations, the importance level of each criteria were determined by a group
decision making process using AHP pairwise comparison. The results were achieved with 82.9 % consensus and CR was found 0.027. As it is shown in the Table 2 weights for the port identity criteria were determined based on local experts surveys in Bodrum cruise port destinations in order to run the GIS-MCE analysis.

As a result of combining MCE with GIS, the port identity was mapped for Bodrum, considering the port identity (quantitative) criteria (Figure 2).

**Figure 2. The port identity distribution map for Bodrum (< 100 %).**

In the Figure 2, colors represent level of port identity in any selected places within researched boundaries. As the sea was masked, it is neither determinant nor descriptive for the port identity level around the cruise port-destination. The map show that the port identity is concentrated in a part of the area rather than spreading over the whole destination.

**Figure 3. The port identity distribution map (< 53 %).**

**Source:** Authors.
In the Figure 3, it is seen that the research area reflects at least 53 % of the port identity as a result of the analysis conducted according to the criteria that constitute the port identity. Since the criteria are not homogeneously distributed to the entire area, it is expected that a higher port identity rate will present a smaller space in the destination. In other word, as the port identity criteria spread more around the region rather than centralize around a small portion of the entire port-destination, the better the port identity can be represented with a higher level (desired result).

**Figure 4. The port identity distribution map (< 70 %; < 80 %; < 90 %; < 93 %).**

As illustration the Figure 4, the highest rate scenario (93 %) shows that the smallest area, as long as covering the cruise port in the destination, represents the highest port identity rate scenario (93 %). The cruise port in the research area is located inside the selected port-destination boundaries even at the highest identity rate scenario (93 %) under consideration it was represented in the smallest area. To sum up, although as shown in the map at the bottom right on the Figure 4, the Cruise Port of Bodrum remains within the boundaries of the area where the identity is highly represented, while still the second most important criterion (natural places, shown grey color at the north on the map) of the port identity is almost completely outside of the map.

By looking at the port identity distribution map (Figures 2-3-4) which was created, for Bodrum, it has resulted that the geographic position of Bodrum Cruise Port reflects the identity at a level of 93 %. Also, as a result of spatial analysis, it was observed that the port identity that is distributed across the whole destination at least a level of 53 %.

Four basic scenarios were obtained via the port identity map that was created in GIS (Figure 4). Different scenarios can be created according to the needs of map users. For example, decision makers may want to spread an important criterion in identity to a space. Or, he may want to
increase natural areas to spread the natural identity to the space. In such cases, the port identity map can facilitate spatial decision process related to the port destination.

3. CONCLUSIONS

The port identity, as phenomenon was pointed out several times in the literature due to its geographic characteristics and its role in setting a coordination among cruise stakeholders (Broeze, 1985; Port Everglades Final Art Master Plan, 2009; Hooydonk 2009; Gui & Russo, 2011; McCarthy & Romein, 2012; CGP, 2012; GEKA, 2014; OECD, 2015). This paper shows that the identity which is defined by quantitative (spatial, geographic) criteria can be digitalized and visualized because local characteristics of a port-destination are connected with a specific location such as monuments, parks, beaches, commercial centers etc. In cruise tourism, port identity concept has potential to be more important than other commercial ports. Ships/passengers visit many ports in one cruise, but there should be some locations which will be stay in passenger mind with identities. Port identity is observed and felt by both travelers and locals. There are some studies about the importance of local identities (Dredge ve Jenkings, 2003; Shao, 2014) in residents’ life. For cruise tourism activities, due to its nature, port identity should be developed and preserved both for locals and for visitors. To do this, the method that explained in this study can be used to develop a cruise port-destination taking into account its identity.

Port identity distribution map or port identity map created in this study is proposed as a useful decision support tool for decision-makers on their local and regional spatial planning and cruise destination planning. It is thought that, the port identity mapping by using GIS based MCE may bring not only a novel and unique approach in decision making process for destination development but also may contribute to the geographical approaches to cruise tourism which is a gap in the literature (Tsiotas et al., 2018).

When using the port identity map as a decision support tool for cruise port-destination it provides advantages to decision makers. The most important advantages offered by decision-making approaches supported with the GIS-supported for decision-makers are; to produce rapid and instant scenarios based on relevant constraints and criteria; to see which reason could not be achieved by what important criterion, and to create alternative scenarios without much cost (Figure 2-3-4). Mapping the port identity by the GIS applications also facilitates the implementation of appropriate action plans by creating visually varied scenarios on the map. Thus, the non-conformities considering the port identity can be discovered through different scenarios that produced quickly and effectively based on objective data via the port identity distribution map. In this study only basic scenarios were created to illustrate how the method works. The method of AHP combination with GIS provide an opportunity to provide information about how compatible and consistent they are those who evaluate the identity criteria, which are advised to be local stakeholders. In Bodrum case, consensus level was found 83.9 %. It can be derived from this indicator that the port identity has a power to combine people in a common point.

Consideration of the port identity in a port-destination development process can help to maximize benefits and ameliorate or mitigate problems based on land-use (McCarthy & Romein, 2012). In theory, existing more space across the port-destination with high identity level means that more time is required for passengers in their visit to a port. This may be defined
a risk for cruise ship operator’s earnings but it is an opportunity to the benefit of local businesses. In addition to this, develop a proper distribution of port identity to a broader space around the port can stronger the relationship between port and city. Unlike traditional overnight tourists (Arbel & Pizam, 1977), cruise passengers mostly prefer to visit as many different attraction sites as possible. Port cities which are developed with their identity can optimize both passenger time outside ship and cruise earning. Although coastal areas have many conflicts while taking spatial decisions considering limited benefit to local in the case of cruise tourism, the port identity can be seen as sustainable catalyzer for the economic development which bring decision makers together.

In this study field observation and stakeholder interviews were utilized for determining boundaries of the research area considering time and cost constraints. However, future studies are recommended to apply different techniques for defining geographic boundaries of a cruise port hinterland. It is expected that different cruise port destinations would give different result. Because sizes, characteristics and shortly the identities will be different from one place comparing to other. As regarding Bodrum case, it is a pilot study area for application that selected to demonstrate the method for mapping the port identity. For future studies, decision makers or practitioners can work with other appropriate areas in different sizes considering cruise potential of a port-destination. Sea areas can also be added in the port identity mapping process if it has touristic characteristics such as sailing and diving locations. In this case, a similar question may raise for maritime spatial planning issue. As a new method, the port identity mapping processes such as determining the hinterland of a cruise port, determination of the criteria that define the port identity are needed to development and improvement via further studies.

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MODELLING THE RELATIONSHIP BETWEEN PERFORMANCE AND SHIP-HANDLING SIMULATOR

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Abstract:
Past catastrophic events as consequences of human navigational errors shows fail of the assessment methods adopted by maritime education and training institutes. Navigation simulators are an exceptional means of training in which the trained person performs tasks similar to those that are exposed in reality. However, the International Maritime Organization does not establish specific methodology with respect to training and assessment through the use of multi-task with simulators. The aim to apply to the simulation an adapted evaluation model that allows estimating a student's performance evaluation based on their workload and level of stress. Practical assessments of mariner skills are executed in the controlled environment than the simulators provide. A feasible scenario is set up using a ship-handling simulator and an experiment is conducted, participants were maritime navigators and students. The results conclude the validity of the adapted assessment model to obtain the performance. Linear regression analyses indicated a direct relationship between the variables workload, stress level and situations to be controlled and positive self-reported learning effects of mariner competency.

Keywords:
ship-handling simulator; workload; performance; training.

1. INTRODUCTION

The international shipping industry is responsible for the carriage of around 90% of world trade. Shipping is the safest and most environmentally benign form of commercial transport (Allianz, 2019). The statistics show a slow but steady decline in maritime accidents over the past years, yet thousands of accidents still occur each year and the great majority of these involve human error. The shipping is also a highly regulated domain, and regulations have been reinforced in the last decades (UNCTAD, 2019). The International Maritime Organization (IMO) has made great efforts to generate a maritime safety culture that is aware of the importance of importance of the training or knowledge of seafarers, and that this will make it possible to reduce the relationship between the human factor and maritime accidents (IMO, 2020).

The global fleet depends on competent, well-trained seafarers to ensure safety of life at sea, maritime security, efficiency of navigation and protection and preservation of the marine environment. The shipping industry expect new officers to manage information and technology, while demonstrating the ability to make safe and efficient use at sea (Berg, Storgård and Lappalainen, 2013; Manuel and Baumler, 2020).
A report by the European Maritime Safety Agency (EMSA), based on the analysis of 794 investigations initiated during the period 2004-2019, showed that most of the safety recommendations were human factors (for 19% of investigation reports) 46% of which relate to training and skills. In 47% of ship related procedures, 29% of which are actual for operations. In another 15% of security recommendations, 42% of which relate to ship equipment/system, 4% shore and water equipment and 15% other procedures. Poor surveillance in itself could be related to inadequate manning, misuse of skills on the bridge, or incompetence. This study includes ships under flag Member State occur within of European Union (EMSA, 2020a).

Past catastrophic events as consequences of human navigational errors shows fail of the assessment methods adopted by maritime education and training institutes. Therefore, the better the education and training received by seafarers is, the safer shipping industry will become (EMSA, 2020b). It is more than necessary to establish systems of constant improvement in training and endorsement systems for degrees.

1.1 SIMULATION

In recent decades, the huge technological developments and the lowering cost of hardware and software is allowing new simulators with high visual quality and a realistic environment. Furthermore, there is a need to reduce the cost of this training (IMO, 2011). Simulators are presented as a study support tool with specific advantages, especially when compared to training on board a real ship, as well as the ability to provide the student with the ability to react as they actually do.

Simulation is close to real replica of equipment, systems, phenomenon or process. The word simulation comes from the Latin verb “simulare”, meaning “to imitate”. It is important to recognize the simulation technology using simulations as a tool to solve real-world problems (Rybing, 2018). It is generally a mathematical model with a set of initial conditions, visualization and interface/controls and instructor control system. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety, testing, training and education. Use of approved simulators to demonstrate certain competence has been specified in STCW 2010. The basic operational features are: representation of real operational scene, provision of control of the scene, the exclusion of the operational scene, recording, playback or debriefing (IMO, 2011).

Under STCW the simulators need to comply with prescribed standards. Instructors and assessors engaged in simulator-based training need to be properly qualified in the use of such equipment. Simulation in general can be described primarily by their attributes: fidelity, resolution, and scale (Birta and Arbez, 2019). The skills requirement which can be enhanced with the use of simulation include: technical and functional expertise training, problem-solving and decision-making skills and interpersonal and communications skills or team-based competencies (Lateef, 2010).

In today's world of navigation simulators, trainers face new challenges and a unique change in the execution of training improvements. Navigation simulators opportunities integrate feedback, debriefing, interactive environment or real situations have demonstrated the ability to facilitate the link between theory and practice, increase students’ ability to synthesize knowledge, and promote insight in a safe space. Navigation and training simulators are an exceptional means of training in which the trained person performs tasks similar to those that are exposed in reality (Carson-Jackson, 2015). However, the International Maritime Organization (IMO) does not establish specific
methodology with respect to training and assessment through the use of multi-task with simulators (IMO, 2001, 2011).

Instructors are challenged to implement teaching strategies that promote learners’ navigation competency and crew resource management skills (IMO, 2011). This challenge has derived from advances in technology, increased levels of certification for seafarers, a major transformation in maritime digitalization, identified issues smart shipping and cyber security (Komianos, 2018), and mandates by International Convention on Training, Certification and Watchkeeping for Seafarers (STCW Convention) 75/95 and Code 2010 Manila Amendments (ITF, 2010).

The goal of any simulation is to provide a controlled environment where the participant performs tasks that are similar to what they should execute if they were exposed to the real environment. The simulators allow intensive training, in which pressure situations are generated with unexpected problems and inconveniences, thus giving the student practice in decision-making in a controlled environment. Instructors are to create learning environments that facilitate students’ critical thinking, self-reflection, and prepare officers for practice in a complex, dynamic navigation environment (Carson-Jackson, 2015).

The use of simulators provides a learning platform where all three elements of learning (knowledge, skill and attitude) can be integrated into a valuable learning experience. The four elements involved in providing training based on simulators show an intensive interaction: simulator equipment, training programme, student and instructor. The role of the instructor for ensuring the successful implementation of simulation training programmes. It is the skill and teaching techniques that can allow the simulator to be used as a powerful means for a student to practice in a safe environment (IMO, 2011). Navigation simulation training concepts then begun to be gradually introduced into safety navigation and other areas of shipping industry like radio communication, radar equipment, cargo operation, etc.

Simulation can be the help to developing professionals’ knowledge, skills, and attitudes, whilst protecting navigation from unnecessary risks. Simulation training techniques, tools, and strategies can be applied in designing structured learning experiences, as well as be used as a measurement tool linked to targeted teamwork competencies and learning objectives (Carson-Jackson, 2015; Lee, 2017). Simulation itself is not new. It has been applied widely in the aviation industry, military or medical education. It helps to mitigate errors and maintain a culture of safety, especially in these industries where there is zero tolerance for any deviation from set standards (Lateef, 2010; Farmer et al., 2017).

The aim to apply to the simulation an adapted evaluation model that allows estimating a student's performance evaluation based on their workload and level of stress. This paper describes the scenario used in the simulation, the participants in the study, the measurements used, and method employed. We evaluated the human performance using questionnaire for evaluating training effectiveness of a virtual navigation scenario.

2. METHODOLOGY

To support the development of the simulations, we have used different methodologies, among which we highlight Problem Based Learning (ABP) (Hmelo-Silver and Barrows,
2006; Boud and Feletti, 2013), the experimental learning methodology or Learning by Doing (Gibbs, 1998), and the concept of stress, focusing on Yerkes Dodson law (Teigen, 1994). It is important to point out the situations generated during navigations in the simulator, it can generate different levels of attention influenced by the officer's perception and, therefore, we can relate attention, arousal, motivation and perception in the same variable, stress, together with the other personal conditioning factors of the person (psychological, physical and environmental) (Figure 1).

Figure 1. Illustration of Yerkes-Dodson law.

Source: adapted from (Teigen 1994).

2.1 PARTICIPANTS AND MATERIALS

48 seafarers, in the rank from deck cadet to master, participated in this experiment. Each participant was an enrolled student in the University of Cadiz. A low prevalence of female participants: 43 of 48 participants were males (89%). All participants needed to possess a certificate of competency according to international regulation (IMO, 1978). Participants were randomly assigned to one of four groups and had an average age (n = 48, M = 25.3, SD = 9.5) and years in service (n = 48, M = 1.1, SD = 10.3). After analysing the results of experiments and submitting the data to a study of analysis of the variances, it was found that the results obtained from groups were analogous, therefore, in the validation and analysis of the results, they will be treated together.

The validity of the groups participating in the simulation was verified using an ANOVA test (SPSS software), with an observed significance value (0.000)/ Cochran's Q (482,32) that validates the hypothesis of equality of means, in addition to similarity between the groups under study (Bakieva, Such and Jornet, 2010). To carry out the simulations, the Polaris V6.3 navigation simulator from Kongsberg Maritime AS at the University of Cádiz was used. Polaris is a functional system that includes: Instructor station; 1 Full mission bridge (OwnShip); and 5 Part Task (OwnShip) Bridges - with ECDIS, Radar/ARPA, Multifunction Stations, panel control, etc. certified under STCW.

2.2 SCENARIO

The detail of the simulation exercise was designed by the relevant simulator instructors, and was conducted in exactly the same way during the different sessions. The scenario was constructed carefully to ensure a high level of realism. The voyage was constructed
to emulate a real voyage in the Strait of Gibraltar and, including port manoeuvre, duties of watch keeping and navigation on a ship's bridge, navigation and collision avoidance situations, mandatory radio reporting points, etc. The following figure shows the officers’ levels, sequence in the simulation (Figure 2).

**Figure 2. Sequence and duration of events of simulation.**

The voyage between Algeciras port and Tanger Med port was repeated in all simulations (only 45 minutes from departure), and many of the events the participants experienced were also repeated because they were normal routine activities on the bridge, and sometimes in same route/localization. On the simulation, an identical amount of traffic was set for each start and was considered realistic for the waters involved. It varied in intensity from light to relatively heavy traffic. Maximum vessel speed (7 Knots/port and 19 knots/open sea) for OwnShip and Target. A feasible scenario is set up using a ship-handling simulator and an experiment is conducted. The weather conditions were consistent (Wind: West, 7-9 Knot); reduced visibility (middle bay, > 2 miles); tidal conditions (HW 1.5 m, Algeciras Port); current/drift (West 1-3 Knot) (Figure 3).

**Figures 3. A model of fidelity in simulation.**

<table>
<thead>
<tr>
<th>Engagement</th>
<th>Realism/Fidelity</th>
<th>Duties</th>
<th>Conceptual</th>
<th>Traffic</th>
<th>Weather</th>
<th>Alarms, Report, VHF, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: author.

Considerations and rules of the scenarios: All vessels in the exercise navigation under COLREGS and international regulations (VTS, Reports, etc.). No groundings or collisions were allowed. Normal events (or situations) were those which a seafarer on a similar vessel would typically encounter during a voyage in the Strait of Gibraltar. These normal events were Keeping communication (port, pilot, vessels or VTS), ship’s position, vessel's logbook. Traffic was realistic for the area and a basic voyage plan was given to the participants during the familiarisation period (15 mins). Finally (40 mins), a fire on board incident occurring on another vessel in the vicinity or in the own ship.
2.3 VARIABLES AND DATA COLLECTION

For the compilation of the study data and its subsequent analysis, a coding of the indicators or variables was carried out, which in turn were related to Workload (WL), Situations controlled (SC) and Level of difficulty (LD) during the simulation with a scale of values from 1 (None) to 7 (Extremely high). The different items were recorded at 10 minutes intervals during the simulation. A comparison of sets of results resulted in a Spearman Rank Difference mean correlation 0.650, indicating a strong relationship. The following Table I shows the coding of the variables and their interval, as well as the approximate location of the vessel.

<table>
<thead>
<tr>
<th>Item</th>
<th>Definition</th>
<th>t_i</th>
<th>Port/berth</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL t_1-t_5</td>
<td>Workload (WL)</td>
<td>t_3</td>
<td>Leaving the port</td>
</tr>
<tr>
<td>SL t_1-t_5</td>
<td>Workload (WL)</td>
<td>t_1</td>
<td>Middle of the bay</td>
</tr>
<tr>
<td>SC t_1-t_5</td>
<td>Situations controlled (SC)</td>
<td>t_3</td>
<td>Leaving the bay</td>
</tr>
<tr>
<td>LD t_1-t_5</td>
<td>Level of difficulty (LD)</td>
<td>t_4</td>
<td>VTS</td>
</tr>
</tbody>
</table>

Table I. Variables and data collection.

Source: author.

3. RESEARCH RESULTS

In this section we will proceed to perform the statistical analysis of the data obtained during the practical simulations, for which the frequency of assigned values, mean and variance that each of these represent in the different items will be studied independently during the time line of the exercise.

In order to improve the feedback from the simulations, participants were asked to rate the grade of difficulty (GD) at certain times (t_0 - t_4) on a scale of 1 to 3, presenting the most repeated value (Medium=2) in “t_1” (67.7%). The answer is 1.63 for “t_0”, 2.05 for “t_1”, 1.91 for “t_2”, 1.89 for “t_3” and 1.58 for “t_4”. The median value remains stable at 2.00 during “t_0”, “t_1”, “t_2” and “t_3”, and falls to 1.0 at “t_4”.

3.1 WORKLOAD

The Figure 4 shows the frequency of values assigned by officers to the perceived workload during the simulation, presenting the most repeated value (High) in “t_3” (36.9%).

Figure 4. Frequency of values assigned to the workload (WL) during the exercise.

Source: own study based on the research results.
3.2 STRESS LEVEL

The Figure 5 shows the frequency of values assigned by officers to the perceived workload during the simulation, presenting the most repeated value (Very high) in “t1” (30.8%).

![Figure 5. Frequency of values assigned to the Stress level (SL) during the exercise.](image)

Source: own study based on the research results.

3.3 SITUATIONS UNDER CONTROL

The Figure 6 shows the frequency of the values assigned to the situations to be controlled during the simulation, presenting the most repeated value in “t3” (33.8%).

![Figure 6. Frequency of values assigned to situations controlled (SC) during exercise.](image)

Source: own study based on the research results.

3.4 DIFFICULTY LEVEL

The Figure 17 shows the frequency of the values assigned to the level of difficulty during the exercise, presenting the most repeated value in “t1” (67.7%).

![Figure 17. Frequency of values assigned to the Difficulty level during the exercise.](image)
Figure 7. Frequency of values assigned to the Level of difficulty (LD) during the exercise.

3.5 DISCUSSION

The results obtained show great variations between “t0” and “t1” for all variables (WL, SL, SC and LD). These variations are related to the degree of immersion of the officers. Low levels at “t0” show low motivation or immersion in simulation. The extreme values (SD) of the items evaluated for “t1” show the moment in which the students “submerge” in the simulation and become aware of the situation they are in and of their responsibilities or duties.

The items with the highest standard deviation value are found in “t4”, this is due to the fire generated in the ship during the last phase of the exercise, the students who generated this fire evaluated their load levels very highly work, stress and situations to control, while the rest of the ships that were navigating the VTS, with low traffic, and showed at much lower levels.

3.6 MODEL FIT EVALUATION

The model was adjusted using the determination coefficient, also called R-Square, this coefficient determined the quality of the model to replicate the results, as well as the proportion of variation of the results that can be explained by the model. The values obtained for the coefficient of determination are those shown in Figure 8. The results allow us to predict the value of two indicator items in the model based on one known, allowing us to calculate student performance in a given situation using a linear regression. a moment “t0”. In the adjustment, the strongest values were those of the (stress level).
4. CONCLUSIONS

The participants need time to adapt to the simulation and real immersion in it. Therefore, in future simulation exercises it would be advisable to give the participants time to adapt to the simulation environment, so that they begin to assess their load levels work, stress and situations to control once they are more focused on navigation or simulation. In the simulations, it was observed that above a certain level of stress, the participants did not respond adequately to the problems posed, even going so far as to “crash” and give practically no performance in certain situations. It was also observed that this level of the stress in which the “blockage” occurred varied widely depending on the officer on duty regardless of his professional experience.

The participants rated the simulations very positively, which had kept them alert and active practically all the time, arguing that the scenario only differed from reality in the traffic situation, but that, during the simulation, generated its own tension of a real manoeuvre. The influence of stress level on performance is an important factor to bear in mind both in the learning process and in planning methodology in navigation simulators.

There was significant variability in the competition shown by the bridge officers. This was due to the randomness of the candidate selection process. In this sense, some officers showed enormous cognitive ability to adapt to a change of scenery in navigation. In addition, some watch keepers were apparently more resilient to stress, but we need to investigate what factors might influence this. Results of this study will be used in the future to guide simulation practitioners in the optimization of human performance using training simulation. It is hoped that the results will make a contribution to the improve training quality and safety navigation.

References:


MANOEUVRE ANALYSIS AND SIMULATION TO PREVENT SEABED SCOUR DUE TO SHIP PROPELLERS

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Abstract:
Erosion of the seabed is produced by cargo and passenger vessels when manoeuvring in a harbour basin due to the high-speed jet flow generated by the main propellers. In case of twin propeller vessels, the ability to perform the whole manoeuvre with no tugs makes the master to use the main propulsion system even close to berthing walls and other structures. Near quay walls, the main variables leading to sediment scour are both related with the propeller behaviour -speed of rotation, pitch- and with the relative position of the propeller to the quay wall and the seabed -axial distance to the quay wall and vertical distance to the seabed-. Therefore, there exists a need to understand the manoeuvre in detail in order to predict the actions of the propellers to the seabed. In this article, AIS data is used to study the target manoeuvre to later reproduce it in the ship simulator. With the output of the simulator, timeseries of the propeller delivered power and the position of the propellers during the manoeuvre are obtained. With these data, the existing formulae in maritime engineering can be applied to obtain the efflux velocity at every ship position. By linking the efflux velocity with the manoeuvre characteristics, -i.e., ship position, ship heading and distance to the quay walls and seabed semiempirical formulation to obtain the flow velocity over the seabed and the expected scour depth is also applied. The numerical simulator turns out to be a very useful tool to analyse any manoeuvre and obtain the locations where it is potentially more harmful, the expected flow velocity and the maximum expected scour depth.

Keywords:
harbour management; propeller induced scour; ship manoeuvre; numerical simulator.

INTRODUCTION

Large commercial vessels have been an important factor to consider in modern times when talking about instability of marine infrastructure due to scour occurring because of their berthing and unberthing manoeuvres. The behaviour of the propeller wash and the seabed scour mechanism near structures have been lately investigated by (Wei et al., 2019; Wei and Chiew, 2019, 2018). These articles show experimentally the flow and seabed characteristics during the development of the scouring hole by Particle Image Velocimetry (PIV) technique and got an interesting picture of the whole process to analyse the physics behind it. However, as stated in several articles relating this topic, the complexity of the field cases due to the presence of
disturbing elements in the flow field such as rudders, the ship hull, the movement of the ship, etc., makes it challenging to model the whole phenomenon.

Although many of the studies in propeller induced scour are performed experimentally, some intended to study the phenomena at field to obtain a better idea of how the scour is produced and to quantify the potential erosion due to the ship usual operations. (Blokland and Smedes, 1996; Liao et al., 2014) studied the characteristics of the generated wash at prototype scale, and the effects of the wash over the sediment in terms of resuspension and evolution of the scour. These field campaigns, performed with acoustic and optical instruments, also showed the limitations when measuring a highly turbulent event such as the propeller jet flow causing an important sediment resuspension. (Mujal-Colilles et al., 2017) showed the impact of a particular type of vessel, in particular the regular ferry operating lines, over a harbour basin based on periodic hydrographic surveys to observe the evolution of the seabed related to the ship manoeuvres in a particular port. This kind of field studies are focused on the effects of the ship in the basin and are useful for port authorities to take actions in terms of port operations management. As shown in (Castells et al., 2018), the change in the manoeuvre or the use of tugs are elements of interest to reduce or even avoid a constant erosive action in the same areas, leading to an eventual failure of the marine infrastructure.

In the present communication, the methodology presented in (Llull et al., 2020) is used to study the ship manoeuvre in order to correlate it with bathymetric surveys, considered as the equilibrium profile of the seabed. The vessel’s manoeuvres are performed in the bridge simulator by a professional pilot to get a first approach of the relation between the engine orders and propellers usage with the scouring pattern. Results are compared to estimation of final scour depth using existing formulae in (PIANC, 2015) international guidelines to the output of the simulator.

1. CASE STUDY

This article is focused on a particular inner harbour basin where two twin ferry ships operate daily. The ferry ships main characteristics are showed in Figure 1. Since they are twin ferry ships and they perform the same manoeuvre, only data of one of them is used in this study.

![Figure 1. Main ship characteristics of the study ship.](image-url)

<table>
<thead>
<tr>
<th>Total length (m)</th>
<th>Width (m)</th>
<th>Draught (m)</th>
<th>Max. SOG (knots)</th>
<th>DWT</th>
<th>GT</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>30.4</td>
<td>7</td>
<td>25</td>
<td>8550</td>
<td>54900</td>
<td>55440</td>
</tr>
</tbody>
</table>

The AIS data of the arrival and departure manoeuvres have been previously studied and analysed in (Castells et al., 2018, 2017), and thus the main manoeuvres are already known. To illustrate how the manoeuvres are performed and their high similarity, together with their relation with the state of the seabed in terms of sediment scour, Figure 1 maps the ship positions with an arrow, indicating the ship heading vectors over a map. The ship propellers position is also mapped with circles, and shows the agreement between the positions and the scour holes up to 18 meters that are found in the bathymetry. Time series of the heading (HDG) and the
speed over ground (SOG) are also showed in Figure 2.

Figure 1. Arrival (up) and departure (down) manoeuvre of the study ship in two different days. Heading vectors and propeller position (marked with empty circles) are mapped (left) along with the HDG and SOG timeseries (right).

The time series have been synchronised and lagged to get the maximum correlation between them ($r^2 > 0.9$ in all cases), thus the manoeuvre time is set and the behaviour of the ship at every time stamp is known. As in (Llull et al., 2020), heading and speed over ground are considered to be the main variables to explain the manoeuvre characteristics. The heading, in this case, is also expressed by the sinus of the angle to avoid the jump when plotting the heading, if its value runs from the NE quadrant to the NW quadrant. The cross correlation is, thus, computed with the timeseries of the sinus of the ship heading to get and correct the lag between them.

2. METHODOLOGY

The harbour basin of this study was also presented in (Mujal-Colilles et al., 2017) showing the areas of maximum scour due to ship operations. The last bathymetry available (year 2014) is used in the present contribution as the final equilibrium profile.
AIS data is also used here to analyse the manoeuvre of the case study ship. The AIS data allow the authors to obtain the characteristics of the ship arrival and departure manoeuvre in two different days, considered as standard manoeuvres after the advice of the Port Authority. The different manoeuvres are performed depending on the quay where the ship is going to berth. As shown by (Mujal-Colilles et al., 2017), there are four different berthing places in this basin, two in the west quay, and two in the north quay.

The resulting AIS manoeuvre is studied along with one of the pilots of the port in order to, later, reproduce it in the ship simulator several times. The heading and the speed are the main variables used to describe the manoeuvre, as in (Llull et al., 2020). The position of the main propellers during the whole manoeuvre is of interest due to the relation between their position, their behaviour and the effects over the seabed and the harbour infrastructure.

The bridge simulator allows the authors to analyse the behaviour of the ship propellers during the manoeuvre, and to obtain simultaneous time series of the propellers and engines regime. This information is used to trigger the propulsion system behaviour to the manoeuvre to the erosive action over the seabed. The time series of the main variables are compared with the AIS data, bearing in mind that differences are expected due to the change of the ship, but willing to obtain the highest similarity.

The behaviour of the main propellers is studied together with its position, obtaining the ship and propeller positions where the delivered power is maximum, both ahead and astern. The area where the generated flow will potentially damage the seabed is, thus, estimated. Calculations to obtain the flow velocity and the scour depth are based on formulae in (PIANC, 2015), widely used in scour depth estimation due to ship propellers.

3. RESULTS AND DISCUSSION

The previously analysed manoeuvres are reproduced by a pilot of the port at the ship simulator to obtain an output of the engine and propellers behaviour during them. The characteristics of the simulator ship are shown in Figure 3.

**Figure 3. Main ship characteristics of the simulator ship.**

<table>
<thead>
<tr>
<th>Total length (m)</th>
<th>Width (m)</th>
<th>Draught (m)</th>
<th>Max. SOG (knots)</th>
<th>DWT</th>
<th>GT</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>196</td>
<td>25</td>
<td>6.1</td>
<td>25</td>
<td>5174</td>
<td>-</td>
<td>50400</td>
</tr>
</tbody>
</table>

Figure 4 maps the heading vectors and the propellers position of the ship during the manoeuvres, along with the time series of the variables also showed in the Case section. The position where the heading vectors are located change slightly in this figure due to the different position of the AIS transmitter in the simulator vessel, although the simulator ship particulars are very similar to the study ship ones.
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The time series of the ship heading and speed over ground are also plotted in Figure 2, along to the mapped manoeuvres. A similar behaviour to the study manoeuvres is obtained, although some differences are found, probably due to the change in the ship and the environment (i.e. the simulator environment). The manoeuvres, however, are considered to be useful to analyse the behaviour of the main propellers in general terms and to get a picture of the set of positions where the ship is using the higher engine power, and thus, is potentially more harmful for the seabed.

To understand the manoeuvre, it is important to use the output of the simulator, focusing not only on the ship behaviour, but also on the engine orders given by the pilot. In Figure 5, the port (left) and starboard (right) propellers position and behaviour are shown, also with some
ship contours to easily show the vessel behaviour, which can also be seen in the above mappings in Figure 4. Since the propellers run independently from each other, the authors considered that the best way to represent their behaviour is in two separate plots. The colour bar shows the engine order given by the pilot in percentage. The contour of every propeller position, which is showed at 5s sampling rate, gives information about the regime (astern or ahead) of the propeller at each position.

Figure 5. Port (left) and Starboard (right) propeller position and behaviour during the arrival (up) and departure (down) manoeuvre. Green borders express astern rotation, while blue borders refers to ahead rotation. The colorbar shows the percentage of the total engine power used at each position.

The main eroded areas appear to be right below the propeller track of the arrival manoeuvre. Also, in the departure manoeuvre, the first steps are coincident with the biggest scoured hole, which reaches the -18 m.a.s.l. This area near the corner of the back and the side quay is seen to be affected by the propellers running at the same time astern and ahead at mid to high engine power during both the arrival and departure manoeuvre.

During the arrival, the manoeuvre can be divided into three different sections, according to the timeseries in Figure 6 (left): direct approach, from t=200s to t= 400s; lateral displacement, until t= 550s; and final steps, until the engines are stopped. During the direct approach, the pilot begins to stop the ship’s inertia by running astern the starboard propeller, also initiating a starboard turn to a new heading NNE. Considering the bathymetry and the propellers position...
during the manoeuvre, this approach could cause several seabed affectations in the middle of the harbour basin and this could be the result of high engine power (up to 40%) applied astern to stop the inertial movement of the ship. During the lateral displacement, both propellers run at mid to high power (20 to 40%). Starboard propeller runs astern while port propeller runs ahead, generating a torque which is compensated by the bow thruster and thus obtaining a lateral movement towards the side quay. During this approach, the propellers are located right above the maximum erosion area, and thus one could expect that, knowing that the ahead propeller should cause erosion far from the propeller position, this scour is occasioned by the action of the astern propeller. A consideration should be done here, because far from the propeller, in the axial direction, the quay wall is found. Thus, according to several experimental studies (Castells et al., 2018; Hamill et al., 1999; Wei and Chiew, 2019), the main erosion should occur right below the main quay wall in this case. In the final steps of the manoeuvre, short ahead orders are given to both port and starboard engines to finally stop the inertial movement. Occasionally, and as per the pilot advise, this behaviour could change depending on the manoeuvre, but the power regime should not exceed the 20% at this stage, which is lower than the previously obtained output from the simulator.

The departure manoeuvre, see Figure 6 (right), is easier to analyse and can be divided in two different sections: lateral displacement and turning manoeuvre. During the lateral displacement, the port propeller runs astern while the starboard propeller runs ahead, both at 30-40% engine power. The moment where the engine regimes are reversed is coincident with the area of maximum erosion. From there on, the port propeller runs ahead at 30% power engine while starboard runs astern eventually (from t=240s to t=300s) to allow the turning to final heading SW and depart the basin.

After the analysis of the manoeuvre, some formulae are applied to obtain an approximation of the expected scour depth according to different situations. The existing formulation in scour prediction is difficult to apply in a complex situation where twin propellers run independently from each other. In (Llull et al., 2020), only the effects of the propeller running ahead are studied by applying, among others, the formulation in (PIANC, 2015). However, the case study and the bridge simulator output in this communication may indicate that the effects of the propeller running astern are equally important.

Regarding the effects that the astern rotation may cause, (Mujal-Colilles et al., 2018) show how the astern rotating propellers may erode the sediment located mostly below themselves, rather than far from them. This hypothesis would fit better as per the results obtained in this paper,
which show that the scouring pattern follow perfectly the propellers track during the arrival manoeuvre.

Depending on the position and the heading of the ship, the propeller rotating ahead generates a wash that may impact on the berthing structure. In this case, the flow is said to be confined, and the formulae to be applied when calculating seabed velocities or erosion is different than for the unconfined situation. As in (Llull et al., 2020), if \( L < X_{mu} \) (find the notation at the end of the article), the generated wash is supposed to be confined and, thus, formulae for a confined flow scenario may be applied. Also, the scour position in this case is considered to be at the quay toe. Since \( L \) increases as the ship is farther from the wall, some threshold is needed. According to (PIANC, 2015) \( 0.12 < \frac{h_p}{X_{mu}} < 0.22 \). With this threshold, the confined situation is mainly obtained at initial positions of the departure manoeuvre and the final positions of the arrival manoeuvre, while the rest of the manoeuvre may be analysed with the formulae for unconfined flow.

Both formulae are applied in the case study, knowing that depending on the ship position and the propellers behaviour the flow is either confined or unconfined. The most restrictive parameters are taken to input to the formulae (e.g. maximum engine power developed in the manoeuvre and shortest distance to the quay wall).

The scour expected near the quay wall can be estimated by applying the known formulae of efflux velocity and scour prediction. The time series in Figure 6, combined with the mapping of the propeller position and behaviour in Figure 5, show that the higher power ahead near the quay wall is developed by the starboard propeller during the departure manoeuvre. Thus, the values of this propeller are considered to be the relevant value to any estimation regarding the potential scour or damage. The maximum ahead power delivered by the engine in this period is around the 30%. This is the percentage used as input to the equation 8-6 of (PIANC, 2015) to calculate the efflux velocity \( (V_0 = f(f_p, P, \rho_w, D_p, C_3)) \). The velocity at seabed \( (V_{seabed} = f(V_0, L, D_p, \alpha)) \) is calculated using the equation 8-13, and finally, the maximum expected scour \( (S_{depth} = f(V_{seabed}, d_{50}, g, \rho_s, \rho_w, C_m)) \) is obtained with equation 10-5.

In the unconfined scenario, the requirements in (PIANC, 2015), equations 10-23 and 10-24 to obtain the scour generated by main propellers are not fulfilled. Instead of the guidelines, the equations in (Hamill et al., 1999) referring to (Hamill, 1988) for unconfined jet scour are applied, as it is recommended in (Mujal-Colilles et al., 2017).

Figure 7 summarizes the input variables value and Figure 8 includes the results obtained.

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**Figure 7. Input variables to the formulae**

<table>
<thead>
<tr>
<th>( f_p \cdot P ) (kW)</th>
<th>( \rho_s - \rho_w )/( \rho_w )</th>
<th>( d_{50} ) (m)</th>
<th>( D_p ) (m)</th>
<th>( C_m )</th>
<th>( C_3 )</th>
<th>( L ) (m)</th>
<th>( \alpha )</th>
<th>( g ) (m/s²)</th>
<th>( h_p ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7560</td>
<td>1.54</td>
<td>3\cdot10^4</td>
<td>5.1</td>
<td>0.3</td>
<td>1.48</td>
<td>6D_p</td>
<td>1</td>
<td>9.81</td>
<td>12</td>
</tr>
</tbody>
</table>
The obtained results show flow velocities in range of the expected magnitude for this kind of ships. The calculated scour, however, yield maximum values smaller than what is shown in the bathymetry, both for the unconfined and the confined formulation. The effect of the rudder is not taken into consideration in the case of the seabed velocity formulae, nor in the scour equations for confined and unconfined flow. According to (Hamill et al., 1998) it could increase the scour depth up to a 30%, yielding a value of scour about 2 m, still underpredicting the obtained from the bathymetric studies.

The methodology is considered to be useful to evaluate the manoeuvre moments which are more harmful in terms of seabed scour, and thus it is considered that actions should be taken to avoid the use of high engine powers at these positions. Measures such as tug assistance during the manoeuvre are to be considered by Port Authorities if the situation is intended to be corrected by applying operational solutions, as described for instance in (Castells et al., 2017).

4. CONCLUSIONS

A methodology to study the ship erosion together with the ship manoeuvre leading to it is used in this case study. This methodology is based on a bridge simulator study performed by a professional pilot to obtain the propulsion system behaviour during any manoeuvre, to later, trigger it to the effects caused by the ship over the seabed.

The position of the propellers during the manoeuvre is seen to be coincident with the areas of major affectation, supporting the hypothesis that the main propellers at reverted regime may be of importance in terms of generated erosion in the harbour basin. The reverted propellers effect has been barely studied at experimental and prototype scale in terms of scouring action so far. It is considered that this could be a new research line to explore due to the extended use of twin propellers, which uses the astern-ahead rotation in parallel to manoeuvre the ship.

The results obtained after applying the formulation show underprediction of the final scour, supporting the hypothesis that the effects of astern regime propulsion may be of major consideration.

Notation:

\( V_0 \) (m·s\(^{-1}\)) \quad \text{Efflux velocity.}
\[ L \ (m) \quad \text{Distance from propeller to back quay.} \]
\[ f_p \ (-) \quad \text{Percentage of engine power.} \]
\[ \rho_s \ (kg \cdot m^{-3}) \quad \text{Sediment density.} \]
\[ \rho_w \ (kg \cdot m^{-3}) \quad \text{Water density.} \]
\[ D_p \ (m) \quad \text{Propeller diameter.} \]
\[ d_{50} \ (m) \quad \text{Sediment’s mass-median-diameter.} \]
\[ h_p \ (m) \quad \text{Distance from propeller hub to bottom.} \]
\[ g \ (m \cdot s^{-2}) \quad \text{Gravity constant.} \]
\[ X_{ma} \ (m) \quad \text{Distance to the maximum eroded depth in unconfined scenario.} \]

References:


Liao, Q.; Wang, B., Wang, P.F. In situ measurement of sediment resuspension caused by


SESSION 4. MARINE ENGINEERING
HOW THE INDUSTRY 4.0 COULD AFFECT THE SHIPBUILDING WORLD

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Abstract

The marine structures are developed with Computer Aided Design (CAD) platforms, but every day we are looking for integrated development of the product involving all its Life Cycle. CAD system integrated with Product Lifecycle Management (PLM) and from the PLM we can conceive all the design but also control the production and include the use of the vessel. The PLM can contain information of all systems of the vessel and also all its components. If the components are designed for the Internet of Ships (IoS) it will have technology that allows to share their situation, diagnosis, functionality with the PLM system which distributes the initial design. The PLM system can use this information for knowing whether they are working properly or if we can improve its performance. It is also possible to identify whether it is necessary to make maintenance of the object or if it is necessary to replace it because its life ends or because it's working wrongly. It will be possible to determine and evaluate its performance comparing to other similar components or comparing to it different operating periods. It will also be possible to know how their performance affects the functioning of the whole product, i.e., the vessel. Furthermore, if the connection of the objects is realized with its PLM, it would be possible to record their history status, make change tracking, and know what is its function or its performance after realizing programmed maintenance. In case of a vessel, this connectivity will be extended to the commercial mission to act autonomously in operation conditions. A commercial vessel can transmit its navigation situation, load situation, the things to be discharged or to be recharged. All these means a huge amount of information to be managed and analysed. New programs have to be developed to obtain the best use of such information so that the design can be improved from real function information of the design and it can be self-maintained with the connection with this huge cloud information to create method that the objects can achieve certain "Intelligence".

The growth of the IoS is linked to the increase of Information and the management of Big Data, with the property that somehow IoS identifies Information and direction and order to a specific purpose, while the concept of Big Data is more generic. The possibilities are countless, but the beginning is the same. It must begin in the initial design. It is necessary to consider what is needed to correctly fulfill the mission of the atomic elements. These requirements must be configurable in the initial design from where it will be extended to relations between each of them with other entities. CAD is one of the first steps, because it is where begins to collect systematically the concept of each component. Therefore, the aim of the paper is to explain why it is necessary to provide CAD tools to carry out the design for IoS.

Keywords:

CAD/CAM/CAE; IoT; Industry 4.0; ship design
1. **STATE OF THE ART AS REGARDS INDUSTRY 4.0**

The *Industry 4.0* transformation implicates a huge collection of interrelated and joined technologies, which can be analysed independently, but must be applied as a complete integrated implementation in each industrial field, moreover, in the *Computer Aided Design, Manufacturing & Engineering* (CAD/CAM/CAE), from now on referred just as *CAD*, and *Product Lifecycle Management* (PLM) development industry. Each technology exposes a set of boundaries which cannot be differentiate evidently from its neighbouring technology.

*Virtual Reality, Augmented Reality* and *Mixed Reality* are closely associated to the *Digital Twin* and interconnected with the *Big Data*, which is produced by the *CAD* tools and all surrounding solutions, which applies some *cloud/edge/fog* computing to this data in a merged technology between finite state machines and *Artificial Intelligence* cognitive processes [1].

To perform in an agile manner all these computing, it requires a network which support different connection ways to add special devices, i.e. *Internet of Things* (*IoT*), which can access to the data, creating and modifying it, in a different layer which affects to the basic information layer created by the *CAD* System in the shipyard.

This network should be secured, *cybersecurity*, but open to allow distributed work, which must be step controlled in a manner that records any modification of each working step done in an open, transparent, trusted and non-modifiable working method for all actors involved in process, like: shipyard, engineering offices, classification society and ship owner, *blockchain*.

Results of the design should be easy integrated with future building ways like *3D printing*, generating printing orders directly from the *CAD* model or from the *PLM*.

Shipbuilding engineering phases involve design and production, but an integrated *Industry 4.0 CAD* System should also be involved in operation and maintenance.

When a ship comes for a reparation, sometimes the model is not available for this operation of maintenance.

In repair and maintenance steps, replicating the full engine room or any other compartment in the *CAD* System could be a nightmare, unless *CAD* tool has an *Artificial Intelligence* processing toolkit which, from a cloud of points, can recreate *CAD* equivalent items which can be converted with a minor user intervention, and lesser as the *Artificial Intelligence* learns, in a *CAD* integrated and full modifiable design.

At the end, this is just a short summary of the *Industry 4.0* technologies, which can be applied to a *CAD* System (as shown in *figure 1*), included in, or as an integrated surrounding solution, or as information producers for the evolutive design process.

To be able to understand how *Industry 4.0* became today’s buzzword, a look at its predecessors might give us a perspective on how this revolution in particular is different.

- **The First Industrial Revolution.** The industrial revolution in Britain came in to introduce machines into production by the end of the 18th century (1760-1840).
- **The Second Industrial Revolution.** It dates between 1870 and 1914, although some of its characteristics date back to the 1850, and introduced pre-existing systems such as telegraphs and railroads into industries.

- **The Third Industrial Revolution.** It is much more familiar to us than the rest as most people living today are familiar with industries leaning on digital technologies in production.

- **The Fourth Industrial Revolution.** It takes the automation of manufacturing processes to a new level by introducing customized and flexible mass production technologies.

Figure 1: Related Industry 4.0 Technologies in a Shipbuilding CAD environment


2. **INTERNET OF THINGS**

2.1 CHALLENGES OF THE IOT

The success of *IoT* will only be possible if the initiatives have a clear component oriented to the business. It is necessary to identify which of the initiatives provide a clear value to the business, but taking into account that this value can be in various terms and not all directly economic. The clearest ones have to do with the optimization of energy costs, fuel consumption, choice of routes, safety at sea, but also in the work itself inside the ship [5].

One of the conclusions of all the analysis about the consequences of the *IoT* is that objects must be re-thought from the early design.

The fact is that ships are subject to harsh environmental conditions makes that any technological advance to be applied inside a ship have to take into account from the very beginning. Currently all the designs in the modern society are made by information technology tools, computer aided designs, supported with adequate databases and with
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One of the conclusions of all the analysis about the consequences of the IoT is that objects must be re-thought from the early design. The fact is that ships are subject to harsh environmental conditions makes that any technological advance to be applied inside a ship have to take into account from the very beginning. Currently all the designs in the modern society are made by information technology tools, computer aided designs, supported with adequate databases and with lifecycle management of the information. To address the challenge of the IoT for ships, it is necessary a new concept, the Internet of Ships (IoS).

2.2 A NEW CONCEPT. THE INTERNET OF SHIPS

It is estimated that in 2020, 25 billion of devices will be connected to Internet [4]. This revolution that began a few years ago has aroused enormous interest in all industries and in some of them already works with apparent normality.

Nowadays it is possible to order directly from our refrigerator as soon as it detects that we need our regular products or smart lamps that light up alone when needed lighting. The world go on steadily toward what will be undoubtedly one of the most important revolutions in the history of humanity.

We could define the IoT as consolidation through the network of networks a “network” that staying a multitude of objects or devices, that means, to connect all things of this world to a network, we are talking about vehicles, appliances, mechanical devices, or simply objects such as shoes, furniture, luggage, measuring devices, biosensors, or anything that we can imagine.

At its core, IoT is simple: it’s about connecting devices over the internet, letting them talk to us, applications, and each other. But IoT is more than smart homes and connected appliances, however. It scales up to include smart cities think of connected traffic signals that monitor utility use, or smart bins that signal when they need to be emptied and industry, with connected sensors for everything from tracking parts to monitoring crops.

Figure 2. Ideal representation of a 3D model with access to the different ship design disciplines monitoring crops.

In this context the question is if the naval sector is ready for this revolution. Is it possible that this traditional and conservative sector moves into this technology? There is already evidence that the shipbuilding industry is no stranger to these developments and is already connected to the Internet some components of ships, as it is exposed on figure 2.
As there smart home or smartphone, there are new smart ships that will be equipped with a network of sensors that capture a range of voyage information, including location, weather, ocean current, status of on-board equipment and status of cargo.

Ship owners can monitor the vessel’s status in real time and apply analytics to current and historical data to make decisions that enable them to run more efficiently, saving time and fuel.

Sensors and Information Technologies are facilitating the introduction of new applications at sea, like energy distribution, water control and treatment, equipment monitoring in real time… The aim is to take this technological revolution also acting in the design and production phases in order to build efficient, safe and sustainable vessels.

In a decentralized sector, like naval, where often the engineering and production are in different locations and where critical decisions cannot wait, the IoS or connection through the network of critical components in the design/shipbuilding, starts to glimpse as something that the sector cannot obviate.

The idea is to monitor all those parts in which early detection of events allows us to make the right decisions. In this sense, the available sensors during the early stages of construction of the ship, allow us to identify if the construction of the boat is completely according to the design we have created with CAD. If we can reduce materials or use another material, if we must change anything according with naval architecture calculations… The continuous monitoring integrated with a naval design CAD will reduce costs and avoid mistakes and make decisions in real time from the shipyard, design offices or from remote locations.

Nowadays CAD and PLM solutions can be used in a pocket tools, making it the indispensable ally in this new technological revolution.

Shipbuilding process, generates a lot of information and data, which a priori makes it seem impossible to have all this data in real time, but the new processors, simpler and smaller, with a good connection to the Internet, make it possible.

The data management is, however, only one side of the coin of the IoS. Energy efficiency is a fundamental aspect also in new devices that connect to the network.

But IoS not only covers the stages of design or production of the boat. Once the sensors are in the components whose information want to monitor, we will be able to obtain information throughout the life of the ship.

IoS is presented as a solution capable of detecting when a component on a boat is close to fail and must be replace, when we take the boat to repair when we have to paint again, when corrosion has reached a certain limit ... and all this from our pocket tool and early enough to avoid late or unforeseen performances. IoS reaches this sector to ensure profitable production, or safe, efficient and sustainable process for all types of fishing vessels, tugboats, tankers, charges, ferries, dredgers and oceanographic ...

3. SIMULATION

During the engineering phase, simulation tools and model tests are intensively used:
● **To analyse structure:** i.e. finite elements.

● **To analyse hydrodynamics:** i.e. CFD’s or tests in the model basin.

● **To design and improve production processes.**

Simulation also has its reason for being in the world of plant operations.

As will be seen in the section dedicated to Digital Twin, simulation can be an important ally in a shipyard, contributing decisively in the optimization of resources, both at the level of human resources and infrastructure as well as the rapid adaptation to new projects.

It is important to emphasize the issues related to plant safety: simulation models will provide the necessary information to be able to decide which will be configuration of the facility that could provide the optimum results for both:

● **Production:** definition and optimization of workflows in physical spaces.

● **Safety requirements:** distribution of spaces to ensure a proper evacuation in case of emergency and the definition of the Evacuation Plan.

A Shipyard 4.0 that implements technologies such as the use of autonomous vehicles, requires a particularly detailed analysis of the spaces, workers interactions, assets location and autonomous vehicles’ paths. For this purpose, simulation tools become fundamental to analyse and provide solutions for the difficulties that could be involved due to the coexistence of autonomous vehicles and workers into the same working space.

A key factor is the constant progress of developments in the world of videogames and the potential that it is demonstrating to have in the world of the engineering.

These game development platforms natively offer access to a virtual world that includes physics, materials, animation, etc. allowing the creation of photorealistic environments in which to have the Digital Twin of the product and the shipyard, as well as the workers and vehicles that interact in it. Once done, there is free way for simulation in this virtual environment.

With these tools, it will be possible to analyse the different distribution and operation’s options into the virtual world and test them under different conditions, like for example:

● **Workers and autonomous vehicles:** operating simultaneously with different routing alternatives.

● **Different environmental conditions:** light, humidity, temperature.

● **Failure of some systems.**

● **Product assembly operations:** requiring the definition of operation strategies.

● **Facilitate evacuation process:** under different conditions.

The creation of the connection between the 3D CAD model of the product and the infrastructure in which the product is manufactured, and the game development platform,
opens the door to endless possibilities, in addition to the simulation itself. In many cases, the core of the products that offers the implementation of Digital Twin and the access to Virtual Reality and Augmented Reality technologies is based on a Video Game development platform. In the paper The use of CAD Systems to manage modularity in multi-role warships [9] it is detailed how CAD tools could help in the design of this kind of warships when we combine simulation and a concept that can be called variants.

If a CAD or PLM System includes the possibility to work with variants, the complex case of the design and construction of multi-role warships can be faced in better conditions. In that case, the importance of the simulation of each variant before taking any decision is a key factor.

4. AUTONOMOUS VEHICLES

We have all heard about autonomous vehicles that promise to change the way we move. Although we may already find vehicles capable of driving autonomously, much remains to be done, both technologically and regulatory.

In the industrial field, the objective sought with this type of vehicle is to improve logistics and the transport of materials in the factory itself, or in our case, the shipyard.

Autonomous vehicles that are already used in industrial environments use different types of navigation systems, so we can distinguish two types of autonomous vehicles based on the navigation system they use:

- **Self-Driving Vehicles (SDV)**: these are the most modern and have sensors, 3D laser scanning, that allow them to move completely autonomously and generate a map of the environment, just as robots vacuum cleaners do today.

- **Automated Guided Vehicles (AGV)**: have navigation systems based on magnetic tape, beacons or additional infrastructure to follow its path around a facility.

For these vehicles, it is essential to have a robust communications infrastructure that allows dialogue between vehicles, as well as with the system that transfers precise instructions on what to transport, where to pick it up and where to take it.

The implementation of this type of vehicle in production processes has been shown to provide significant cost savings, although it is true that the necessary investment may be a factor that does not offset the expense. These autonomous vehicles are widely used in the automotive industry or large logistics centres, but is the shipyard a good place to use them?

The transport of materials from one point to another is where this type of technology can add value, but for proper operation of these vehicles it is necessary to have space, cleared roads and a lot of order.

In an environment such as a shipyard, SDVs are the vehicles that have the greatest possibilities of being able to work properly due to their capabilities. Those capabilities are mainly provided by the sensors that allow navigation with a dynamic analysis of the environment, the detection of obstacles and the intelligence to avoid them, as well as a
dynamic planning of the route to follow.

The distribution and the way of working in a shipyard is far from what can be found in a car factory or a large logistics centre, environments with a clear definition of spaces. In both cases, it is feasible to reduce interference between humans and autonomous vehicles. The implementation of autonomous vehicles in a shipyard may not be feasible if minimum conditions are not met so that these types of devices cannot move properly and, in any case, only SDVs seem to be viable.

Recent advances in SDVs make autonomous vehicle-human compatibility in the same working environment increasingly feasible. Examples of this type of vehicle are: OTTO1500 model (as publicised in figure 3) with a load capacity of 1,500 kg and OTTO100 with a load capacity of 100 kg.

![Figure 3. OTTO 1500 can be equipped with a conveyer belt.](Source:ottomotors.com)

In the area of inspection, the use of multi-copter air drones equipped with cameras and sensors to avoid collisions is another possibility on which work is being done. The internal inspection of large cargo tanks or the monitoring of the evolution of the construction from an aerial view can be good application examples. If we add photogrammetry, it is possible to make 3D models with multiple uses, like for example the possibility of carrying out an analysis of the evolution along time of the construction of a ship, something that is already being used to monitor the evolution of a land construction, for example, or to calculate volumes.

5. ROBOTICS

Robotics aims at the design, construction and operation of robots, in its broadest meaning. Many technologies are involved in the development of machines designed with the aim of replacing humans in some of their activities and the technological advances we are undergoing mean that more and more activities carried out by humans can be executed by robots.
A key factor for the correct implementation is the standardization and optimization of business models before these types of technologies come into play. The more orderly and clear the processes, the more effective this technology will be. In diffusely defined processes, automation is not an option.

Beyond these two types of robots, exists a type of technology that could be included in robotics and, in the industrial field, especially in the environment of a shipyard, can have a brilliant future.

We talk about devices that enhance human capabilities when carrying out their activity. It could be said that a person endowed with a Google Glass type device (google.com/glass/start), which allows access to contents superimposed on reality, is equipped with a device that enhances its capacity through access to information invisible or inaccessible to someone who does not have that device. This gives the advantage when performing certain jobs in which access to that information enables the user to perform tasks more efficiently and safely, but this is not the type of robotic device to be treated it is the exoskeletons. These devices are capable of multiplying capabilities such as the strength of a human being, something that can be especially useful when working with large and heavy pieces, such as those that can be found in a shipyard or facilitate the performance of tasks that require forced postures.

It seems like science fiction, but it is a technology that is present and that is also improving at a good pace, although its application is still limited and mainly at the prototype level. Important advances have been made in the military field, but good examples can also be found in medicine, such as devices that allow people who have never been able to get back on their feet, have suffered accidents or degenerative illnesses that have put them in a wheelchair.

One of the main difficulties faced by this type of devices is the autonomy; many of them require external power, as the weight of the battery for having a minimum operating autonomy makes it unfeasible, so advances in the field of batteries are essential to have really useful exoskeletons.

Some examples of this technology:

- **Raytheon XOS 2 Exoskeleton**: exoskeleton (revealed in figure 4) developed for military purposes that allows the user to lift and carry heavy weights without loss of agility.

- **Berkeley Lower Extremely Exoskeleton**: This exoskeleton system is designed for soldiers, disaster relief workers, and other emergency personnel and provides the ability to carry heavy loads with minimal effort over any type of terrain for extended periods.

- An industrial application of this type of exoskeleton can be found in the Spanish company Telice, a company in the railway sector. In March 2019 they tested two exoskeleton models that fit to the worker's body allowing him to handle easily heavy parts, perform tasks in forced postures that thanks to this armour required less effort. These exoskeletons could be used by operators who perform repetitive tasks, work with heavy parts or need to keep postures that produce strong joint and muscle wear,
allows them to improve their working conditions and reduce the chances of injury and with it, medical leaves.

Exoskeletons promise to be important in the Industry 4.0 and in particular in the Shipyard 4.0 since the conditions for considering their use in shipbuilding are evident.

**Figure 4. Soldier wearing Raytheon’s XOS 2**

![Soldier wearing Raytheon’s XOS 2](source: www.army-technology.com)

6. **ARTIFICIAL INTELLIGENCE**

Control system in the ship can include some Artificial Intelligence predictive processes integrated in the bridge overall control system, which helps to deduce the consequences of maintenance operations, from doing in the correct time as well as delaying or skipping them [8].

This procedure applied is including in the edge/fog computing methods, due to only involves the ship inner communication network, delaying the massive download of operation data upon arrival at port. During navigation data transfer should be only applied to critical operations.

Navigation data can be also useful in design and production phases, to correct some processes in order to obtain more efficient systems, and more efficient designs. This is only possible applying some Artificial Intelligence process to this data, classifying, processing and getting some results.

This working methodology, to be deeply profitable for both actors, requires a joint venture between ship-owner and shipbuilder.

Artificial Intelligence processes based on navigation data, in the multi-boat paradigm, can obtain information to improve design and production processes, which can be applied to the current series, or an evolved variant of this vessel type, or other ones [2].
Ship operation phase is not the only one which produces a set of Big Data to be processed by an Artificial Intelligence System, in the production phase, some calculus can be done in the workshops or even delegated in a cloud system, to be distributed. This data, in CAD Artificial Intelligence tools, can be classified generating working sequences, design automatic checks, and automatic design processes.

At this point, some sceptic people can think: Artificial Intelligence is going to substitute designers work, but Artificial Intelligence is going to augment the capabilities of this designer, making work less stressing and more efficient.

Artificial Intelligence applied to a CAD System should be based on the standard ways to control a design:

- Rules based design.
- Lessons learned.
- Cognitive rules.

First on the list, rules based design, it is the shipyard standards book of rules. These rules are the base of any shipyard design, and are the first one to be learned by our Artificial Intelligence System.

To improve it, some other technologies can be applied, like Cognitive Artificial Intelligence, which is the base of natural language processing in an Artificial Intelligence solution. This cognitive Artificial Intelligence can be run over the shipyard standards book of rules, and with some user help, try to improve understanding in application of the rules from the Artificial Intelligence tool. All Artificial Intelligence solution requires a specific time to learn the correct ways to apply the set of rules.

Next step, also based on natural language spelling, can be add the lessons learned to our Artificial Intelligence solution, creating a mixed ecosystem of rules to be applied to the current design process.

And last step, but not less important, Cognitive Rules, these rules are deduced from the current design and also from production error input in the CAD System, like design incidences.

### ADVANCED MATERIALS

Among one of the most defining technology trends is related to advanced materials. Advanced materials, referred also to as lightweight materials, are developed from compounds at a molecular level through applied physics, materials science, and chemistry. Advanced materials may generally be considered to fall into three categories, including metals, composites and polymers (typically fibre-reinforced polymers, is a composite material made of a polymer matrix reinforced with fibres, which are usually glass, carbon, aramid, or basalt), in addition to new materials, such as ceramics, carbon nanotubes and others nanomaterials. Nanomaterials are one of the main products of nanotechnologies which involve designing and producing objects or structures at a very small scale, on the level of 100 nanometres or less.
Overall advanced materials enable reduced weight of a product, component or system while maintaining or enhancing performance, operational supportability, survivability and affordability. When executed efficiently, weight reduction encompasses the early integration of design, development, and implementation of lightweight materials, component fabrication, assembly, joining, and other technologies, as well as the capability to manufacture and produce such materials and components at reasonable cost. Advanced materials increasingly important to the competitiveness of transportation manufacturing sectors because lighter vehicles have better performance and use less fuel. Subsequently, they can carry larger loads and travel the same distances at lower cost and with fewer carbon emissions.

Today's researchers and engineers are also finding a wide variety of ways to deliberately make materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts.

Manufacturing at the nanoscale is known as nano-manufacturing. It involves scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems.

8. 3D PRINTING

3D printing is one of the technologies that can mean one of the main changes and more disruptive in the manufacturing value chain. It is a technology that allows a customization of the product never seen before, and in many cases is a real alternative to manufacturing technologies.

The impact is not only due to the way the products are manufactured, but the effects can also be seen in the way that the products are distributed and maintained. An example is the possibility of changing from stockage of a determined product with storage room occupation and aging until the moment it is used, to the printing of that product in the moment it is needed.

We have examples in which 3D model is the purchase element, and then, with a 3D printer we can print it by ourselves as many times as necessary.

There are many 3D print types, but in general we can say that are techniques based on material addition layer to layer until model geometry is reproduced, while conventional techniques are based in subtraction, this is removing material by cutting, drilling or by means of moulding and normally several machines for the whole process are involved.

In 3D print there is a key factor, the 3D model, which origin can be from two different ways:

- **Model made with CAD tools**: particularly applications from those that are made for prototyping and conceptual design to those of mechanic CAD type: this is the more usual method for model creation that are going to be printed with 3D technology.

- **3D scanning**: we find two main techniques: laser scanning and photogrammetry.
Today, it is not unusual to find a combination of CAD models that integrate geometries obtained from 3D scanning. This is useful when modifying an engine room, for instance, scanning it and performing the re-design based in the 3D cloud of points. 3D scanning of the affected area will allow to generate a simulation that may define a strategy to face this operation from the best approach, by modelling tools and simulation of the different process stages combined with a system for collision detection.

3D printing evolves very fast, although speed is not one of its qualities, in fact it is a critical point where development is focused.

It is important to stand out that one of the biggest difficulties that arises when printing a 3D model is to configure the printer based on the material that is going to be used, quality of the pretended print end piece and the proper preparation of the model for its printing by one of these adding technologies. Periodic calibration of these printers is fundamental and depending on the type of printer chosen, factors such as ambient temperature can influence greatly in the process.

Industry like automotive and aerospace are the ones driving most of the progresses in 3D printing media, meanwhile in shipbuilding industry there is still a long way to make, challenges are very important and, in some cases, different to those that may exist in other sectors.

9. DIGITAL TWIN

Digital Twin is a widespread concept that belongs to the Industry 4.0 ecosystem but, what does it means and what is it for?

This concept means the connection between the real asset and the design, the virtual world. There are industries where this concept is widely applied, but shipbuilding industry is still starting with it.

Aero-generators, energy platforms, airplane engines are nowadays the most common cases where we can find Digital Twin applied to, with two possible approaches: create a Digital Twin of the product and create a Digital Twin of a complete factory and control the facility through its Digital Twin.

According to a Gartner’s study, Digital Twin is used by the 24% of the organizations with IoT technologies in production or with undergoing IoT projects and in the next three years, another 42% is planning to implement it.

Many technologies, most of them described in this paper, are necessary to make possible a real effective Digital Twin, but IoT could be considered the most important, without forgetting the most basic and important technology necessary to make the Industry 4.0 works, the communications infrastructure and, as always when we talk about data, security.

Digital Twin means a continuous and bidirectional exchange of Data between the real asset and the model, with the objective to have a real-time synchronization between those worlds. Real Asset to Virtual Data flow will be possible with a combination of sensors sending information through the communication infrastructure and human operators
sending data by using Apps normally designed for devices that allow mobility and wireless connection. Human or automatic processes, if the virtual asset includes Artificial Intelligence or some automatic program that simply has an output depending on some input parameters, can manage both communication flows. At the basis of the Digital Twin, the model is a must.

There are different ways to have it:

- **Spherical photographs**: it is a 360° horizontal and 180° vertical photograph that can be reproduced in an interactive way into a 3D representation.

- **3D scanning**: This method is widely explained in the paragraph that talks about 3D printing.

- **3D CAD model**: This is the best option for a new infrastructure, or for a facility that already has the 3D model that can be easily updated to current situation and be used as Digital Twin without excessive effort.

The combination of 3D CAD model and 3D scanning is perhaps the most interesting. With both technologies, it is possible to measure, and this is a very important advantage. Shipyard is not a static scenario, that is why the best option is a Digital Twin based in 3D models generated with a CAD system and when necessary with models generated by using 3D scanning technologies by transforming the clouds of points in volumes and surfaces.

It is important to assume that a fully integrated Digital Twin is not always reachable and it will be frequent to find partial implementations that consists just in data acquisition from machines in order to analyse and use for different purposes, but once reached this first step, it will be easier to move in the Digital Twin direction.

10. **CLOUD AND CYBERSECURITY**

Cloud computing requires transfer of sensitive data through an external network to our system, where it is processed and the response, which can include even more delicate data, used in the client system.

Some crypto processes are required to hide this data to curious, or even malicious, people. These processes require a secured channel, a double check to validate the information and some special operations all developed in the cybersecurity paradigms.

Based on those paradigms, in 2009, the blockchain methods, designed in 1991, are applied to cryptocurrency opening a new interchange trusted world which ends with the bank intermediary requirement in monetary transactions [6].

11. **BLOCKCHAIN**

This cybersecurity paradigm opens a new tool for distributed and shared work in all the industries, even more in shipbuilding, and its huge security requirements sibling, naval shipbuilding.
Blockchain technology offers a secure channel which requires an invitation, special program which knows all connection data, and where every operation performed is validated for all available connections and saved in a non-modifiable way, and where all the agents have a full copy of these operations, generating a trusted work methodology.

A CAD or PLM tool that includes the possibility of a blockchain creation per each distributed work, and which locks items based on the assignation to a blockchain operation can be included in the new era of Industry 4.0.

12. VIRTUAL REALITY AND AUGMENTED REALITY

Both Augmented Reality and Virtual Reality are technologies that cannot be considered as new, especially Virtual Reality, whose origins go back to the Second World War. Until not long ago, the use of Virtual Reality in industrial area was something very rare, due to among other, to the high cost of this technology, but up to now and thanks to the recent progress in computer sciences, miniaturization, storage, graphic processing and the new high-resolution screens as well as technology is cheaper, Virtual Reality and Augmented Reality have revived. Today, and thanks to the possibility of using smartphone for watching/interact in Virtual Reality environments or visualize Augmented Reality contents, these technologies are available to everyone without need of having a very powerful device.

Nevertheless, Augmented Reality is the technology that may seem to have more power in industrial sectors, proving in the cases it has been implemented that:

- Significant error reduction.
- Increase in productivity.
- Drop in employee injuries.
- Reduction of ergonomics issues.
- Favour collaborative environment.
- Improves efficiency.

The use of these technologies is more present and every day more important in automotive technology and also aerospace industry. In other industries, the progress is slower, as for instance in the shipbuilding, but for Digital Twin, Virtual Reality and Augmented Reality comes along and Digital Twin is an unstoppable wave in Industry 4.0 and Shipyard 4.0.

Augmented Reality application in Industry could be wide, and in part also offers many of the possibilities that Virtual Reality proposes but it is necessary to distinguish in each case what is the best option. Augmented Reality has a strong link with reality; this doesn’t happen the same way with Virtual Reality, but if this Virtual Reality is used over Digital Twin, the link is stronger. This link with reality consists on the exploiting and visualization of the information generated by IoT. Augmented Reality allows as well to overlap the information generated by the IoT infrastructure directly, see history, trends, forecasts, warnings... Never-ending possibilities that Digital Twin, through Virtual
Reality could also offer remotely, being able in a future, who knows, to reach a completely remote management of a complex infrastructure interacting with Digital Twin.

13. CONCLUSIONS

As an example of IoS, the connectivity in smart ships will be extended to the commercial mission to act autonomously in operation conditions. A commercial vessel can transmit its navigation situation or its loading conditions. All these means a huge amount of information to be managed and analysed. New programs have to be developed to obtain the best use of such information so that the design can be improved from real function information of the design and it can be self-maintained with the connection with this huge cloud information to create method that the objects can achieve certain intelligence.

The growth of the IoS is linked to the increase of information and the management of Big Data, with the property that somehow IoS identifies information and direction and order to a specific purpose, while the concept of Big Data is more generic.

Last advantage is, if something happens in a ship, it can be reproduced in the shipyard based on this model, and getting a full condition simulation. This helps to focus the problem.

Adding some Radio Frequency IDentification (RFID) tags to the parts, can improve system information in ship brain, and if some parameters can be improved due to new known experiences can be downloaded in the ship to improve her behaviour.

After the review of all this technology presented in the paper, it is possible to have an idea of the magnitude and complexity of the changes that Industry 4.0 is demanding. In most cases, it is an unavoidable step that must be taken to remain competitive, but with the adoption of only a part of what is exposed; it could mean a too risky and complex step that should be studied carefully before taking any decision. Some of these technologies are in early stages for industrial implementation but it is important to be aware and analyse what can offer and what can be useful for each case.

Most of the different technologies exposed in this paper are well known since long, but the true potential came a few years ago with the improvements in the communications infrastructures, that is why a concept like Digital Twin is something that seems reachable. Now with 5G, it is expected that IoS will grow in an exponential way and its true potential will arise, which will also mean the Digital Twin impulse.

The Virtual Reality technology have reappeared mainly thanks to the Game Development Industry and the lower cost of technology derived from the evolution of flat screens and miniaturization among other factors. Virtual Reality seems to have an important future for training and simulation purposes, but its implementation in companies has a lower interest compared with AR.

There is another important piece of the puzzle: the security, veracity and trust in the data transactions between all the different participants. Cloud and security are two pieces of the game and without them, all this ecosystem will never work. Data transactions should be guaranteed and all the steps should be tracked from the first step to the last one of the process thanks to blockchain.
Repetitive tasks and dangerous activities that nowadays are carried out by labour force, can be replaced or supported by robots, which means an important change for the companies and the people that works there, but this transformation is unstoppable. New jobs will be created and new profiles will be necessary but those jobs that could be replaced totally or partially with robots will disappear. People should react to this new conditions and adapt.

The implementation of robots and autonomous vehicles in the Industry will also mean the presence of new tools that will improve working conditions for current workers, but it is necessary an adaptation to all these new technologies and sometimes it will not be easy. Shipbuilding is an Industry that could take advantage by using them, but depending on the particularities of each shipyard, this technology will be more or less easy to implement and even if it is feasible, the decision should be taken with perspective, because physical robots and autonomous vehicles needs special conditions to work.

New materials and 3D printing techniques will have an important role in the future of Shipbuilding as is already being demonstrated in other industries such as aeronautics and automotive but in shipbuilding there are interesting challenges, the use of 3D printing on board.

In the middle of this ecosystem we will find a 3D model, created mainly with CAD tools and this means that the importance of CAD will be even more capital than today. The interface between the 3D model and the rest of the Industry 4.0 is the Digital Twin, the link between the reality and the virtual world, both living concurrently during the evolution of the construction and extending this world of possibilities to the entire lifecycle of the product.

CAD and PLM tools, as an important part of all this environment, should also evolve to be easily linked to these technologies, but also it is important to be adapted to the new generation of users that demands a different kind of interfaces and workflow and this will require an important effort.

This big world is now open and Shipbuilding is starting in it, but the potential is clear and to remain competitive is mandatory to study how these technologies can improve the benefits by upgrading processes, resources, workflow, cooperation between stakeholders… the tools are here, now it is necessary to study and analyse our particular case. There is no global solution for all industries, not even a global solution for a particular industry, but digitalization is on hand and it is mature enough to start implementation and be part of our strategy for the future.

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ADAPTING THE EXISTING COASTAL PATÍ A VELA FLEET FOR SCIENTIFIC PURPOSES

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Abstract:

This paper presents the first results of the Barcelona Institute of Culture’s grant for research and innovation projects under the 2019 Barcelona Science Plan entitled “Development of a citizen monitoring program for the Barcelona waters: The Scientific Patí a Vela”. The main objective of this project is to develop a small Patí a Vela (PV) fleet that can routinely sample the Barcelona coastal waters and report their observations to an open-access interactive web. The Patí a Vela boat was designed in 1942 by the Mongé brothers. It is a lightweight one-person catamaran with a single Marconi sail and no boom.

The main objective of this contribution is to adapt the Patí a Vela model attaching an on-board platform with scientific instruments (sensors and devices) and determine the new stability characteristics and seakeeping performance. This will allow an adequate sampling of the Barcelona coast waters and the systematic measurements of the essential physical and biogeochemical variables detecting variations along the coast, hence identifying potential sources of contamination. It will also provide the necessary knowledge of natural and anthropogenic seasonality.

Keywords:

Stability; seakeeping, recreational sailing; ocean monitoring, low cost environmental sensors

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INTRODUCTION

The low-lying coasts and nearshore communities face vulnerability to the natural disasters and climate change. On one hand, recent events like the powerful Storm Gloria in January 2020 caused severe damages devastating coastal areas along the Mediterranean and beat several historical records of rain, wind and waves (1)(2). On the other hand, coastal marine environments are a major focus of concern regarding the potential impacts of anthropogenic climate change (3) and has implications for marine ecosystems, with far-reaching consequences for human and welfare.

Coastal population densities are nearly three times that of inland areas, and they are increasing exponentially (4). Monitoring the coastal waters is essential to understand how the planet is changing and how these regions evolve due to natural and anthropogenic effects.

The knowledge of the oceans has improved drastically during the last decades, particularly thanks to satellites remote-sensing and a fleet of and autonomous underwater instruments present in all the oceans far from the coast. However, coastal waters are undersampled both in time and space (5). Sample nearshore coastal waters sometimes is difficult from conventional oceanographic platforms. There are different innovative ways of sampling these waters, like attaching sensors to marine mammals as platforms for oceanographic samplings (6). (7) draw attention to the vast number of participants that engage in nautical recreation sports and found that it could be an option to improve the large-scale sampling efforts: for instance, (8) equipped recreational surfers with a temperature sensor to estimate the sea-surface temperature; (9) equipped SCUBA divers as oceanographic samplers and (10) designed a sensor package to be mounted on paddleboards.

Barcelona’s climate is conditioned by the Mediterranean Sea, which acts as a natural regulator to prevent extreme weather conditions. Further, the surrounding sea provides natural resources for local fisheries and a gathering space for local people and visitors, for recreational and social activities. Despite its relevance, the Barcelona marine environment remains very poorly sampled. Apart from the water quality control carried out in summer (11) only a systematic year-long offshore sampling has been regularly maintained since 2002 (12).

In order to improve this lack of samples, we propose a local strategy for protecting Barcelona coasts and nearshore communities using a recreational boat widely used on Barcelona’s coast and nearby, the Patí a Vela (PV) sailing boat. It is a wooden sailing boat that was born on the beaches of Badalona and Barcelona (Spain) because of the need for swimmers to pass over the polluted nearshore waters. It is a lightweight one-person catamaran with a single Marconi sail and no boom. This boat has the peculiarity of not having a rudder nor a centreboard. The steering is only controlled using the bodyweight of the crew member and the tension in the sail. The Patí a Vela boat was designed in 1942 by the Mongé brothers. Today, the Patí a Vela fleet is distributed over Catalonia, Andalusia and Valencia, but also reaches the French, Belgian and Dutch coasts. According to the International Patin Sailing Association (ADIPAV) data, more than 200 Patí a Vela could directly interact with the samplings. If part of these recreational boats were equipped with the scientific on-board platform with sensors, this could be potential to acquire large volumes of data enhancing the sampling volume of environmental indicators in Barcelona and nearby coast waters.
The main objective of the research project is to develop a first prototype a Scientific Patí a Vela (SPV) that can routinely sample the Barcelona coastal waters using relatively low-cost sensors package (https://atlas-scientific.com/) and report their observations to an open-access interactive web (13).

To ensure its success, the impact of this recreational activity with the attached sensor package should be minimal, with implications for weight and size requirements. Moreover, the sensor package should be easily accessible and appropriately positioned for good data collection without damaging the crew member activity.

Therefore, the first step of this project is to model a Patí a Vela boat, define the appropriate sensor package and its position and finally evaluate the new stability characteristics and seakeeping performance to hold an on-board platform with scientific instruments. In this contribution, we present the results of this first step. The paper is organized as follows: after the Introduction, Section 1 (methodology) presents the Patí a Vela model considering the official Class Rules. Also, the scientific sensors and devices are described showing the appropriate position of the experimental set-up on-board platform. Section 2 (results) shows the intact stability and seakeeping analysis of four load cases: (1) Patí a Vela without scientific platform (PV), (2) Scientific Patí a Vela (SPV), (3) Patí a Vela with the crew member without scientific platform (PV-crew) and (4) Scientific Patí a Vela with the crew member (SPV-crew). Finally, conclusions are highlighted in the final section (Section 3).

2. METHODOLOGY

The methodology to study the new PV stability characteristics and seakeeping performance to hold a scientific on-board platform is described below. Four load cases have been considered: first, following the body plan attached at the PV Class Rules (14), the 3D model of the Patí a Vela is designed in Catia V5 (PV load case). Then, the experimental set-up on-board platform is described and the scientific devices have been appropriately positioned for good data collection with the minimal impact on navigation (SPV load case). Other two load cases have been considered, the PV load case with the weight and position of the crew member on-board (PV-crew load case) and SPV load case with the weight and position of the crew member on-board (SPV-crew load case).

2.1 PV LOAD CASE

Figure 1 shows the PV model following the body plan attached at the Patí a Vela Class Rules.

Figure 1. Body plan3 (PV Class Rules) and PV 3D model in Catia V5.
To compute the PV lightweight and its centre of gravity, the weight and centre of gravity of each item are considered according the PV Class Rules. The weight and centre of gravity of the hull is determined considering that the construction material is marine plywood with a density of 440 kg/m³. The thickness of the different parts of the PV is shown in Table 1 and 17 bulkheads are considered:

**Table 1. Thickness of the different parts of the PV boat**

<table>
<thead>
<tr>
<th>Item</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull</td>
<td>5</td>
</tr>
<tr>
<td>Deck</td>
<td>7</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>5</td>
</tr>
</tbody>
</table>

The frame of reference considered is presented in Figure 2, the positive x axis is forward, the positive y axis is starboard and the positive z axis is up.

**Figure 2. PV Frame of reference.**

Finally, the weights and centre of gravity of the lightweight condition is shown in Table 2:

**Table 2. Weights and Center of Gravity (CGx: longitudinal, CGy: transversal, CGz: vertical) (PV load case)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (t)</th>
<th>CGx (m)</th>
<th>CGy (m)</th>
<th>CGz (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull</td>
<td>0.089</td>
<td>2.87</td>
<td>0</td>
<td>0.35</td>
</tr>
</tbody>
</table>
The total weight for the PV load case is 101 kg and the position of the centre of gravity is $CG_x=3.03$ m, $CG_y=0$ m and $CG_z=0.664$ m.

### 2.2 SCIENTIFIC PATÍ A VELA (SPV LOAD CASE)

To adapt the PV model, the scientific equipment includes: a sensor box with a sea surface temperature sensor and a conductivity sensor, an electronic box that must be connected with the sensor box, a 12 V battery, a water collector/evacuated tube with pump connected with the sensor box and a Sechhy disk (Figure 3 and Figure 4). All this equipment will be well suited into a platform with a waterproof box and data will be transferred via wireless or mobile data upload with charging capabilities and cloud-based data storage.

Table 3 shows the size and the weight of the experimental scientific equipment:

<table>
<thead>
<tr>
<th>Component</th>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mast</td>
<td>0.009</td>
<td>4.51</td>
<td>0</td>
<td>3.1</td>
</tr>
<tr>
<td>Rigging</td>
<td>0.001</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sail</td>
<td>0.002</td>
<td>3.27</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 3. Experimental scientific platform

Figure 4. Sensor Box (left) and Electronic Box (right)
Table 3. Size and weight of the Experimental Scientific Equipment.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dimensions (cm) [height (z)· depth (x)· width (y)]</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery (12V)</td>
<td>9.2·9.4·14.4</td>
<td>3.94</td>
</tr>
<tr>
<td>Electronic Box with Battery (5V)</td>
<td>8 · 17.5 · 22</td>
<td>0.92</td>
</tr>
<tr>
<td>Sensors Box (without water)</td>
<td>13 · 13 · 13</td>
<td>0.55</td>
</tr>
<tr>
<td>Water Collector/Evacuated tube with pump</td>
<td>-</td>
<td>0.4/0.17</td>
</tr>
<tr>
<td>Waterproof Equipment Box</td>
<td>20 · 96 · 74</td>
<td>10</td>
</tr>
</tbody>
</table>

Then, the position of the scientific devices has been appropriately positioned for good data collection with the minimal impact on navigation. The platform and the waterproof box must be placed between the second and third beds from the bow, since it is the position with minimum interference with the crew member to trim the PV (Figure 5).

**Figure 5. Platform and waterproof box position (SPV load case)**

The sampling water will be obtained through the water collector. The box sensor will be filled of sea water and then will be drained through the evacuation tube. For a good data collection, the water must be collected with the minimum turbulences, so the pump must be placed as forward as possible. The collector tube will pass through the waterproof box on the side parallel to the water. It must be taken into account that in this area, there are also the cables to trim the sail (Figure 6).

**Figure 6. PV trimming cables.**
The sail can be trimmed to forward or to aft, therefore the tube collector must be positioned in a location that does not disturb the movement of the cables to trim the sail. As can be seen in Figure 7, the cables to trim the sail are positioned in the maximum forward position (yellow line) and in the maximum aft position (green line). Both configurations have been analyzed in order to decide the position where the tube collector will go through the waterproof box and the position of the different elements that make up the final scientific equipment position at the PV.

**Figure 7. Cables to trim the sail in forward position (yellow line) and aft position (green line)**

The configuration of the scientific instruments described in Table 3 is presented in Figure 8. The sensor box (red item), is situated in a side, as forward as possible and without interfering with the movement of the trimming cables. The electronic box (pink item) is positioned behind the Sensor Box and in the same side. In order to keep the center of gravity of the PV boat in the plane of symmetry, the position of the Battery (light blue item) is positioned on the other side and as aft as possible.

**Figure 8. Scientific instruments configuration**
Finally, the centre of gravity and weights for the new load case are shown in Table 4:

Table 4. Weights and Center of Gravity (CGx: longitudinal, CGy: transversal, CGz: vertical) (SPV load case).

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (t)</th>
<th>CGx (m)</th>
<th>CGy (m)</th>
<th>CGz (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship</td>
<td>0.101</td>
<td>3.03</td>
<td>0</td>
<td>0.664</td>
</tr>
<tr>
<td>Platform and Waterproof Box</td>
<td>0.010</td>
<td>3.043</td>
<td>0.002</td>
<td>0.6</td>
</tr>
<tr>
<td>Sensor Box</td>
<td>0.003</td>
<td>3.278</td>
<td>0.346</td>
<td>0.565</td>
</tr>
<tr>
<td>Electronic Box</td>
<td>0.001</td>
<td>3.025</td>
<td>0.301</td>
<td>0.540</td>
</tr>
<tr>
<td>Battery</td>
<td>0.004</td>
<td>2.749</td>
<td>-0.316</td>
<td>0.572</td>
</tr>
</tbody>
</table>

The total weight for the SPV load case is 119 kg and the position of the centre of gravity is CGx=3.023 m, CGy= 0 m and CGz=0.652 m.

2.3 PV WITH CREW (PV-CREW LOAD CASE)

A new load case has been considered the PV with the crew member on board. The weight of the crew member is 69 kg and it is positioned at CGx=0.5m, CGy=0m and CGz=1m in the fifth bed (see Figure 9). In this case we have considered the crew member is situated in the centreline but, in function of the wind direction, the position of the crew member will change at the starboard or port site.

Table 5. Weights and Center of Gravity (CGx: longitudinal, CGy: transversal, CGz: vertical) (PV-crew load case)

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (t)</th>
<th>CGx (m)</th>
<th>CGy (m)</th>
<th>CGz (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship</td>
<td>0.101</td>
<td>3.025</td>
<td>0.000</td>
<td>0.664</td>
</tr>
<tr>
<td>Crew member</td>
<td>0.069</td>
<td>0.500</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The total weight for PV-crew condition is 170 kg and the position of the centre of gravity is CGx=2 m, CGy= 0 m and CGz=0.9 m.

2.4 SCIENTIFIC PV WITH CREW LOAD CASE (SPV-CREW)

Finally, a last load case (PV with both scientific platform and crew member on-board) has been considered.

Figure 9. Position of the crew member (orange circle) and position of the waterproof box (blue rectangle) for SPV-crew load case
The total weight for the SPV-crew load case is 188 kg and the position of the centre of gravity is \( CG_x = 2.097 \) m, \( CG_y = 0.001 \) m and \( CG_z = 0.78 \) m.

### 3. RESULTS

Once the design has been modelled, the hydrostatics, stability and the seakeeping performance of described four load cases (PV, SPV, PV-crew and SPV-crew) have been assessed using Maxsurf stability analysis module.

Table 6 shows the hydrostatics particulars of the three described conditions.

**Table 6. Hydrostatics particulars (PV: Patí a Vela; SPV: Scientific Patí a Vela; PV-crew: Patí a vela with crew member; SPV-crew: Scientific Patí a Vela with crew member)**

<table>
<thead>
<tr>
<th>Hydrostatics</th>
<th>PV</th>
<th>SPV</th>
<th>PV-crew</th>
<th>SPV-crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft Amidships m</td>
<td>0.109</td>
<td>0.122</td>
<td>0.199</td>
<td>0.210</td>
</tr>
<tr>
<td>Displacement t</td>
<td>0.1010</td>
<td>0.1186</td>
<td>0.170</td>
<td>0.188</td>
</tr>
<tr>
<td>Heel deg</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Draft at FP m</td>
<td>0.253</td>
<td>0.267</td>
<td>-0.142</td>
<td>-0.173</td>
</tr>
<tr>
<td>Draft at AP m</td>
<td>-0.035</td>
<td>-0.023</td>
<td>0.255</td>
<td>0.248</td>
</tr>
<tr>
<td>Draft at LCF m</td>
<td>0.167</td>
<td>0.180</td>
<td>0.197</td>
<td>0.207</td>
</tr>
<tr>
<td>Trim (+ve by stern) m</td>
<td>-0.288</td>
<td>-0.290</td>
<td>0.114</td>
<td>0.075</td>
</tr>
<tr>
<td>WL Length m</td>
<td>4.290</td>
<td>4.449</td>
<td>4.302</td>
<td>4.48</td>
</tr>
<tr>
<td>Beam max extents on WL m</td>
<td>1.491</td>
<td>1.499</td>
<td>1.511</td>
<td>1.518</td>
</tr>
<tr>
<td>Wetted Area m²</td>
<td>2.347</td>
<td>2.611</td>
<td>3.487</td>
<td>3.723</td>
</tr>
<tr>
<td>Waterpl. Area m²</td>
<td>1.207</td>
<td>1.298</td>
<td>1.340</td>
<td>1.430</td>
</tr>
<tr>
<td>Prismatic coeff. (Cp)</td>
<td>0.558</td>
<td>0.559</td>
<td>0.635</td>
<td>0.629</td>
</tr>
<tr>
<td>Block coeff. (Cb)</td>
<td>0.105</td>
<td>0.108</td>
<td>0.120</td>
<td>0.124</td>
</tr>
<tr>
<td>Max Sect. area coeff. (Cm)</td>
<td>0.188</td>
<td>0.193</td>
<td>0.198</td>
<td>0.204</td>
</tr>
<tr>
<td>Waterpl. area coeff. (Cwp)</td>
<td>0.189</td>
<td>0.195</td>
<td>0.206</td>
<td>0.210</td>
</tr>
<tr>
<td>LCB from zero pt. (+ve fwd) m</td>
<td>3.061</td>
<td>3.059</td>
<td>1.982</td>
<td>2.068</td>
</tr>
<tr>
<td>LCF from zero pt. (+ve fwd) m</td>
<td>3.000</td>
<td>2.994</td>
<td>2.208</td>
<td>2.299</td>
</tr>
<tr>
<td>KB m</td>
<td>0.118</td>
<td>0.126</td>
<td>0.123</td>
<td>0.129</td>
</tr>
<tr>
<td>BMT m</td>
<td>5.200</td>
<td>4.766</td>
<td>3.434</td>
<td>3.316</td>
</tr>
<tr>
<td>BML m</td>
<td>13.348</td>
<td>13.036</td>
<td>8.805</td>
<td>9.114</td>
</tr>
<tr>
<td>KMT m</td>
<td>5.306</td>
<td>4.882</td>
<td>3.556</td>
<td>3.445</td>
</tr>
<tr>
<td>KML m</td>
<td>13.436</td>
<td>13.133</td>
<td>8.925</td>
<td>9.241</td>
</tr>
</tbody>
</table>
Once the design has been completed, the total weight for the hull is calculated using the hydrostatics module. The total weight of 188 tonnes and CG 0.001 m have been assessed using the seakeeping performance analysis module.

The results show that the hydrostatics, stability, and seakeeping criteria have been satisfied for the three described load cases, SPV-crew (3): Scientific Patí a Vela with crew member (4)).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PV</th>
<th>SPV</th>
<th>PV-crew</th>
<th>SPV-crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersion (TPc) tonne/cm</td>
<td>0.012</td>
<td>0.013</td>
<td>0.014</td>
<td>0.015</td>
</tr>
<tr>
<td>MTc tonne.m</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.004</td>
</tr>
<tr>
<td>RM at 1deg = GMt.Disp.sin(1) tonne.m</td>
<td>0.008</td>
<td>0.009</td>
<td>0.008</td>
<td>0.009</td>
</tr>
<tr>
<td>Max deck inclination deg</td>
<td>3.8418</td>
<td>3.8738</td>
<td>1.5219</td>
<td>1</td>
</tr>
<tr>
<td>Trim angle (+ve by stern) deg</td>
<td>-3.8418</td>
<td>-3.8738</td>
<td>1.5219</td>
<td>1</td>
</tr>
</tbody>
</table>

The stability criteria (15) has been applied to ensure the compliance with the class requirements. The ISO 12217-3:2017 specifies methods for evaluating the stability and buoyancy of intact boats of hull length less than 6 m, whether propelled by human or mechanical power. One important parameter related on initial static stability is the metacentric height (GM). The GM of the four described load cases are calculated as the distance between the vertical centre of gravity and its metacentre being: $GM_{PV} = 4.642 m$, $GM_{SPV} = 4.23 m$, $GM_{PV-crew} = 2.756 m$ and $GM_{SPV-crew} = 2.665 m$.

Another important stability parameter is the statical stability curve (GZ). This curve is a plot of the righting arm or righting moment against angle of heel for the given loading condition. Figure 10 shows GZ curve for the four conditions described above.

Figure 10. Statical stability curve (PV: Patí a Vela (1); SPV: Scientific Patí a Vela (2); PV-crew (3): Scientific Patí a Vela with crew member (4))

![Figure 10](image-url)
(2) Stability

Max GZ = 0,579 m at 12,7 deg.
DF point = 93,4 deg.

(3) Stability

Max GZ = 0,454 m at 14,5 deg.
DF point = 130,9 deg.
The new stability characteristics according to the metacentric height and large angle stability have been assessed. As can see, the metacentric height is slightly higher in initial PV load case without scientific platform nor crew member on-board and lower in the SPV-crew condition, but this value remains positive and high in the four load cases. Also, from Figure 10, the variation in GZ values are similar in the four load cases and the stability characteristics according the stability criteria ISO 12217-3:2017 are ensured.

Table 7 presents some of the significant parameters related on the stability and seakeeping performance of a ship and also the variation between PV and SPV load cases (with and without crew member). In general terms, these parameters can be described as:

- Metacentric Height (GM): higher metacentric height indicates higher initial static stability.
- Length/Displacement ratio (L/Dis): for a given length, the less the displacement, the better the seakeeping quality is.
- Length/Beam ratio (L/B): the pitch motion increases slightly with an increase of the L/B.
- Longitudinal Centre of Gravity (CGx). The effect of CGx position on ship motion is not so clear. For the head sea condition an increase in heaving motions is observed when the CGx position is located forward. When CGx is moved forward, both pitching motion and relative bow motion are slightly decreased.
- Longitudinal Centre of Buoyancy position (LCB) minus Longitudinal Centre of Flotation position (LCF): Seakeeping response are sensitive to LCB-LCF.
Table 7. Significant parameters on the stability and seakeeping performance for 4 load cases (PV, SPV, PV-crew and SPV-crew)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PV</th>
<th>SPV</th>
<th>Variation SPV/PV</th>
<th>PV-crew</th>
<th>SPV-crew</th>
<th>Variation SPV-crew/PV-crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM (m)</td>
<td>4.642</td>
<td>4.230</td>
<td>-0.412</td>
<td>2.756</td>
<td>2.665</td>
<td>-0.091</td>
</tr>
<tr>
<td>L/Dis (m/t)</td>
<td>42.475</td>
<td>37.513</td>
<td>-4.963</td>
<td>25.306</td>
<td>21.277</td>
<td>-4.029</td>
</tr>
<tr>
<td>L/B</td>
<td>2.877</td>
<td>2.968</td>
<td>0.091</td>
<td>2.847</td>
<td>2.635</td>
<td>-0.212</td>
</tr>
<tr>
<td>CGx (m)</td>
<td>3.030</td>
<td>3.023</td>
<td>-0.007</td>
<td>2.000</td>
<td>2.097</td>
<td>0.097</td>
</tr>
<tr>
<td>LCB-LCF (m)</td>
<td>0.061</td>
<td>0.065</td>
<td>0.004</td>
<td>-0.226</td>
<td>-0.231</td>
<td>-0.005</td>
</tr>
</tbody>
</table>

As can be seen in the above table (Table 7), the values between PV and SPV load cases (with and without crew member) are similar, indicating that the stability characteristics and seakeeping performance for all load cases are not affected by the attached scientific platform on-board.

4. CONCLUSIONS

In the past few years, some recreational activities have been used for data collection and environmental sampling. Thanks to low cost environmental sensors, there is scope to expand the range of environmental indicators that could be measured. In the first stage of this project, physical environmental indicators like temperature, salinity and turbidity will be analysed. Further research will analyse other chemical environmental indicators like oxygen and pH.

In this contribution the first prototype of the Scientific Patía Vela with an on-board platform with the scientific instruments is presented. Main hydrostatic parameters have been assessed to ensure the stability and seakeeping performance for new three load cases (with crew member and scientific platform on-board). Also, the position of the scientific devices has been appropriately positioned for good data collection with the minimal impact on navigation. Results indicate that the stability and seakeeping performance will not be affected with an on-board platform with scientific instruments. However, the attachment of the scientific on-board platform would also influence the ship manoeuvrability. Therefore, manoeuvring prediction of these load cases should be taken into account during the Scientific Patía Vela design step in further research.

Next steps of this project will show the first observations taken with the Scientific Patía Vela from a Barcelona coastal zone, which will be about 4-5 km long and between 0.4 and 2.4 km wide. All data will be freely available thanks to the development of an open-access interactive web where data will be incorporated and retrieved.

References:

References:


DIGITAL TWIN OF AN INTERNAL COMBUSTION ENGINE

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Abstract:

Major marine engine companies such as Wartsila have developed both their new 4-stroke and 2-stroke using gas and hence strongly believe that Internal Combustion Engines (ICE) have a place in marine power propulsion and auxiliary units. A recent announcement that Mazda sees a bright future for ICE is also indicative of the automotive industry has not lost hope in the future of ICE. This paper reports on recent developments to construct a digital twin of these power units with a view to improve their performance and also as a means of monitoring their behaviour when changes are introduced. This paper is composed of two parts. Part 1 is the digital half of an Internal Combustion Engine (ICE) which concerns the development of a mathematical model of the ICE and a suite of computer simulation programs which would allow the effects of various design and operational changes to be reliably and accurately predicted with the ultimate aim of producing cleaner engines and/or more efficient power units. The model has been tested against the experimental results of the Paxman engine at Newcastle University and earlier against the Atlas engine at Ricardo, Brighton, UK and most recently on the TUDEV Engine (2015). Part 2, contains the other digital half of the ICE which describes the rig developments viz., the physical model of an Engine. The key features of both Parts of the paper will be presented at the conference due to commercial confidentiality. However, the idea is to match the two parts using an earlier model developed by Ziarati (2009) to produce a fingerprint of both the mathematical model and the physical model. The matching of both parts would enable the mathematical model to be used for various design and operational changes with a view to reduce fuel consumption and/or engine harmful emissions. The predicted results and the experimental data are in good agreement.

Keywords:

Digital Twinning, Internal Combustion Engines, Cleaner Diesel.

NOMENCLATURE

$s'$: instantaneous stroke

$l$: conrod length

$s$: stroke

$V'$: instantaneous volume

$M_T$: trapped mass

$P_A$: piston area
\[ \eta_v: \text{volumetric efficiency} \]
\[ V_{cl}: \text{clearance volume} \]
\[ R: \text{gas constant} \]
\[ \bar{d}: \text{valve diameter} \]
\[ \bar{l}: \text{valve lift} \]
\[ P_{in}: \text{inlet pressure} \]
\[ P_{ex}: \text{exhaust pressure} \]
\[ \rho_{in}: \text{inlet density} \]
\[ \rho_{ex}: \text{exhaust density} \]
\[ SR: \text{scavenge ratio} \]
\[ m: \text{polytrophic index} \]
\[ M_F: \text{mass of fuel} \]
\[ \text{LHV}: \text{lower heating value} \]
\[ A: \text{flow area} \]
\[ h_n: \text{number of holes} \]
\[ T_I: \text{injection period} \]
\[ d_n: \text{injector hole diameter} \]
\[ \theta: \text{crank angle} \]
\[ t_w: \text{time at wall impingement} \]
\[ V_f: \text{fuel velocity} \]
\[ C_n: \text{mean piston speed} \]
\[ \text{Re}: \text{Reynolds number} \]
\[ T_w: \text{wall temperature} \]
\[ \text{FMEP}: \text{friction mean effective pressure} \]
\[ \text{ECHR}[\text{cal/g}]: \text{1st law heat release} \]
\[ P_2[\text{kPa}]: \text{cylinder pressure} \]
\[ TT_2[\text{K}]: \text{combined cylinder temperature} \]
\[ TAZ[\text{K}]: \text{air zone temperature} \]
\[ TBZ[\text{K}]: \text{product zone temperature} \]
\[ \text{CHR}[\text{cal/g}]: \text{maximum possible heat release} \]
\[ CQL[\text{cal/g}]: \text{heat loss} \]
\[ \text{PWU}[\text{kW}]: \text{indicated power} \]
\[ \text{PWB}[\text{kW}]: \text{brake power} \]
\[ \text{TORQ}[\text{Nm}]: \text{brake torque} \]
\[ \text{IMEP}[\text{kPa}]: \text{indicated mean effective pressure} \]
\[ \text{BMEP}[\text{kPa}]: \text{indicated mean effective pressure} \]
\[ \text{SFCI}[\text{kg/kWh}]: \text{indicated specific fuel cons.} \]
\[ \text{SFCB}[\text{kg/kWh}]: \text{brake specific fuel cons.} \]
\[ \text{ANGPM}[\text{degree}]: \text{crank ang. at max. cylinder pres} \]
\[ \text{PMAX}[\text{kPa}]: \text{maximum cylinder pressure} \]
\[ \text{TMAX}[\text{K}]: \text{maximum cylinder temperature} \]
\[ \text{TEX}[\text{K}]: \text{exhaust temperature} \]
\[ \text{ETAM}[\text{nd}]: \text{mechanical efficiency} \]
\[ \text{DP}[\text{kPa}]: \text{initial pressure rise} \]
\[ \text{DT}[\text{s}]: \text{duration of initial pressure rise} \]
\[ \text{CCW}[\text{kJ}]: \text{compression and combustion work} \]
\[ \text{HTF}[\text{nd}]: \text{fraction of total heat lost} \]
\[ \text{FRCOM}[\text{nd}]: \text{fraction of fuel burnt} \]
\[ \text{EW}[\text{kJ}]: \text{expansion work} \]
WBD[kJ]: blow down work
WEX[kJ]: exhaust work
WOL[kJ]: overlap work
WS[kJ]: suction work
VOL[cm³]: instantaneous cylinder volume
TEMP[K]: cylinder temperature

INTRODUCTION

Calculating and analysing the performance characteristics of an engine before the production is a very cost and time effective process for engine manufacturers, especially for marine engine sector because of the size, cost and the production time of marine engines. For this reason computer simulation programs and mathematical models are very important research tools. Furthermore, the importance of reducing exhaust emissions cannot be overstressed. The reduction of diesel exhaust emissions at sea and in port has now become a major environmental issue with major national and international bodies promoting research to reduce these harmful pollutants.

The mathematical model developed has one main program and two auxiliary programs. The main program is called, “Element Mixing Program” which calculates cylinder pressure and hence engine performance parameters from combustion equations that leads to the calculation of heat release. The first auxiliary program is known as “Heat Release”, which calculates heat released in one engine cycle using experimentally measured cylinder pressure data. The second auxiliary program is called “Rate of Injection”. In this program the total mass of fuel injected into the cylinder in one engine cycle is obtained. The output for rate of injection is used as input data to the main program.

The main issue for the engine modelling is to calculate the fuel-air mixing process which is the fundamental part of the heat release. After calculating and understanding the heat release characteristic of the diesel engine, other parameters can be calculated easily.

The main aim of this paper is to design and develop a clean diesel mathematical model and computer simulation program to predict the overall engine performance for changing load and speed parameters. The model should be able to respond to the changes in various parameters according to already established experimental trends and observations. The initial computer programs were developed by Ziarati (1991) and subsequently in revised Ziarati (1995). These programs were translated into FORTRAN programming language in 2007 and several changes were carried out in 2015.

In order to test the computer programs against experimental data, in 2008 a computer controlled engine rig was set up at TUDEV, Turkey. The intention is apply the programs and enable it also to predict the exhaust emissions (Ozkaynak, 2009). The tests were repeated in 2014 to ascertain use of diesel and gas combinations (Ashok et al, 2015; Ziarati and Akdemir, 2015). Due to commercial sensitivity, the type of fuel and engines used cannot be revealed but will be discussed at the conference. The results of 2014 engine test were compared with latest results by major engine manufacturers including Warsila’s new gas engine.
1 DESCRIPTION OF THE MODEL

The programs use the modified air standard cycle as shown in Figure 1.

![Figure 1 RZ Cycle - Generalised Air Standard Cycle representing Diesel, Carnot and Diesel/Gas cycles](image)

The RZ Cycle is subdivided into:

a) Closed Cycle Considerations:
   - Compression period (1-2)
   - Combustion period (2-3)
   - Expansion period (3-4)

b) Open Cycle Considerations:
   - Blow down period (4-5)
   - Exhaust period (5-6)
   - Overlap period (6-7)
   - Suction period (7-8)
   - Pre-compression period (8-9)

The model can be divided into two calculation parts: Analysis and Synthesis. The analysis part has its own program named “Heat Release Analysis Program”. The synthesis part is the “Element Mixing Program”.

1.1 ELEMENT MIXING PROGRAM

The model assumes that after injection the air entrainment is controlled by an elemental fuel jet until the wall impingement. After the injected fuel impinges to the wall the air entrainment is controlled by an elemental wall jet and close to this jet the intimate fuel air mixing within the jet is controlled by turbulent diffusion. The entrainment of the fuel jet and wall jet is controlled by entrainment ratio and micro mixing of the remaining fuel by
diffusivity constant. These values are dependent on engine load, speed and boost depending on the application. The model can be used to predict heat release qualitatively for any direct injection engine using estimated values of the diffusivity constant and entrainment ratio.

The mixing of air with the injected fuel in the combustion chamber is directly proportional to the air entrainment by the fuel jet at any instant quantities. Micro mixing of fuel and air depends on a simple consideration of turbulent diffusion. This expression includes an Arrhenius type function which controls the rate of burning (micro mixed fuel and air). The following assumptions are made:

- The molar change of the cylinder content is negligible before, during and after combustion
- During combustion, that is, during the period of heat release, the increase in the internal energy is based on the data (Gilchrist, 1947) which takes into account the effect due to changes of specific heat and dissociation. Hence, in considering internal energy and specific heat, dissociation has to be taken into account although the effect of its molar change on pressure and volume may be neglected.

1.1 OBJECT OF THE PROGRAM

The total fuel injected is divided into a number of elements and the individual fuel-air mixing history of each element is calculated independently using the model. From these histories an aggregate mixing condition can easily be calculated and from this latter the cylinder pressure and heat release are determined (Ziarati, 1991).

1.1.2 PRE-COMPRESSION CONSIDERATION AND COMPRESSION PERIOD

The compression period starts from the initial atmospheric conditions. The compression process is assumed to obey the rule:

\[ PV^n = \text{constant} \]  \hspace{1cm} (1)

Assuming compression starts at bottom dead centre, the crank angle dependent volume can be calculated as follows (Heywood, 1988):

\[ s' = l + (s/2) - (l\cos\phi + (s/2)\cos\beta) \]  \hspace{1cm} (2)
\[ V' = s'.\text{pistonarea} \]  \hspace{1cm} (3)

Then the trapped mass must be calculated at point 1. The following two methods can be used:
• Simplified perfect displacement model:

\[ M_T = (s \cdot P_A \cdot \eta_v + V_{cl} \cdot \frac{T_1}{T_{coh}}) \frac{P_1}{R \cdot T_1} \]  
(4)

• Simplified perfect mixing model:

\[ M_T = (s_{eff} \cdot P_A + V_{cl}) \frac{P_1}{R \cdot T_1} \]  
(5)

The air flow through the clearance volume during the scavenge period is given by:

\[ V_a = 2 \cdot \pi \cdot \bar{d} \cdot \bar{l} \cdot \sqrt{\frac{(P_{in} - P_{ex})}{\rho_{in} - \rho_{ex}}} \]  
(6)

For perfect mixing the scavenge efficiency:

\[ \eta_s = 1 - e^{-SR} \]  
(7)

After calculating scavenge efficiency, the loss of air to exhaust and trapped residual gases can be calculated. The inlet temperature can be modified using the universal gas equation;

\[ T_1 = \frac{P_1 \cdot V_1}{M_T \cdot R} \]  
(8)

So the temperature at start of injection;

\[ T_2 = T_1 \cdot (\frac{V_1}{V_2})^{m-1} \]  
(9)

Compression work,

\[ W_{1-2} = P_1 \left[ V_1 - V_2 \cdot \left( \frac{V_1}{V_2} \right)^m \right] \cdot 10^{-6} \]  
(10)

Other parameters calculated at this stage are as follows:

Air-fuel ratio;

\[ R_T = \frac{M_T}{M_F} \]  
(11)

Total heat input per unit mass of air,

\[ H_i = \frac{1 \cdot LHV}{R_T} \]  
(12)

Fractional air utilization:

\[ U' = \frac{R_{stoich}}{R_T} \]  
(13)

Applying the momentum equation (Bernoulli’s equation) the overall mean injection pressure is also calculated as follows:

Volumetric flow rate,

\[ \dot{Q} = KA \sqrt{\frac{2 \Delta P}{\rho_f}} \]  
(14)
Therefore;
\[ M_F = \dot{Q} \rho_f \frac{T_I}{6\text{RPM}} \]  

(15)

Thus
\[ \Delta P = 71.0433 \times 10^{-6} \left( \frac{M_F\text{RPM}}{h_nT_id_n^2} \right)^2 \]  

(16)

Before the start of combustion, air zone temperature is equal to product zone temperature and is given by:
\[ \text{TAZ} = \text{TBZ} = T_1 \left( \frac{V_1}{V_2} \right)^{m-1} \]  

(17)

This leads to the evaluation of the internal energy of the compressed air using the given Gilchrist Table (Gilchrist, 1947) and the gas constant function. There are two periods: The period of pre-mixed combustion and rate of pressure rise (and therefore initial rate of heat release) is governed by the quantity of fuel injected during the delay period. In the second period, the burning is controlled by the mixing rate which has an empirical expression.

1.1.3 Free Jet

The fuel injected first forms a free jet and may later form an axi-symmetric wall jet. For a given step, rate of injection is assumed constant, and the position of free jet at time ‘t’ since the beginning of injection is assumed to be governed by the following equation (Ziarati et al., 1988):
\[ y = 1020, B \left( \frac{d_nP_p^{1/2} \rho_{\text{equiv}}}{\rho_c} \right)^{1/2} \]  

(18)

Application of momentum equation leads to:
\[ \Delta E = \int_{t}^{t+\Delta t} \frac{\pi \tan^2 \theta y^3 \rho_d}{3} \, dt \]  

(19)

Integrating equation (19) and using equation (18) lead to:
\[ \Delta E = \frac{\pi}{3} \rho_d \tan^2 \theta \left[ 1.042 \times 10^6 d_nP_p^{1/2} \rho_{\text{equiv}} \right]^{3/2} \left[ (t + \Delta t)^{3/2} - t^{3/2} \right] \]  

(20)

Figure 3 Spray Presentation (Ziarati, 1991)

1.1.4 WALL JET

Once \( t \) is greater than \( T_Y \) (impingement time) the jet front changes from a free jet to a wall jet (Ziarati et al., 1988). Transition time, air entrainment during transition and loss of kinetic energy in the direction of flow for the transition are neglected. The initial conditions for the wall jets are:
\[ r_0 = Y \tan \theta \]  \hfill (21)

and since the velocity and flow areas immediately before and immediately after transition are assumed to be the same, initial volume flow at wall jet can be found:

\[ Q_0 = \pi r_0^2 W_0 \]
\[ Q_0 = \pi y^2 \tan \theta W_0 \]  \hfill (22)

The equation of Glauert (Glauert, 1956) is now can be used to describe the velocity \( W \), jet thickness and volume flow \( Q \) (of the wall jet) assuming again a square velocity profile for the jet front,

\[ \Delta E_{wall} = \frac{Q_0 \rho_a}{1.459} \left( t_w + \Delta t \right) \left( t_w \right)^{1.459} - t_w^{1.459} \]  \hfill (23)

After the end of the injection the net increment in air entrainment is then:

\[ \Delta E = \Delta E_{jetfront} - \Delta E_{jetback} \]  \hfill (24)

Further, the jet is assumed to expand or contract with cylinder volume.

1.1.5 MICRO MIXING

While the air entrained by the gas jet at any instant quantifies the larger scale mixing of fuel and air in the chamber, intimate mixing of fuel and air is represented by a simple consideration of turbulent diffusion. The macro mixed quantity of air within the jet boundaries, as determined by air entrained \( E \) is assumed to micro mix with injected fuel according to the equation:

\[ \frac{dM_a}{dt} + DV_f M_a = DV_f E \]  \hfill (25)

Multiplying both sides of the equation by \( e^{DV_f t} \) and integrating:

\[ M_a e^{DV_f t} = E e^{DV_f t} + c \]  \hfill (26)

Heat release therefore;

\[ H_{release} = \frac{M_a LHV}{15} \]  \hfill (27)

2.2 Combustion Work Done

The combustion work can be obtained from the 1\(^{st}\) law of thermodynamics (Heywood, 1988, Ferguson, 1986) as follows:

\[ W_{2-3} = W_{\text{combustion}} \]  \hfill (28)

1.2 DELAY PERIOD

With the following empirical expression, the delay period can be calculated (Ziarati, 1990):

\[ \text{DEL} = 15.375 \times 10^{-3} \text{RPM}(C_n)^{-a}(P)^{-0.38} e^{AE/T} + 39.04 \Delta P^{-0.35} d_{n.4} \]  \hfill (29)

Where \( a = 0.7 \) to 1.0 and \( AE \) is the activation energy.
1.3 HEAT TRANSFER

The heat transfer formula used in the model is Annand’s based on the actual cylinder piston surface areas and is calculated step by step throughout the calculations (Annand, 1963). This equation can be expressed as follows:

\[ \dot{q} = A \frac{aK}{D} (Re)^b (T - T_w) + c(T^k - T_w^k) \]  

(30)

1.4 WORK DONE

Expansion work: The expansion process starts from the condition at the end of combustion and this period is the last sequence of closed cycle calculations. The expansion work (Heywood, 1988, Ferguson, 1986):

\[ W_{3-4} = \frac{(P_5V_3 - P_4V_4)}{n-1} \times 10^{-6} \]  

(31)

Closed period work done: Closed period work done is the total work of the processes 1-2, 2-3 and 3-4:

\[ W_{1-4} = \int_1^4 P \, dv = W_{1-2} + W_{2-3} + W_{3-4} \]  

(32)

Blown-down period work done:

\[ W_{4-5} = \frac{P_{4-5}}{2} (V_5 - V_4) \]  

(33)

Exhaust period work done:

\[ W_{5-6} = -P_6 (V_6 - V_5) \]  

(34)

Overlap period work done:

\[ W_{6-7} = -P_5 (V_6 - V_{cl}) + P_7 (V_7 - V_{cl}) \]  

(35)

Suction period work done:

\[ W_{7-8} = P_7 (V_8 - V_7) = P_7 (V_5 - V_7) \]  

(36)

Pre-compression work:

\[ W_{4-8} = \int_4^8 P \, dv = W_{4-5} + W_{5-6} + W_{6-7} + W_{7-8} \]  

(37)

2.6 Overall Cycle Parameters:

\[ W_{ind} = W_{closenperoid} + W_{openperiod} \]  

(38)

Since the friction mean effective pressure is generally known, the brake work is given by:

\[ W_{brake} = W_{ind} - FMEP \cdot V_{swept} \]  

(39)

The power output indicated and brake can be calculated respectively as:

\[ P_{ind} = W_{ind} \cdot RPM \]  

(40)

\[ P_{brake} = W_{brake} \cdot RPM \]  

(41)
Similarly, specific fuel consumption is given by:

\[ \text{SFCI} = \frac{RPM_M F}{P_{\text{ind}}} \]  \hspace{1cm} (42)

And

\[ \text{SFCB} = \frac{RPM_M F}{P_{\text{brake}}} \]  \hspace{1cm} (43)

The computer program represents equations (1) to (43) with some exceptions and additional complications and facilities (Ziarati, 1991).

2 HEAT RELEASE PROGRAM

The basis of this “Heat Release” program depends on the 1st law of thermodynamics (Heywood, 1988, Ferguson, 1986):

\[ Q - W = U \]

Therefore:

\[ Q = \int_{AB} PdV + U \]  \hspace{1cm} (44)

3 RATE OF INJECTION PROGRAM

This program can be used only when practical injection diagrams are considered. Rate of injection program calculates the rate of fuel injected at specified crank angle. The annular area between the needle and the seat and total nozzle holes area are assumed to be two orifices in series. Knowledge of the line pressures \( P_L \), cylinder pressures \( C_P \) and needle lifts \( L \) for specified crank angles for any given step enables the rate to be calculated:

\[ Q = K_e A_e' \sqrt{\frac{P_{\text{diff}}}{RPM}} \]  \hspace{1cm} (45)

\( Q \) can therefore be calculated for each element. The equation (45) can only be correctly determined if \( A_s \) and \( A_h \) can be calculated as shown:

**Figure 4 Valve Seat Presentation (Ziarati, 1991)**

If the seat angle is assumed to be 60°, the truncated cone \( A_s' \) equals to:

\[ A_s' = \frac{\pi}{2} dl - \frac{\pi}{2} d'l' \]

\[ = \frac{\pi}{2} (dl - d'l') \]  \hspace{1cm} (46)
Thus,
\[ A'_s = \pi L \sin(\alpha/2)[d - L \sin(\alpha/2) \cos(\alpha/2)] \]  \hfill (47)

Assuming \( d = d' \) and \( \alpha = 60^0 \), \( A'_s \) expression reduces to:
\[ A'_s = \pi r_{sac} L \]  \hfill (48)

4 VALIDATION OF THE PROGRAMS

The developed model was applied to a single cylinder direct injection diesel engine (Ricardo, Atlas) for a number of nozzle configuration, plunger sizes, engine speeds and engine loads. The experimental heat release data was available. Engine dimensions are below:

<table>
<thead>
<tr>
<th>Table 1 Research Engine Specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Cylinders</td>
</tr>
<tr>
<td>Bore</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Swept Volume</td>
</tr>
<tr>
<td>Compression Ratio</td>
</tr>
<tr>
<td>Inlet Valve Opening</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 Theoretical and Experimental Results (Ziarati, 1991).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plunger (mm)</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>22</td>
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<td>20</td>
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<tr>
<td>20</td>
</tr>
<tr>
<td>18</td>
</tr>
</tbody>
</table>
Table 2 above summarizes the theoretical and experimental results for various conditions.

The test data sets are taken from previous works.

The screenshots of outputs from “Element Mixing Program”, “Heat Release Program” and “Rate of Injection Program” can be seen in Figures 5, 6 and 7 respectively:

Figure 5 Output Screenshot of Element Mixing Program.

As can be seen from Figure 5, all necessary outputs are calculated and cylinder pressure, cylinder temperature, heat release data are predicted. Also, wall impingement time, heat loss and air entrainment are shown.
Heat release program calculates the heat released by using experimental cylinder pressure data according to 1st Law of Thermodynamics. From Figure 6 it can be seen that fuel injection starts at 163 degrees CA, because the heat release is zero before that crank angle. After the injection heat release is going below zero, this is because the fuel absorbs energy from its environment to evaporate. After evaporation the heat release increases.

In Figure 6 the work done is decreasing in the compression period. But after top dead centre (180 degrees CA) it starts to increase due to the expansion period.

Figure 6 Output Screenshot of Heat Release Program.
The predicted cylinder temperature against the experimental cylinder temperature calculated from “Heat Release Program” is shown in Figure 8 below:

Figure 7 Output Screenshot of Rate of Injection Program.

Figure 8 Predicted and Experimental Cylinder Temperature.
The graphical comparison of predicted heat release and experimental heat release data for a given engine condition is shown in Figure 8. The predicted heat release is gross heat release which includes the heat loss so the differences between the predicted and experimental results are the heat loss.

**Figure 9 Predicted and Experimental Heat Release.**

5 ENGINE RIG DESIGN

The application of diesel engines in automotive and marine industries and its use as stand alone power units have been rapidly increasing in recent years mainly due to the development and applications of new technologies. These developments on diesel engines are focused on the performance increase and the emission control. To increase the performance, higher thermal efficiency and to control the emission, lower toxic gases
are targeted. Improving diesel engine performance and reducing exhaust emissions as well as using environmental friendly fuels have become important research topics recently. Therefore, a reliable and functional diesel engine test unit is required to perform research and train maritime cadets.

Rillings et al (1973) developed a computer controlled diesel engine test unit to carry out the transient analysis of an automobile engine. A mini computer was used for data acquisition and closed loop control of the dynamometer. The dynamic process provided real time data acquisition, logging and graphically presentation. Campell et al (1985) designed a low cost computer aided engine test unit. It was aimed to provide students for research facilities. Hydraulics dynamometer flow rate was controlled by an electric motor and various temperatures were logged in a PC. Williamson&Al-Khalidi (1989) tested internal combustion engines for only torque and power measurements at full throttle using dynamometers converting mechanical energy to heat. Kawarabayash (1990) aimed to improve a test stand control system. In this system, load transition was made faster and smoother. Voigt (1991) developed enhanced test laboratory to test an engine under various road conditions. In this test unit, computer based data acquisition and real time dynamometer control system were used. Turley&Wright (1997) developed a test automation system using Labview® for air craft engine tests. They selected Labview® due to its powerful tools such as measurement, data acquisition, appearance and preparing general algorithm which allows users to rapid prototype. Schmidt (1998) examined the vehicle model and effects of environmental factors. In the other test unit, electric motor was used to apply real load value based on the vehicle model. Plint&Martyr (2002) developed a standard test unit to measure torque, power, speed, temperature and emission. In addition to these, noise, vibration and cylinder pressure were measured. Celik et al. (2007) designed a diesel engine test unit developing a user interface algorithm. Due to convenience of the user interface, students could operate and test easily.

In this study, a computer controlled diesel engine test laboratory was established at Piri Reis University. The research facility is fully instrumented using a range of sensors and a computerized data processing and analysis system. The research rig is capable of computing diesel engine performance characteristics. The laboratory is separated into two facilities, one holding the instrumented engine and the other computing and display units with a view to improve safety and to decrease noise. Analogue, digital controls and measurement signals supplied by sensors and actuators in the engine room are conditioned by data acquisition card. The required data are displayed on the graphical user interface using Labview® and logged by transferring signals from the engine room to the computerized engine control room.

6 THE TEST ENGINE SETUP AND INSTRUMENTATION

The research facility is fully instrumented using a range of sensors and a computerized data processing and analysis system and it is capable of computing diesel engine performance characteristics. The laboratory is separated into two rooms, one holding the instrumented engine and the other computing and display units with a view to improve safety and to decrease noise. Analogue, digital controls and measurement signals supplied by sensors and actuators in the engine room are conditioned by data acquisition card. The required data are displayed on the graphical user interface using Labview® and logged by transferring signals from the engine room to the computerized engine control room.

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In the engine room, Antor 4LD820 single cylinder diesel engine is used and it is head to head coupled to a shunt excited DC generator which is used to load the Diesel engine. The electrical power produced by the generator is consumed by external load resistances.
The cylinder pressure and cylinder head temperature are measured by a piezoelectric pressure sensor and a thermocouple which are mounted on the cylinder head. A mass air flow meter (MAF) is used to measure air flow rate and inlet air temperature. Fuel flow measurement is accomplished by a level sensor which floats in the cylindrical fuel tank with 5 cm diameter. An incremental encoder is coupled to engine shaft to measure engine speed and crank angle. Also, a load cell mounted on the DC generator body is used to measure the engine torque.

All control systems including engine start-stop, throttle and load buttons are located in the control room. Therefore, users can operate the whole system easily without entering the engine room. An operation system for the engine starter motor is designed and it stops automatically after the engine reaches a given speed. Throttle is controlled by a micro stepping motor with linear actuator. A decoder, a driver and contactors are used to control the number of resistances to load the engine. Diesel engine can be stopped with the help of a solenoid. Data acquisition card is used to acquire signals and generate control signals. With appropriate wiring to pins of counter/timer, digital and analog inputs/outputs, all signals are transferred between engine room and control room. Specifications of the Diesel engine, DC-generator, piezoelectric sensor and data acquisition card are given in Table 3.

**Table 3 Specifications of the engine, generator, piezoelectric sensor and data acquisition card.**

<table>
<thead>
<tr>
<th>Diesel Engine</th>
<th>Generator</th>
<th>Piezoelectric Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Type</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>Nr. Of Cylinder</td>
<td>Max. Armature Current</td>
<td>Type</td>
</tr>
<tr>
<td>Displacement</td>
<td>Max. Armature Power</td>
<td>Max armature Power</td>
</tr>
<tr>
<td>Engine RPM</td>
<td>Field Voltage</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>Power</td>
<td>Field Current</td>
<td>Natural freq.</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>Max. Revolution</td>
<td>4000 rpm</td>
</tr>
<tr>
<td>Data Acquisition Card</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturer</td>
<td>National Instruments</td>
<td>Analog Input</td>
</tr>
<tr>
<td>Model</td>
<td>Number of Channels</td>
<td>16 SE/8DI</td>
</tr>
<tr>
<td>Measurement Type</td>
<td>Sample Rate</td>
<td>250 kS/s</td>
</tr>
<tr>
<td>Counter/Timers</td>
<td>Resolution</td>
<td>16 bits</td>
</tr>
<tr>
<td>Nr of Counter</td>
<td>Max. Voltage Range</td>
<td>-10...10V</td>
</tr>
<tr>
<td>Resolution</td>
<td>Resolution</td>
<td>16 bits</td>
</tr>
</tbody>
</table>

**Figure 10. Block diagram of the laboratory.**
A dual-core cpu computer and two 19” monitors are used in the control room. A user friendly user interface algorithm was prepared using Labview® which has flexible, powerful and attractive tools for algorithm design. Block diagram of the laboratory is shown in Fig. 10. In addition to that emission measurement devices were set up to measure and track the values of CO, NOx, CO2, O2 and THC at the various diesel engine operating conditions. Technical specifications of the emission measurement devices are given in Table 4.

Table 4 Specifications of the emission measurement devices.

<table>
<thead>
<tr>
<th>Manufacturer&amp;Model</th>
<th>Siemens,Ultramat 23</th>
<th>Siemens, Fidamat 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>Non-dispersive Infrared</td>
<td>Flame ionization detection</td>
</tr>
<tr>
<td>CO</td>
<td>NOx</td>
<td>CO2</td>
</tr>
<tr>
<td>0-2500 ppm</td>
<td>0-2500 ppm</td>
<td>0-25 %</td>
</tr>
</tbody>
</table>

7 GRAPhICAL USER INTERFACE

A graphical user interface program was developed using Labview® (Travis, J. and Kring J. 2007). This program has several control functions and it displays measurement results and records the data on the hard disk. The graphical user interface consists of three parts; a control panel, indicator panel, and chart panel. Each panels were selected in different colors. The buttons of engine start, load control, throttle control, measurement results
saying path, cycle number, measurement type (continuous-single), and measurement record type (continuous-single) are installed on the control panel. Users can see and log data immediately after adjusting throttle and load by selecting measurement type (continuous or single). The user interface also provides two logging options as continuous and single, these measured data are stored in an .xls file.

Buttons of engine speed (rpm), fuel level (%), fuel flow (kg/h), air flow rate(kg/h), air/fuel ratio, torque (Nm), power (kW), air temperature (ºC), status window are installed on the indicator panel. To take the exact value of the data both numerical and analog results are displayed on the panel at the same time. The indicator panel is refreshed after all measurements completed. Status window provides users instructions and information about progress. The indicator and control panels are shown in Fig.11.

**Figure 11. Control and indicator panel.**

The graphs of cylinder pressure (bar) vs. crank angle (º) and cylinder pressure (bar) vs. cylinder volume (m³) are displayed on the chart panel at a data sampling rate of 0,1º.

8 MEASUREMENTS

8.1 CYLINDER PRESSURE MEASUREMENT

A piezoelectric pressure sensor mounted in the cylinder head and connected to a charge amplifier is used to measure the cylinder pressure. Cylinder pressure is measured using the trigger signal from encoder’s zero pulse and at a sample rate (0,1º) provided by encoder output. Block diagram of cylinder pressure measurement is shown in Fig. 12.

8.2 AIR FLOW AND TEMPERATURE MEASUREMENTS

Air flow and inlet air temperature are measured with air mass flow meter (MAF). Its output signal is calibrated to 1,239-4,4578 V. for 8-480 kg/h. MAF’s flow-output graph is shown in Fig. 13 and the fitted equation is given by equation 1.
\[ \text{Air Flow (kg/h)} = -0.7165V^6 + 12.327V^5 - 82.178V^4 + 282.14V^3 - 508.88V^2 + 485.06V - 189.4 \]  

Figure 12. Block diagram of cylinder pressure.

Since single cylinder diesel engine is used, some amount of suction air returns back to the surge tank again. Therefore, both suction and backward air flows are measured accurately to calculate the correct inflow to the cylinder. Suction signal frequency has to be the half of the engine speed frequency. Therefore, the MAF output is examined in frequency spectrum to realize filter for return signal. To measure inflow, low pass filter whose cut-off frequency is changed according to engine speed is added into the program. Cut-off frequency is adjusted between 8 and 25 Hz while engine speed frequency is between 16 and 50 Hz. A thermistor in the MAF is used with Wheatstone bridge to measure inlet air temperature. Frequency spectrum of MAF output is shown in Fig. 13. The block diagram of air flow measurement is shown in Fig. 14.
Figure 14. Frequency spectrum of suction.

Figure 15. Block diagram of the air flow measurement and return flow signals.

8.3 FUEL FLOW MEASUREMENT

To measure fuel flow, a level sensor is mounted in a cylindrical tank whose diameter is 5 cm and length is 75 cm. The level sensor is calibrated by measuring the mass of fuel and corresponding output voltage difference. The calibration values are shown in Table 5. The block diagram of fuel flow measurement is shown in Fig. 16.

Table 5 Calibration data of the level sensor

<table>
<thead>
<tr>
<th>Voltage [v]</th>
<th>Mass [g]</th>
<th>Sensitivity [v/g]</th>
<th>Mean Sensitivity [v/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.59</td>
<td>90.8</td>
<td>0.006479</td>
<td></td>
</tr>
<tr>
<td>0.59</td>
<td>90.7</td>
<td>0.006504</td>
<td>0.00645</td>
</tr>
<tr>
<td>0.6</td>
<td>94.2</td>
<td>0.006369</td>
<td></td>
</tr>
</tbody>
</table>
8.4 TORQUE AND POWER MEASUREMENTS.

A loadcell is mounted to DC generator’s frame to measure torque. Its technique is based on that armature current being consumed by load resistances is directly proportional to rotational force of field winding fixed generator body. Torque values are filtered by low pass filter whose cut-off frequency is 10 Hz to reduce noise due to engine vibration. Torque is calculated by multiplying the force on the loadcell and the arm length. Torque and power are calculated as follows:

\[ \text{Torque (Nm)} = F_{\text{Loadcell}} \times \text{Arm Length (m)} \]  \hspace{1cm} (2)

\[ \text{Mechanical Power (kw)} = \frac{\text{Torque (Nm)} \times \text{Speed (rpm)}}{9550} \] \hspace{1cm} (3)

8.5 ENGINE SPEED MEASUREMENT

Encoder’s zero pulse is connected to counter/timer input of the data acquisition card to measure frequency. Zero pulse provides one pulse per revolution. The frequency value is multiplied by 60 to obtain engine speed as rpm. This final value is sent to the indicator chart and log file.

8.6 EXHAUST EMISSION MEASUREMENT

Exhaust emissions are measured when engine conditions are adjusted by the graphical user interface. Emission values can be seen on the graphical user interface. The block diagram of emission measurement system is shown in Fig. 17.

9 CONTROLS

9.1 THROTTLE CONTROL

Throttle is controlled by using micro stepping motor with linear actuator. The actuator is linked to the throttle pedal to move data acquisition card’s counter/timer and digital output is connected to micro stepping motor driver to enable motion and its direction. The block diagram of the throttle control is shown in Fig. 18.
TORQUE AND POWER MEASUREMENTS.

A loadcell is mounted to DC generator's frame to measure torque. Its technique is based on that armature current being consumed by load resistances is directly proportional to rotational force of field winding fixed generator body. Torque values are filtered by low pass filter whose cut-off frequency is 10 Hz to reduce noise due to engine vibration.

Torque is calculated by multiplying the force on the loadcell and the arm length. Torque and power are calculated as follows:

\[
\text{Torque (Nm)} = \frac{F}{\text{Arm Length (m)}}
\]

Torque (Nm) Speed (rpm)

\[
\text{Mechanical Power (kw)} = \frac{9550 \times \text{Torque (Nm)}}{\text{Speed (rpm)}}
\]

ENGİNE SPEED MEASUREMENT

Encoder's zero pulse is connected to counter/timer input of the data acquisition card to measure frequency. Zero pulse provides one pulse per revolution. The frequency value is multiplied by 60 to obtain engine speed as rpm. This final value is sent to the indicator chart and log file.

9.2 LOAD CONTROL

A resistance box is designed to load the engine. There are 16 resistances in the box and each of them has 1kw electrical power. All resistances are controlled as percent on the control panel. A 3 bit digital data is sent to decoder and the decoder activates required numbers of contactors’ driver.

9.3 DİESEL ENGİNE START/STOP CONTROL

A relay and its driver connected to data acquisition card are used to start the engine. Motor starter is energized by pressing the start button on the control panel, The starter motor is turned off automatically after 4 sec. to keep starter motor undamaged. A solenoid is connected to the engine’s stop valve to stop the engine from the control room. When the solenoid is energized, it pulls the fuel valve and engine stops. The block diagram of Diesel engine start-stop control is shown in Fig. 19.

Figure 17 Block diagram of the emission Measurement system.

Figure 18 Block diagram of throttle control system.

Figure 19 Block diagram of the engine start control.
10 RESULTS

The research facility is fully instrumented using a range of sensors and a computerized data processing and analysis system and it is capable of computing diesel engine performance characteristics. Results of measurements are obtained using the graphical user interface in the control room. With the help of user friendly properties of the graphical user interface, any further test procedures can be programmed. Sample measurement results are given in Table 6.

Table 6 Sample measurements.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1636 RPM</td>
<td>25,045 Nm</td>
<td>4,289 KW</td>
<td>39,143 Kg/h</td>
<td>1,675 Kg/h</td>
<td>23,36</td>
<td>25,9 °C</td>
<td>40%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission Measurements</th>
<th>CO</th>
<th>NOx</th>
<th>CO₂</th>
<th>O₂</th>
<th>THC</th>
</tr>
</thead>
<tbody>
<tr>
<td>306,872 ppm</td>
<td>518,022 ppm</td>
<td>4,66%</td>
<td>14,35%</td>
<td>318,91 ppm</td>
<td></td>
</tr>
</tbody>
</table>

Obtained data are in a good agreement with the engine manufacturer’s data. The maximum power of the diesel engine is 15 HP (11,19 kW) and as can be seen from Fig.20., the obtained maximum power from the diesel engine test rig at 2500 rpm under 60% load is 11,6 kW.

Figure 20 Pressure (Bar) vs. CA(Deg) and Volume (m³) diagrams.
RESULTS

The research facility is fully instrumented using a range of sensors and a computerized data processing and analysis system and it is capable of computing diesel engine performance characteristics. Results of measurements are obtained using the graphical user interface in the control room. With the help of user friendly properties of the graphical user interface, any further test procedures can be programmed. Sample measurement results are given in Table 6.

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<th>Diesel Engine Measurements</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>1636 RPM</td>
<td>25,045 Nm</td>
<td>4,289 KW</td>
<td>39,143 Kg/h</td>
</tr>
<tr>
<td>Air Temp.</td>
<td>25,9 °C</td>
<td>40%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emission Measurements

<table>
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Obtained data are in a good agreement with the engine manufacturer’s data. The maximum power of the diesel engine is 15 HP (11,19 kW) and as can be seen from Fig. 20, the obtained maximum power from the diesel engine test rig at 2500 rpm under %60 load is 11,6 kW.

Figure 20 Pressure (Bar) vs. CA(Deg) and Volume (m³) diagrams.

Figure 21 rpm versus power.

Figure 22 rpm versus NOx.
Figure 23 rpm versus CO2.

Figure 24 rpm versus AFR.
Also Figs. 22-23-24 show the variation of power with rpm and measured NO\textsubscript{x} and CO\textsubscript{2} exhaust emissions under variable engine speeds and loads. The effects of engine speed and load on air fuel ratio (AFR) can be seen from Fig.24.

In Section 6-10 above a computer controlled and fully instrumented ICE test facility which was designed and developed successfully at TUDEV/Piri Reis University was described. The engine laboratory is separated into two facilities, one holding the instrumented engine and the other computing and display units with a view to improve safety and to decrease exposure to noise. Analogue and digital control and measurement signals supplied by sensors and actuators in the engine room are conditioned and displayed on the graphical user interface using Labview® and logged by transferring signals from the engine room to the computerised engine control room. The facilities have proven to produce accurate and reliable experimental results at varying engine loads and speeds. The application of Labview and the engine software are novel features of the new engine rigs at TUDEV/Piri Reis. Therefore, noise of engine and the risk of injury have been decreased as well as convenient and safe laboratory environment has been provided. This physical model was matched with the mathematical model. Various designing changes can be made to the rig and the mathematical model used then to project changes in engine behaviour. Alternatively, the mathematical model can be matched to any engine and then a series of change can be made using the model to predict changes in the engine performance and likely benefits. The actual engine tests can be found in Ziarati and Akdemir (2015) and similar results Ashok et al (2015). All test results were in line with Warsila’s most recent gas engine results reported in 2018.

11 CONCLUSION

As can be seen the predicted theoretical values are in good agreement with the experimental results. The ability of the model to predict engine performance parameters of several engines of different type and sizes and considering the latest test on TUDEV Engine, to within the experimental error band (the instrumentation error range), for different test conditions must be considered very encouraging and a proof of the model. The air cycle used in the modelling of the engine is known as RZ Cycle which can represent any air standard cycle including diesel and gas or a combination. The Element Mixing Program can now be used reliably in establishing the effects of changes to running conditions or testing of changes to any given engine design parameters or to fuel injection equipment as well as to turbocharger configuration, and indeed to any other engine sub-system, without resorting to running the engine unnecessarily. This would reduce the cost of engine design and development to a minimum and allows changes to be introduced and their impact assessed while the engine itself is running without any changes made to it.

The model has used to study thermal efficiency; hybrid propulsion; alternative fuels, catalysts, exhaust recirculation systems; exhaust treatment; multi-Stage inter-cooling; variable geometry turbochargers, lighter materials; efficient bearings; water injection; novel injectors; high injection pressures, common rail systems. The next set of experiments is expected to study the application of quantum physics.

It is important note that the work in parallel and in addition to those reported above has been carried primarily to save fuel saving. Some of the methods used are listed below:
Slow steaming; Weather routing; Green energy – wind and sun (Flettner rotor & sun panels); Use of sea currents; e-navigation; Ballast water management; Hull and trim optimisation; Ship-port and port-ship system integration; Port-road-train-airport system integration; On-board ship management: such as AI and VR applications, Virtual arrival, advanced communications, JIT and predictive methods.

The results obtained to date can be considered very encouraging with substantial fuel savings and notable reductions in engine emissions.

The most important consideration is that diesel and gas combination is a feasible way forward for all diesel propulsion systems including ship engines which are invariably of diesel type. The reduction in emission of NOx and PMs were considerable and the results at high load conditions were better than with purely diesel fuel albeit it produced some adverse effect at low load conditions. The combination of gases with diesel as the ‘pre-igniter’ proved to enhance the brake thermal efficiency except that at mainly at part loads no improvements were observed. So, the results favours ship which often run at the design load and speed. Overall a mixture of gases as secondary fuel reduces the un-burnt hydrocarbon and produces less NOx and smoke at higher load conditions. The results cannot be published due to commercial restriction but good accounts of them are given in Ashok et al (2015).

References:


References:


OPEN LOOP EXHAUST GAS CLEANING SYSTEM, A DEEP ANALYSIS OF EFFECTS PRODUCED BY ITS RESIDUAL WATERS

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*Correspondence author

Abstract:

New regulation implemented through Marpol Convention on its Annex VI has come into force on 01st January 2020. We are talking about a new sulphur cap in fuels used by ships which is established in a 0.5% mass/mass. We can find this regulation, in Marpol Convention, on its Annex VI, regulation 14.1.3. To follow this new regulation, some shipping companies are investing in the installation of exhaust gases cleaning system, commonly known as scrubbers, on board their ships. There are three different systems, open loop, close loop, and hybrid. We are going to focus and break down the open loop method. Open loop exhaust gases cleaning system discharges overboard the residual water used during the cleaning process of exhaust gases from ship engines once that water has been analysed by the system. The aim of this analysis is to make sure that water follows all parameters and caps regulated in a resolution from Marine Environment Protection Committee, specifically the MEPC.259(68), before this water is being discharged overboard. Water parameters regulated by Resolution MEPC.259(68) are acidity (pH), Polycyclic Aromatic Hydrocarbons concentration (PAH), heavy metal/ashes concentration (turbidity) and nitrates concentration without forgetting the wash water additives and other substances used in exhaust gas cleaning systems.

Keywords:
Open loop, water pollution, acidification.

1. INTRODUCTION

Nowadays we can assert that there is a global concern over environment and our society is slowly more and more committed with its protection. It is increasingly present today in our culture, in our society as well as in our industry. Maritime industry and shipping companies are not an exemption and among many other regulations, there are international conventions whose main objective is to improve the marine environmental protection. The International Convention for the Prevention of Pollution from Ships, commonly known as Marpol Convention, is the main international convention for looking after the pollution prevention of the marine environment caused by ships.
Marpol Convention, like the rest of International agreements, is subject to constant amendments and changes. Last Marpol Convention amendment which has come into force, has been on the regulation 14.1.3, sulphur oxides and particulate matter, of Annex VI, Prevention of Air Pollution from Ships. This amendment has come into force on 1st January 2020 and sets the prohibition on the carriage of non-compliant fuel oil for combustion purposes, for propulsion or operation on board a ship. Non-compliant fuel means, after entering into force the above-mentioned amendment, a fuel with a sulphur content limit of 0.5% mass by mass.

Shipping companies have few options for their ships to follow this new sulphur limit. One of them is to use a fuel on-board which sulphur content is less than or equal to 0.5% mass by mass. This fuel is commonly known as VLSFO, from its acronyms, Very Low Sulphur Fuel Oil. The main problem of this option is that ship depends on the availability of this fuel oil in each port and its price per tonne. Very Low Sulphur fuel oil has achieved its maximum price on January 2020. For instance, in port of Singapore, one of the biggest ports around the world, the price of VLSFO touched a high of 742$ per metric tonne. It should be noted that at beginning of December 2019, the price for this fuel was around 550$ per metric tonne, at same port.

The second option and at the same time, the less chosen one by shipping companies, in case of existing ships, is to use alternative clean fuels, for instance, natural gas. Installation of natural gas propulsion on board an existing ship supposes a great investment and the lack of space enough on board usually requires a long time in a dry dock. Due to all of the above, ship’s owners are mainly using this option for new ships.

Shipping companies have other option to deal with this new regulation, and is to install on board of their ships, an exhaust gas cleaning system, also known as “scrubbers”.

These systems represent a great investment as well for shipping companies furthermore the profitability of this investment is strongly joined to the ship’s life. It seems to make no sense to invest in an exhaust gas cleaning system which cost range between 1.8 and 4 million dollars, depending on the vessel, for a ship whose useful life is going to expire.

Nevertheless, this second option, is what the most of ship’s owners are choosing for their ships. These systems are classified generally in two main groups, as follows: dry scrubbers and wet scrubbers. Dry scrubbers basically, are removing sulphur oxides from exhaust gases through granules of hydrated lime in a reactor. During exhaust gas cleaning process, dry scrubbers do not generate wastewater to discharge into the sea.

Wet scrubbers are using water which is sprayed over the exhaust gas cleaning system during cleaning process, to remove sulphur oxides. Wet scrubbers are also classified in three main groups: open loop system, closed loop system and hybrids. In this paper, we are going to talk about these systems, its classification, components, and operation.

Although we will focus in open loop system. This is because, as we are going to analyse later, one of the main features of open loop type is the residual water discharge overboard, after being used during the exhaust gases cleaning process and being treated in the water treatment unit. We are going to expose this problematic situation.

There are no studies and analyses enough which allow us to know for sure, the impact of this discharges, from open loop systems, inside the port and coastal waters.
This scenario has encouraged me to start this investigation about the effect produced by these residual water discharges. Specifically, we have the purpose to study and analyse the effect of these discharges in the port of Barcelona and its surrounding waters.

2. ANALYSIS OF THE CURRENT SITUATION

At present and since 01st January 2020, we have a new sulphur cap in a truly clear regulation about sulphur oxides emissions on board the ships. This regulation is contained in Marpol Convention, specifically on its Annex VI, regulation 14. This regulation states that the sulphur content of any fuel oil used or carried on board of a ship for its use shall not exceed 0.5% mass by mass.

As we have seen before, one of the options that ship’s owners have, to be in compliance with this new regulation, is to install on board of their ships an exhaust gas cleaning system and they have to choose one of its modalities, open loop, closed loop or hybrid system. But here we find one of the main current problematic.

Presently, there are several countries and certain ports which have been banned the use of open loop exhaust gas cleaning systems in their waters. The main reason is because this system, as we are going to see later, discharges its residual water overboard. Although this residual water, theoretically, is not a pollutant residue at all, because certain parameters from this residual water, must follow an IMO Resolution from Marine Environment Protection Committee. This Resolution is MEPC.259(68), 2015 guidelines for exhaust gas cleaning systems.

The above-mentioned Resolution regulates among others, on the point 10 of its Annex, the washwater discharge criteria. This point states that the washwater used in the gas cleaning process of exhaust gas cleaning systems, must be continuously monitored, and recorded, when this system is being used by ships in ports, harbours, or estuaries.

The values which must be monitored are at least pH, PAH (Polycyclic Aromatic Hydrocarbons), turbidity/suspended particle matter, and temperature. For the parameters listed above, this Resolution indicates the limits which must comply any washwater discharge from scrubbers.

Furthermore, Resolution MEPC.259(68) defines both schemes, A and B, for the approval, survey and certification of an exhaust gas cleaning system.

In this section, the Resolution establishes the minimum content and all requirements for Technical Manual for Schemes A and B.

MEPC.259(68) also determines the type and scope of inspection that each exhaust gas cleaning system is subjected as well as the documentation set that a ship fitted with an scrubber system must have on-board, available for its inspection, if required by authorities, for instance during a Port State Control. This Documentation is set out in the above-mentioned Resolution and depending on the scheme, is required as follows:

- Ships fitted with an exhaust gas cleaning system certified as per Scheme A, must have on-board:
  - Sulphur Oxides Emissions Compliance Plan (SECP) approved by the Administration.
  - Sulphur Oxides Emissions Compliance Certificate.
- Technical Manual for Scheme A approved by Administration.
- On-board Monitoring Manual approved by Administration.
- EGC Record Book, with a form approved by the Administration.
- Ships fitted with an exhaust gas cleaning system certified as per Scheme B, must be provided with:
  - Sulphur Oxides Emissions Compliance Plan (SECP) approved by the Administration.
  - Technical Manual for Scheme B approved by Administration.
  - On-board Monitoring Manual approved by Administration.
  - EGC Record Book, with a form approved by the Administration.

3. EXHAUST GAS CLEANING SYSTEMS

As mentioned above, Marpol Convention on its Annex VI, regulation 14, establishes that ships cannot use a fuel with a sulphur concentration cap over limits prescribed on regulations 14.1 and 14.4. Regulation 4 of same Annex defines what should be understood as “equivalents”. Equivalents concept, as per Annex VI definition, is any fitting, material, apparatus or appliance to be installed on board of a ship as well as any alternative fuel, procedure or compliance method used as an alternative to the required by the Annex VI of Marpol Convention, if such fitting, material, apparatus or appliance to be installed on board of a ship as well as any alternative fuel, procedure or compliance method are at least as effective in terms of emission reductions, so in this case, we are talking about sulphur oxides emission reductions, as that required by this Annex.

If we analyse the above-mentioned regulation, we can extract that the Administration of a Party may allow to its ships the use of any of the mentioned options, to be in compliance, for instance, with regulation 14. So, the exhaust gas cleaning systems are considered, effectively, equivalents or an equivalent arrangement. In this way, is stated on the supplement, also known as Record of Construction and Equipment, to International Air Pollution Prevention Certificate of a ship fitted with an scrubber system approved by the Administration. We can check on section 2.3 of this supplement, if ship is fitted with an equivalent arrangement approved in accordance with regulation 4.1 an that is at least as effective in terms of sulphur oxides emission reductions as compared to using a fuel oil with a certain sulphur content limit.

Exhaust gas cleaning systems are basically an air pollution control system, which is used to remove certain particulates, specifically sulphur oxides particulates from the exhaust gases of a ship. Generally, the molecules of sulphur oxides that are part of exhaust gases from engine, are separated from the gas flow when they meet a liquid. This liquid may be only water, a chemical compound, or a combination of both.

This technology has been used in chemical industry from several years ago, mainly to remove certain pollutant gases, for example, hydrogen sulphide, sulphur dioxide, dioxins, hydrogen fluoride, heavy metals as well as certain methane compounds and carbon dioxide (biogas).
The operation principle of the scrubbers used on board of a ship is the same than the scrubbers used in the chemical industry. The exhaust gas cleaning system installed on a ship, is formed basically by an exhaust gas cleaning unit, also known as scrubbing tower, a water treatment unit, where residual water from cleaning process is treated to obtain water in compliance with system parameters and in case of open loop system, with MEPC.259(68) Resolution parameters, a sludge tank for storing all residues from water treatment unit and finally a group of water pumps, valves and sensors that compounds all system.

As we mentioned above, an exhaust gas cleaning system can be approved and certified by two different schemes, A and B. Next and prior to analyse all types of wet exhaust gas cleaning systems, we will check the differences between both schemes.

3.1. SCHEME A FOR APPROVAL, CERTIFICATION AND SURVEY OF AN EXHAUST GAS CLEANING SYSTEM

Scheme A contemplates an initial verification and certification of the system. Resolution MEPC.259(68) foresees three options for this initial verification and certification. These options are as follows:

- Unit approval, in which the exhaust gas cleaning unit, is certified for an emission limit value established by manufacturer, using a fuel with a sulphur content cap limited by manufacturer too and for a range of operating values.

- Serially manufactured units used for exhaust gas cleaning units which are nominally similar with same mass flow ratings as that certified as per unit approval option. In this case, the equipment manufacturer may submit, for acceptance by Administration, a conformity of production arrangement. Units certified through this option are subject to the number of surveys that the Administration may consider assuring that these units follow values approved by Administration.

- Product range approval, used for exhaust gas cleaning units with the same design, but with different maximum exhaust gas mass flow capacity. In this case, Administration may accept, instead of testing the exhaust gas cleaning unit with all capacities, to test the scrubber units with only three of its capacities, but these capacities should include the highest, the lowest and intermediate one.

Each exhaust gas cleaning unit should be certified in compliance with the certified value (from manufacturer), for each operating condition and limits stated on the exhaust gas cleaning unit Technical Manual, which should be approved by Administration. All values should follow all parameters regulated by Resolution MEPC.259(68).

For each unit approved and certified under specification of scheme A, the Administration should issue a Sulphur Oxides Emissions Compliance Certificate (SECC). Furthermore, all these units should have an Exhaust Gas Cleaning Technical Manual, approved by the Administration. This Manual should keep on board of the ship and should contain all data specified in the above-mentioned Resolution.

All units certified and approved by scheme A, are subject to survey on installation and at initial, annual, intermediate and renewals surveys by the Administration, as well as, to the Port State Control inspections.
3.2. SCHEME B FOR APPROVAL, CERTIFICATION AND SURVEY OF AN EXHAUST GAS CLEANING SYSTEM

Scheme B for certification and verification consists in the approval of the system by the continuous monitoring of ship’s emissions. This continuous monitoring system should be approved by the Administration and the results of each parameter monitored should be provided to the Administration, during a ship’s inspection, if required. The approval of an exhaust gas cleaning system by scheme A, is intrinsic to the good working order of the continuous monitoring system, otherwise system should lose its certification.

Each exhaust gas cleaning unit, approved and certified by scheme B, is subject, in the same way than scrubber units certified by scheme A, to survey on installation and at initial, annual, intermediate and renewals surveys from Administration, as well as, to the Port State Control inspections.

The continuous monitoring emission in terms of sulphur dioxide and carbon dioxide \( \text{SO}_2 \text{ppm}/\text{CO}_2 \%), should be carried out from a set of gases emission analysers that should be placed after scrubber tower, when emissions are leaving from its cleaning process. In case that an exhaust gas cleaning system is set out with several gases emission analysers, these should be properly adjusted and synchronized in order they provide similar measurements and sampling times. All system data outputs should be aligned to the sulphur dioxide and carbon dioxide ratio, is a representative sample of emissions.

Furthermore the above-mentioned parameters, exhaust gas cleaning systems, approved and certified by scheme B, should continuously monitor, at least, the washwater pressure and flow rate of the unit’s inlet connection, exhaust gas pressure before and pressure drop across the exhaust gas cleaning system, fuel oil combustion equipment load and the exhaust gas temperature before scrubbing process and at its leaving.

Exhaust gas cleaning system certified by scheme B, should have, in the same way than scheme A certified systems, a Technical Manual for scheme B. This Technical Manual should contain, as a minimum, the following information:

- Unit identification, with manufacturer details, model and type and serial number, as well as, other relevant data.
- Description of the unit, components and any other ancillary system or equipment.
- The operating limits or range of operating values, for which the system is certified. This section should, as minimum include:
  - Maximum and minimum mass flow rate of exhaust gas.
  - Engine parameters for which the exhaust gas cleaning system will be used. Among these parameters should be included the type, pressure, and power of engine/s.
  - Minimum and maximum washwater flow rate, minimum inlet water alkalinity and inlet pressures.
  - The range of maximum and minimum temperatures of exhaust gases on the entrance and leaving of system.
- Exhaust gas differential pressure range and the maximum exhaust gas inlet pressure with engine/s operating at maximum nominal rate or at 80% of power rating.
- Requirements of water used on the system, in terms of salinity, basicity, etc.
- Other parameters concerning the system performance.
  - Corrective measures to apply if any of parameters limits are exceeded, for instance the SO₂/CO₂ ratio or water discharge parameters (pH, PAH, turbidity, etc.) adopted by Resolution MEPC.259(68).
  - The variation in whole operating range, of washwater parameters.
  - Design requirements of washwater unit.

Technical Manual for each unit certified through scheme B should be approved by Administration and will be available on-board for its inspection if required.

3.3. OPEN-LOOP EXHAUST GAS CLEANING SYSTEM

As we have mentioned before and independently to the type of scheme, there are three kinds of exhaust gas cleaning system, open loop, close loop, and hybrid systems.

The main goal of an open loop exhaust gas cleaning system, in the same way than its counterpart, is scrubbing the exhaust gases from engine/s which are being used on-board of a ship using a fuel with a sulphur content which is greater than limits established by the above-mentioned regulation.

Open loop exhaust gas cleaning systems are basically formed by a set of pumps whose main goal is to provide the system with sea water through the scrubber inlet valve. Furthermore, there are a set of water pipes which conduct seawater until the scrubbing tower. Before its use in the scrubbing tower, seawater has been analysed by a set of sensors which are placed next to inlet water valve, to get the seawater parameters which has been used in each moment.

On the scrubbing tower, the exhaust gases from engines are subjected to cleaning process which consists in a continuous spraying seawater over the exhaust gases, at several height levels. Through this cleaning process, the sulphur content of emissions is greatly reduced. In this process is used one of main characteristics of water, the alkalinity. We should take into account, that some open loop exhaust gas cleaning systems, are using, during the cleaning process, alkalinity solutions, which is injected in the line in order to increase the water alkalinity and get a better sulphur oxides cleaning process.

Alkalinity is defined as the capacity of water to neutralize acids. This is the water feature that allows the system to remove sulphur oxides from exhaust gases. The acidity, in this case, is determined by sulphur oxides concentration on the exhaust gases. On the other hand, alkalinity of seawater is determined by salts concentration on the water. These salts are mainly composed by sodium chloride, sulphates, calcium bicarbonate, etc.

Once the exhaust gases have been cleaned through the above-mentioned process, residual water from scrubbing tower is conducted through a set of pipes and valves, to the water treatment unit. In that moment, residual water is being to be treated and depending on the manufacturer and the design of the system, the process may change. Generally, there is a pipe which fits the water
treatment unit with seawater in order to lower the concentration of molecules of sulphurous acid, heavy metals and aromatic polycyclic hydrocarbon, among others components, all of them formed after mixing seawater with exhaust gases from engines, during the cleaning process in the scrubbing tower.

The reaction produced between seawater and sulphur dioxide is as follows:

\[ \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 \]

Recall that a molecule of sulphur dioxide is formed by 2 oxygen atoms and 1 sulphur atom. When sulphur dioxide is dissolved in water, sulphur atom is working with its oxidation number 4, forming a new substance, called sulphurous acid (H$_2$SO$_3$).

Once this residual water, from scrubbing tower, has been diluted in the water treatment unit, is pumped to the filter zone. In this filter zone, larger particles are removed from the water, through the first filtering. One of the filtering systems used is the granular activated carbon. These types of filter, which are widely used in the chemical industry both for the scrubbing of gases and for water cleaning, acts as an adsorbent, removing certain substance and particles from the gas cleaning water.

It is important to point up that according to technical manuals consulted, from several exhaust gas cleaning system manufacturers, resulting wastewater from the first filtrate, is the one which contains most of the particles in suspension and highest concentration of polycyclic aromatic hydrocarbons. Once residual water has been filtered for first time and depending on the manufacturer and the system’s design, wastewater may be stored in a tank for its discharge in an authorized port facility or is conducted to a filter press, where an auxiliary system is used to minimize the sludge produced by the action of the filters. This system collects these wastewaters and with the application of a polymer which is dosed according to the amount of water received, flocculation of the particles presents in the wastewater is carried out. Then this water residue becomes into a dry sludge which is stored on-board into big bags or drums, to be disposed on shore into authorized reception facilities.

Let us see an example of this filter press and the appearance of the above-mentioned residue on figures nº 1 and nº 2.

**Figure 1. View of a model of filter press used for minimizing the sludge produced after flocculation of particles.**

Source: the authors.
Then, after first filtering, treated residual water is conducted to a second filter zone (filter 2) and depending on the system and manufacturer, on this second filtering operation, it is used a membrane filtration system where treated residual water is recirculated through the filter, several times, if needed, in order to get a best filtering result. After this second treatment, treated water is considered good enough in order to be discharged overboard, however water should be analyzed through water parameters sensors, which main goal is to check the compliance of the treated water parameters with the limits established by Resolution MEPC.259(68).

As we mentioned before, these parameters are pH, PAH, turbidity (heavy metals and ashes), nitrates, additives and other substances used during the water cleaning process.

If system detects, during treated residual water analysis, that any of the above-mentioned parameters are not in compliance with the limits established by Resolution, then system restarts the water recirculation on the filtering zone or send the treated residual water again to the water treatment unit, until desired parameters are achieved.

This is basically the operational mode of an open loop exhaust gas cleaning system.

Our investigation is intended to analyze which is the real effect, on short and long term, of discharging these residual treated waters overboard, in Barcelona port waters. We are going to carry out a sampling of these treated residual waters above-mentioned, over several ships which are using the open loop scrubbers during their call in the port of Barcelona.

But the first thing we should do is to understand how Resolution MEPC.259(68) is regulating certain water discharge parameters. In this way, we are going to analyze this section of the above-mentioned resolution.
3.3.1. WATER DISCHARGE REGULATION

All parameters related to the discharge of treated residual waters used on the exhaust gas cleaning systems are regulated by Resolution MEPC.259(68). Specifically, this regulation establishes on its section 10.1 and subsequent, the washwater discharge criteria.

It is essential to consider that an exhaust gas cleaning system with overboard discharge, should be fitted with a washwater monitoring and recording equipment. This is because is necessary to control in each moment, the washwater parameters which are intended to discharge overboard and its compliance with the above-mentioned regulation. The values monitored should include, as per Resolution, pH, PAH, turbidity, and temperature. These parameters should be continuously monitored and recorded when a ship is discharging these waters into a port, harbour or estuary as well as in other areas, where being necessary. Let is see how ResolutionMEPC.259(68) is regulating these parameters.

3.3.1.1. pH DISCHARGE CRITERIA

Resolution MEPC.259(68) establishes that the washwater used during exhaust gas cleaning process and intended to discharge overboard, after being treated in washwater treatment unit, should comply with one of the following requirements which, as per the above-mentioned Regulation, should be recorded in the Exhaust Gas Technical Manual for scheme A or for scheme B, as applicable:

- The discharge waswater should have a pH of no less than 6.5 measured at the ship’s overboard discharge, considering the next exception applied for ships which are under manoeuvring or in transit. For the above-mentioned ships, is allowed a maximum difference between inlet and outlet of 2 pH units, measured at the ship’s inlet and overboard discharge.

- The minimum value that the water discharge pH will achieve, at the overboard monitoring position (outlet), is the value which not will be lower of pH 6.5 measured at 4 meters from the overboard discharge point with the ship stationary, and this minimum pH value at the overboard monitoring position, is to be recorded as the overboard pH discharge limit in the Exhaust Gas Technical Manual for scheme A or for scheme B. This overboard discharge limit can be determined, as per the above-mentioned Resolution, either by means of direct measurement, or by calculation-based methodology, which can be based in computational fluids dynamics or in an equally scientifically established empirical formulae. If option chosen is the calculation-based methodology, this should be approved by Administration. Furthermore, and for both cases, the determination of pH discharge limit should be in accordance with certain conditions, established in Resolution MEPC.259(68) and recorded in the Exhaust Gas Technical Manual for scheme A or for scheme B.

The above-mentioned values for pH and limits established by this Resolution are clear, but we must consider them to the possible scenarios. What we are going to study and analyze the effect of these discharges in a port such Barcelona, where the tide effect is practically non-existent and where are several docks and port areas which are really closed to the water renewal. It is possible to achieve a scenario where we could have in these docks, several ships operating during their calls, using an open loop exhaust gas cleaning system and that means, discharging the treated residual water to the port waters.
Every day, more and more ships are installing this modality of scrubber on-board. For instance, we could find it in several passenger ships, car carriers, ferries, chemical tankers, etc. which are calling to Barcelona every week. Although they are in full compliance with one of the requirements established by the Resolution for pH limit values, we cannot forget that these ships are discharging a more acidic water than they have taken it. For instance, we are going to check the pH values for a certain time, of a ship, which was using an open loop exhaust gas cleaning system.

This is an abstract from electronic monitoring and recording equipment for washwater parameters. These washwater parameters has been analyzed as required per Resolution and showed the following results for pH values:

Table 1. View of water pH values monitored at inlet and outlet water points, by an exhaust gas cleaning system.

<table>
<thead>
<tr>
<th>Inlet pH</th>
<th>Outlet pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.11</td>
<td>5.88</td>
</tr>
<tr>
<td>8.11</td>
<td>5.86</td>
</tr>
<tr>
<td>8.12</td>
<td>5.84</td>
</tr>
<tr>
<td>8.32</td>
<td>5.88</td>
</tr>
<tr>
<td>8.32</td>
<td>3.68</td>
</tr>
</tbody>
</table>

Source: washwater report from an open-loop exhaust gas cleaning system.

The ship is in full compliance with Resolution because she is using a calculation-based methodology, approved by Administration, and based in an equally scientifically established empirical formulae. This is the case where, the minimum value that the water discharge pH will achieve, at the overboard monitoring position (outlet), is the value which not will be lower of pH 6.5 measured at 4 meters from the overboard discharge point with the ship stationary.

This minimum pH value at the overboard monitoring position, is recorded as the overboard pH discharge limit in the ship’s Exhaust Gas Technical Manual for scheme B. For this ship, this value is pH 2.3.

Taking into account all the above-mentioned, it seems to be very difficult that treated wastewater, with pH 3-4 which is being discharged overboard, can achieve the minimum pH 6.5 desired, at a distance of 4 m from the overboard discharge point with the ship stationary. Also, we should consider, the port of Barcelona features, its docks and types of ships berthed, main currents and water renewals.

Furthermore, we should consider the rate of discharge of treated wastewater by an open loop exhaust gas cleaning system. It depends on the ship, system, manufacturer but mainly, on the main engine load. For instance, for the ship of reference, which is using, for the period analyzed, an engine load between 54 % and 65 %, is discharging an average of treated wastewater of 358.761m³/h. Taking into account these value, we should consider as well, that the average time
call, in the port of Barcelona, of this type of ship is about 12 hours. So, only this ship, during this call, has been discharged, an average of 4305.132 m³ of treated wastewater from the open loop exhaust gas cleaning system.

If we consider the volume of ships that currently are installing these kind of scrubbers on board, which some of them, are calling to Barcelona port, in order to use this system during their calls, the volume of treated wastewater from the exhaust gas cleaning processes, is going to be increased exponentially.

This is one of the reasons because, we are carrying out this study. It is particularly important to know how the treated wastewater discharges from the open-loop exhaust gas cleaning systems installed on board the ships recalling in the port of Barcelona, can change the pH water of the port. We are going to analyze the current system and its evolution through the time. Although, we must consider several parameters and multiple variables in order to achieve a reliable result.

In case, we conclude that the treated wastewater discharged from these systems are going to decrease the pH of Barcelona port water, we are going to extend our study to find a way for minimizing this effect.

3.3.1.2. POLYCYCLIC AROMATIC HYDROCARBONS (PAH)

The treated washwater PAH should be specified in the Exhaust Gas Technical Manual for scheme A or for scheme B and should follow Resolution MEPC.259(68) requirements. These requirements are:

- Maximum continuous PAH concentration in the washwater intended to be discharged should not be greater than 50 μg/L of phenanthrene equivalence (PAH phe) over the inlet treated washwater PAH concentration. The washwater PAH concentration measurements should be done downstream of the water treatment unit. In case of using any washwater dilution or reactant, the measurement of PAH concentration should be upstream of this dilution/reactant.

- The above-mentioned PAH concentration limits is established for a treated washwater flow rate of 45 t/MWh. As indicated in Resolution MEPC.259(68), the limits for all flow rates values below 45 t/MWh should be adjusted upwards and vice-versa, according to the values established in the above-mentioned Resolution.

3.3.1.3. TURBIDITY / SUSPENDED PARTICLE MATTER

The treated washwater turbidity should be measured in formazin nephelometric units (FNU) or nephelometric turbidity units (NTU) or in any equivalent unit. Resolution MEPC.259(68) establishes the turbidity limit of treated washwater should be not greater than 25 FNU/NTU. Due to the lack of precision on the measuring when water turbidity is high and the small lapse time between inlet and outlet water readings, the 25 FNU/NTU limit should be applied in a period of 15 minutes and using the average of turbidity readings from the system, during this period. Turbidity of this washwater should be measured downstream of the water treatment unit but upstream of washwater dilution prior to discharge. We should take into account that, as per Resolution, the above-mentioned turbidity limit, could be exceeded by 20% during a 15-minute period for each 12 hours period.
The turbidity limit should be detailed in the ship’s Exhaust Gas Technical Manual for scheme A or B.

3.3.1.4. NITRATES

In the case of nitrates, Resolution limits the concentration of nitrates discharges with treated wash water in the necessary concentration in order to remove the 12% of nitrogen oxides from exhaust gases or a limit of 60mg/l for washwater discharge rate of 45 tons/MWh, in case this second value is greater.

3.3.1.5. WASHWATER ADDITIVES AND OTHER SUBSTANCES

In case of exhaust gas cleaning system which are using chemical products or any necessary additive used by system for instance to increase the basicity of water, as well as the chemicals created by the own system, an assessment of the water will be required. If necessary, additional washwater discharge criteria should be adopted.

3.4. CLOSED-LOOP EXHAUST GAS CLEANING SYSTEM

Close-loop exhaust gas cleaning systems, despite could seem quite similar to the open-loop exhaust gas cleaning systems, regarding to all basic equipment are composed, both have big differences with each other, especially in its operational mode as well as the auxiliary equipment that they use during exhaust gas cleaning process and in the washwater treatment unit.

Close-loop exhaust gas cleaning systems are other option for ships to follow the above-mentioned regulation 14.1.3, sulphur oxides and particulate matter, of Annex VI, Prevention of Air Pollution from Ships, of Marpol Convention. Those systems are also composed by a set of lines, valves, pumps, sensors and by a scrubbing tower, a washwater treatment unit and several storage tanks.

The closed-loop systems are using, during the exhaust gas cleaning process, fresh water instead of seawater. The system is fed with this fresh water proceeding from a set of tanks. Generally, this water is conducted firstly to the recirculation tank, where fresh water from tank is mixed with wastewaters from scrubbing tower and treated washwater from water treatment unit.

As we mentioned before, water alkalinity has a particularly important role during the exhaust gases scrubbing process. We should remember that alkalinity is defined as the capacity of water to neutralize acids.

In case of closed-loop scrubbers, fresh water used during the exhaust gas scrubbing process, has a reduced alkalinity compared with seawater as this alkalinity is determined by salts concentration on the water. For this reason, an external alkaline additive input is required to increase the alkalinity of fresh water.

The above-mentioned alkaline additive input generally is carried out when wastewater is coming from scrubbing tower to the recirculation tank. In that way, wastewater is entering to the recirculation tank with a high basicity. Generally, the main additives, used in closed-loop exhaust gas cleaning systems, which are conferring to the fresh water the required basicity, in order to increase its scrubbing capacity, are sodium hydroxide (NaOH), also known as caustic soda solution and magnesium hydroxide (MgOH₂).
We should mention that, closed-loop exhaust gas cleaning system requires too, to increase the capacity and the performance of washwater treatment unit, a set of additives which are added directly to the washwater treatment unit. These additives are composed by a set of chemical products which main goal is to confer to the water treatment unit, a required flocculant capacity, for removing from wastewater, certain residues. Polyaluminium chloride is one of the most used chemical solutions and which greater efficiency has during wastewater treatments. This is due to the high flocculant capacity of this chemical product, which creates during wastewater treatment process and in a truly short time, big residue flocs, facilitating in this way, their sedimentation and increasing the wastewater treatment unit performance. Furthermore, the sodium hydroxide has a low impact in the water pH level, so the treated water pH, from wastewater treatment unit, is not increased during this process.

Once waste waters have been treated, residues generated as well as flocs and captured particles are stored into sludge tank. Treated water is conducted into recirculation tank where is going to be pumped to the system to start a new cleaning cycle.

However, water used during the exhaust gas cleaning process is being heated during the process. This is because, exhaust gases which are being cleaned into the scrubbing tower, are coming from engine at high temperatures.

For this reason, the water used that comes from recirculation tank and before is entering to the scrubbing tower, is being recirculated in a plate heat exchanger, where its temperature is lowered before is pumped to the scrubbing tower. Generally closed-loop exhaust gas cleaning systems are using a plate heat exchanger to decrease water temperature. This is because, unlike scrapped heat exchangers, welded plate heat exchangers have greater resistance to high temperatures and pressures.

In the same way than open-loop exhaust gas cleaning system, closed-loop scrubbers are fitted with a water monitoring system. This monitoring equipment allows to the system control some water parameters such temperature, washwater flow rate, pressure, alkalinity and additives concentration needed for increasing this alkalinity. This monitoring equipment is installed in several points of the system. One of these monitoring points is placed in the water conduct which supplies the scrubbing tower.

Another highlight of closed-loop exhaust gas cleaning system is that are fitted, in the same way than open-loop scrubbers, with an overboard discharge valve. This overboard discharge valve is used to carry out a water bleed off, if required. Due to high temperatures of exhaust gases during cleaning process, water used by the system is being warmed continuously. This fact produces to the system two main problems. On the one hand there is an evaporation of the water used during exhaust gas cleaning process So system should be refilled with fresh water. On the other hand, and regarding to the overboard discharge valve, due to high temperatures of the water and to avoid precipitation of salts, a bleed off from the closed-loop system must be performed. This system bleeds off is a continuously treated wastewater discharge, whose flow rate depends on the operating system rate and usually is around 2m$^3$/h.

We should take into account that before discharges, wastewater is conducted to the water treatment unit and the clean washwater is also monitored before its discharge in order to control that parameters such pH, turbidity, PAH and temperature are in compliance with limits established by Resolution MEPC.259(68).
Therefore closed-loop exhaust gas cleaning system are also fitted with an overboard discharge valve.

Compared to treated wastewater discharge from open loop exhaust gas cleaning systems, closed-loop scrubbers discharges seem to be not significant, taking into account that water should be also monitored and in compliance with water discharge criteria stablished by Resolution MEPC.259(68).

3.5. HYBRID EXHAUST GAS CLEANING SYSTEM

The hybrid exhaust gas cleaning system is a combination of open-loop and closed-loop scrubbers. To scrub these exhaust gases, both scrubber’s modalities, open and closed loop, are using seawater.

When system is operating in closed-loop mode, it requires an alkaline solution input, in order to increase the basicity of seawater, once it has been used and treated on the water treatment unit during several times, for scrubbing process.

In closed-loop mode, system is not discharging treated wastewater more than necessary, solely for bleeds off required, to avoid the above-mentioned salts precipitation.

When system is being operated as open-loop exhaust gas cleaning, seawater is also used and after scrubbing process, this wastewater is going to be treated and discharged in compliance with water discharge criteria of Resolution MEPC.259(68). In the same way than open-loop scrubbers, certain parameters of treated washwater, such such pH, PAH, turbidity (heavy metals and ashes), nitrates and other substances which are used during the water cleaning process, are going to be monitored, before its discharge.

All residues generated, as sludges, by the hybrid exhaust gas cleaning system, are going to be stored into the sludge/s tank/s, to be delivered in authorized port facilities.

4. CONCLUSIONS

We understand that is necessary to carry out this investigation due that there are no studies enough which guarantee that treated wastewater discharges from open-loop exhaust gas cleaning system neither hybrid scrubbers operating in open-loop mode, are not polluting seawater. More concretely, we are going to study how it could affect, to Barcelona port waters, an increasing of acidity of these waters, with the continuous discharge of treated wastewater, in several port areas at the same time, day after day. Furthermore, we must consider the probably increase of polycyclic aromatic hydrocarbons and nitrates concentration as well as the particle matters and other substances, used during the cleaning process, in the port waters.

We are going to study the current situation of Barcelona port waters, knowing its composition, including the waters parameters such pH, PAH, turbidity (heavy metals and ashes), nitrates and other substances which are used during the water cleaning process. Our specific investigation scenario inside the port of Barcelona is going to be the South Dock. We have chosen this Dock due to the greatest part of ships which are berthing on its piers are using an open-loop exhaust gas cleaning system or hybrid exhaust gas cleaning system. This will be our starting point, from which we will study the probably evolution of South Dock water, taking at least 2 wastewater
samples per month to be sampled from an exhaust gas cleaning system operating in open-loop mode. Furthermore, at the end of each month a sample is going to be taken directly from South Dock water to check the evolution of water in real time. The next water parameters are going to be analyzed in each sample:

1- Acidity (pH)
2- Concentration of Polycyclic Aromatic Hydrocarbons (PAH)
3- Turbidity (concentration of heavy metals and ashes)
4- Nitrate concentration.

All data and results obtained are going to be introduced into a specific program which will allow us to carry out a prediction model and getting an approximation of the possible long-term scenario.

Probably, we will achieve a result which demonstrate that acidification, among other port water parameters, are going to increase in this scenario. In case of an increasing of port waters pH, next step should be to know how is going to affect this more acidic water condition to the normal ship’s hull corrosion. And final step should be how we can counter or minimize this effect.

It is particularly important to remove the Sulphur oxides from ship’s emissions to protect our environment, and for this reason regulations are setting increa singly stricter sulphur caps. Technologies are going to make easier the compliance with these new regulations, but it is especially important to make sure that we are using the most environmentally respectful option. Otherwise, we are only changing the source of pollution, seawater instead the air.

References:


ANALYSIS OF SHIP VOYAGE DATA BASED ON CHOW-LIU TREE AUGMENTED NAÏVE BAYES-METHOD TO SUPPORT BIOFOULING MANAGEMENT

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Abstract:

The Baltic Sea is a sensitive marine environment and a unique brackish water basin. In spite of environmental protection policies of its coastal states, the sea is still under unsustainable load. Environmental impact of shipping is one of the concerns, as the area is a major transport corridor for both passengers and cargo. Many restrictions and environmental regulations direct the shipowners actions. However, there is still issues yet too complicated to be regulated by laws. One such an issue is the spreading of harmful invasive species. In order to gather more data that the future regulations can be based on, the EU Interreg Baltic Sea Region programme funded a multinational research project called “COMPLETE”. Ballast waters are well known pathways for invasive species, but migration by immersed hull structures is a lesser known vector. The role of the South-Eastern Finland University of Applied Sciences in the project is to conduct onboard measurements and data collection on ships’ performance. The data is collected 2018...2019 during normal operation of the ships, and consists of information extracted from voyage data; shaft power, fuel consumption, propeller pitches and rotation speeds, trim, draught, DWT, speed over ground, AIS data and weather conditions provided by coastal meteorological stations. The aim is to demonstrate on individual ship level the impact of biofouling on resistances and fuel consumption, and, in consequence, increase the shipowners’ motivation to keep immersed hulls clean and thus save fuel, reduce gaseous emissions and prevent the spreading of invasive species. However, causation network of collected data includes powerful mixers such as weather conditions. The objective of this paper is to present experiences of utilizing Chow-Liu tree augmented Naïve Bayes formulation for analysing the voyage data. The method is computationally efficient and usually gives quite reliable results even if the collected data contains a lot of noise or inadequacies.

Keywords:

Biofouling, big data, Naïve Bayes, Baltic Sea, COMPLETE.
Acknowledgements:

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INTRODUCTION

Through the ages, biofouling has produced additional challenges for seafarers when biofouled immersed hull structures increase the drag of ships. This problem has been identified early and a variety of methods has been applied to limit accumulation of organisms on ships’ hulls [1,2]. Copper-based immersed hull coatings are effective but toxic for marine environment [3]. As a result, treatment of hulls with copper-paints has reduced significantly in the Baltic Sea region and focused just on strategic locations, such as sea chests, where biofouling can cause serious problems and cleaning is often challenging [4]. During winter times, on the long-term average, the Gulfs of Bothnia, Finland and Riga, archipelagos of Estonia, Stockholm and south-west of Finland are covered by sea ice. Therefore, the immersed hull coatings must be resistant for heavy mechanical stress caused by operating in icy conditions and therefore many types of silicone based foul-release paintings are not usable at all.

Epoxy-based hard coats are suitable for operating in icy conditions. However, this kind of coating gets biofouled especially during summer season and, to avoid the increasing hydrodynamical resistances, immersed hulls are cleaned periodically [3,5]. At the latitudes of the Baltic Sea, the summertime temperatures of surface seawater can reach +20 °C or sometimes even more [6]. However, normal summertime temperature level stays around +15 °C. Seawater temperature levels decrease rapidly in spring and in autumn, but this might be subjected to significant changes due to global warming in the future [7,8]. The biggest change seems to occur during just these seasons.

The biofouling reaches noticeably levels monthly on surfaces treated with hard-coatings: The immersed hull sides near the water surface (0-2 meters) rate 0-20 mm long seaweed within the period of one month. If the summer season is warm and there is plenty of sunlight available, the length of the weeds can reach 30-50 mm, sometimes even 100 mm, and weeds can be found deeper also (4-5 meters from the water surface). Monthly aged weeds are usually soft and can be brushed off relatively easily, whereas two months old weeds are attached harder to the hull. After two months, other organisms such as barnacles, can typically be found. If the hull is heavily biofouled with hard-shelled varieties, only mechanical cleaning with metal brushes is a practicable method. However, this cleaning method usually damages the hull coating too. [9]

Invasive species can be a major threat for the original ecosystem [10]. Worldwide, numerous cases can be found where aggressive non-indigenous species have pushed
native ones on the brink of extinction by causing changes in food chains. Often disadvantages have touched human activities too, for example, spreading of pathogens, impact on agriculture and fisheries and other harm to the economy. Ballast waters carried all around the world have been identified as a major vector for uncontrolled spreading. Therefore, international ballast water convention entered into force on 7th September 2017 [11] with the aim of limiting uncontrolled spreading of invasive alien species.

The “COMPLETE” is an international research project funded by the Interreg Baltic Sea Region Program of the European Union [12,13]. The project is ambitious: The aim is to generate new knowledge to support decision makers both in administrative and shipowner sectors to find more sustainable solutions to prevent spreading of invasive alien species both through ballast waters and biofouling of immersed hulls. One practical objective is to provide an evaluation tool for shipping companies and other operators to clarify different consequences of the biofouling issue and raise environmental awareness simultaneously.

The “COMPLETE” project is implemented during years 2017…2020. The responsible coordinator is Kotka Maritime Research Centre. The project partners are Universities of Helsinki, Tartu, Latvia, Klaipeda, Gdansk and Chalmers. The public authority representatives include Helsinki Commission HELCOM, Finnish Environment Institute and Federal Maritime and Hydrographic Agency of Germany, and the association sector is represented by Keep the Archipelago Tidy Association. The South-Eastern Finland University of Applied Sciences (Xamk) is one partner of the project. The main responsibility of Xamk is to execute data collection and onboard measurements in order to observe how biofouling effects a ship’s voyage, fuel consumption and hydrodynamic drag. Validating the true impact is quite challenging in such cases where immersed hulls are constantly cleaned and heavy biofouling is not attained.

The effects of biofouling on ship speed and fuel consumption, published in several forums, are often observed cases where the immersed hulls are completely biofouled [4,14,15]. Based on this knowledge, deciding the appropriate hull cleaning intervals is challenging. Shipowners rarely have resources to carefully analyse this issue: Using of rules of thumb and tacit knowledge of the crew often provides reasonable results to plan hull cleaning intervals – while acknowledging that biofouling is just a single element of the cost structure of the ship [16,17]. However, the level of experience among the vessel crews varies and attitudinal atmosphere differs between companies, even between separate ships. Contributing to the level of knowledge is therefore one aim of the project: In addition to the dissemination of the research results, sharing the gathered information with individuals is also essential.

1. THEORETICAL FRAMEWORK

In this study, the collected voyage data contains several variables: Shaft power, fuel consumption, propeller pitches, rotation speeds, trim, draught, DWT and speed over ground are recorded from the ships’ systems. In addition, based on AIS data provided by HELCOM, the ships’ position and course were analysed. Weather data provided by coastal meteorological stations was utilized for taking into account the effect of changing weather conditions. Current estimations were provided by the Federal Maritime and Hydrographic Agency of Germany (BSH), whereby comparability of different voyages
can be assured. This research frame creates a typical mass data problem containing the following features:

- Voyage data is collected from several sources; time step, format and accuracy varies
- Voyage data gives primary or indirect information based on the source
- Voyage data is not intended to be used for analysing this research problem
- Voyage data collection is mainly an automatic process
- Voyage data includes all main features of mass data (volume, variety, velocity, value, veracity).

The collected voyage data contains a lot of information about the physical environment of the followed ship. In addition, the chosen approach enables the solving of this research problem by using options that are actually available for shipowners without investments to equipment. However, making reliable conclusions still needs an appropriate framework [18]. The Bayesian network probability theory provides a statistical approach for problem solving. In fact, this kind of mass data-based research problem basically leads statistical inference requirement: Interdependencies between various variables can be observed, but in all cases, the influence of numerous unknown variables is also involved to formed causation system [19,20]. Actually, this is not a surprising issue at all: Especially in human, social or medicine sciences, research is often faced with a similar problem and applications of causation models have been proven an effective method to reach reliable results.

In this case, the observed interactions in the causal network may be directly dependent on physical factors or dependencies can have a more indirect form. Interaction between thrust and hydrodynamic resistance is based directly on physics, but physical models that take into account all factors are very complex and, in any case, finding out real values for input variables is challenging [2,21]. Wind impact assessment is even more complicated: Drag can increase straigthly, but wind can also increase drifting, in which case steering resistances increases synergistically. Wind also affects wave formation and surface currents and the winding profile over sea is turbulent [1]. Also, ship’s DWT and especially trim have an effect and with bulbous bow construction, interaction can be complex [22].

Causation tree system based on Bayesian network is a functional and efficient approach to study a problem where variables contain lot of information about sub-variables [23]. Naïve Bayes classifier [24] is one machine learning method based on applying Bayes’ theorem [25]. It is a simple model that has a strong independence assumption between all the features of the system. The real system rarely follows this assumption but, despite of this “naïve” approach, this classifier works quite reliably even if the research problem is complex and includes strong dependencies. The equation of Naïve Bayes classifier can be written as follows:

\[ p(x_1, ..., x_n|C)p(C) = p(C) \prod_{i=1}^{n} p(x_i|C). \]  

where \( C \) is a chosen class and \( x_1, ..., x_n \) are independent variables of the system. Using this approach, a two-level Bayesian network can be formed. However, two-level network contains restrictions and due to this reason, method is often applied in a complemented
form. Chow-Liu tree provides a computationally efficient method for expanding construction to second order level [26]. This is made by using joint probability distribution of variables minimized by Kullback-Leibner divergence. This leads to form:

\[ p(C|x_1, ..., x_n) = p(C) \]  

(2)

Achieved Chow-Liu tree augmented Naïve Bayes method can be applied as a classifier for large amounts of data. In this case, the chosen input variables are shaft power, DWT, trim, speed over ground, energy efficiency and computational efficiency. Shaft power is measured from torsion meters of the propeller shafts by using one-minute time interval. Same interval is used for trim data and speed over ground. Trim data contains bias depending of the system errors of the ship type. However, the trim trend is estimated to be sufficiently reliable. Speed over ground is GPS-speed and DWT is given by officers at the time of the departure. Energy efficiency contains relation of shaft power to DWT and sailed distance. Computational efficiency compares shaft power to calculated hydrodynamic resistance of the ship. Based on this framework, the following Naïve Bayes network is formed:

Figure 1. Formed Chow-Liu tree augmented Naïve Bayes network.

Efficiency is a factor that does not contain primary information about measurements but is based on the relationship between theoretical resistance and measured shaft power. Direct data of the drag is seldom available. However, estimations based on vessel main dimensions can be implemented quite straightforward and these methods have been comprehensively used in marine architecture before the era of computational fluid
dynamics. In addition, with the research problem such this, the modelling accuracy of the hydrodynamics is actually not the most important issue: Selecting the routes the ship is cruising at constant speed as well as the observed difference between biofouled and clean hull are more essential than absolute accuracy. However, this approach gives more certainty as environmental conditions are comparable. This reduces the risk that biofouling effect is mixed with changes in the weather conditions.

The hydrodynamic drag of the ship [1,2] can be observed by equation

$$F_{\text{hydr}} = \frac{1}{2} \rho S C_T v^2$$  \hspace{1cm} (3)

where $\rho$ is density of water, $S$ immersed hull area, $C_T$ hydrodynamic coefficient and $v$ speed of the ship. In this study, coefficient factor is formed as:

$$C_T = C_f + C_r + \Delta C_f + \Delta C_a + \Delta C_{bl} + \Delta C_l$$  \hspace{1cm} (4)

including coefficients of viscotic ($C_f$) and wave resistances ($C_r$), roughness resistance factor ($\Delta C_f$), scale factor ($\Delta C_a$) and effects of bulbous bow ($\Delta C_{bl}$) and steering ($\Delta C_l$). Viscous resistances is defined by using Grigson’s method [27,28] based on Reynold’s number of the ship

$$10^3 C_f = (1,032 + 0,02816(\log R_n - 8) - 0,006273(\log R_n - 8)^2) \frac{0.075}{(\log R_n - 2)^2}$$  \hspace{1cm} (5)

when $10^8 < R_n < 4 \cdot 10^9$,

Wave resistances are defined by using method presented by Harvald-Getler and Taylor-Guldhammer [29,30]:

$$10^3 C_r = 1,2 \cdot 10^{-3} (10 F_n - 0,8)^4 (10 C_p - 3,3)^2 (10^3 C_v + 4)$$ \hspace{1cm} (6)+0,05 \cdot 10^3 C_v + 0,2 + 0,17 (\frac{B}{T} - 2,5),$$

where $F_n$ is Froude number, $C_p$ prismatic coefficient, $C_v$ displacement-length ratio, $B$ beam and $T$ draught. Bulbous bow factor [31] is used for supplementing wave factor formulation

$$10^3 \Delta C_{bl} = -0,2 - 1,1 F_n,$$ \hspace{1cm} (7)

and roughness resistance factor brings effect of surface roughness to hydrodynamic coefficient [32]:

$$10^3 \Delta C_f = 0,044 (\frac{k_s}{L_w t} - \frac{10}{\sqrt{R_n}}) + 0,000125.$$ \hspace{1cm} (8)

In this case, biofouling is understood physically for changes to immersed hull surface roughness giving this factor a significant role and scaling coefficient must be used along with this factor. Steering resistance is minimized by observing ships cruising in straightforward legs in good weather conditions. While environmental conditions remain comparable, the vessel is operated at constant speed and the ratio of computed hydrodynamic drag and thrust power remains in equal level. As wind conditions become rougher (or other changes occur, such as currents), this is reflected as difference in this computed efficiency. Comparing this to the data obtained from the coastal weather stations and current estimations, conditions prevailing in the area can be estimated reliably considering, as in this study, that the lanes are relatively close to the coast.
2. RESULTS

This study investigates two ship voyages, which took place in the Baltic Sea: one voyage from Germany to Finland on 24th July 2018 and second voyage from Finland to Germany on 28th...29th July 2018.

The data recorded onboard during the first voyage (24th July) contains a 12 hour set obtained during 11:00...23:00 UTC. On that period, the weather conditions were quite calm over the Baltic Sea region. The average wind speeds in the coastal weather stations were as follows: In Skillinge, the average wind speed was 3.8 m/s, and recorded wind range 1,0...6,6 m/s. In Utklippan, the corresponding values were 5.0 m/s and 2,2...7,5 m/s. In Ölands Södra Udde 3.8 m/s (1,6...5,5 m/s), in Hoburg 1,9 m/s (0,7...3,6 m/s), in Östergarnsholm 3,1 m/s (2,2...3,9 m/s) and in Gotska Sandön 2,2 m/s (0,7...2,8 m/s). On the second voyage, in 28th...29th July, the corresponding values were 2,0 m/s (3,4...5,6 m/s) in Gotska Sandön, 6,6 m/s (4,8...7,7 m/s) in Östergarnsholm, 3,7 m/s (1,2...4,9 m/s) in Hoburg, 2,2 m/s (1,2...4,9 m/s) in Ölands Södra Udde, 2,3 m/s (0,5...4,7 m/s) in Utklippan and 2,0 m/s (1,0...4,2 m/s) in Skillinge. Wind directions varied over all cardinal points. This is common when the wind conditions are calm.

During the studied voyages, the cargo and trimming conditions were quite comparable: On 24th July declared DWT was 7074 tons and 28th...29th July 7037 tons with a bow trim of 0,4...0,5 meters. The immersed hull was cleaned on the 25th July and the previous cleaning had been carried out on the 25th June. This means that, at the time of the first leg, the biofouling had accumulated about a month and the second leg was sailed with a freshly cleaned hull. During the intervening days, the ship had been in regular traffic but weather conditions had been windier and the loading condition varied between voyages.

Because the wind conditions have a significant impact on the ship dynamics and therefore play an essential mixer in the system, the analysis is based only on data sets, during which wind conditions were discretized in class 1,00-2,34 m/s (wind conditions are discretized in 5 classes between range of 1,00-7,7 m/s). Increased accuracy is reached by choosing discretized speed classes of 22,17-22,25, 22,25-22,33 and 22,33-22,41 knots. With the selected ranges of the speed, the data is distributed between the voyages in the following proportions: 55,02/44,98%, 54,53/45,47% and 36,53/63,47%, correspondingly. Classified curves of shaft power are illustrated in figures 2...4.
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Classificated curves of shaft power are illustrated in figures 2…4.

Figure 3. Shaft power (speed range of 22,25-22,33 knots).

Shift of emphasis can be noticed from the shaft power curves but doing conclusions based on visual observing is challenging. Expected values of the functions are giving a numerical evaluation of this issue. In the speed range of 22,17-22,25 knots the expected values are 19 879 kW for cleaned hull curve and 20 511 kW for a biofouled case. This leads to a 3,18% difference. In the range of 22,25-22,33 knots, the corresponding values are 19 785 kW, 20 411 kW and 3,16% and in the range of 22,33-22,41 knots 19 880 kW and 20 173 kW, where the difference is 1,47%. Although the speed class is already included in the power curves, more certainty is obtained by observing the energy consumption of the ship per ton-miles. For the corresponding speed classes, the energy consumption curves are illustrated in figures 5…7.
Figure 5. Energy consumption (speed range of 22.17-22.25 knots).

Figure 6. Energy consumption (speed range of 22.25-22.33 knots).

Figure 7. Energy consumption (speed range of 22.33-22.41 knots).
Trends of the energy consumption curves follow power curves, although the difference is slightly lesser. The energy consumption per ton-miles in the speed range of 22.17-22.25 knots is 0.1270 kWh/(DWT·NM) for cleaned and 0.1303 kWh/(DWT·NM) for biofouled hull and the difference is 2.57%. In the range of 22.25-22.33 knots, the values are 0.1260 kWh/(DWT·NM), 0.1295 kWh/(DWT·NM) and 2.72%. In the range of 22.33-22.41 knots, the corresponding values are 0.1263 kWh/(DWT·NM), 0.1274 kWh/(DWT·NM) and 0.89%. In figures 8...10, the curves of theoretical efficiency are illustrated in the same speed classes as earlier.

**Figure 8. Theoretical efficiency (speed range of 22.17-22.25 knots).**

**Figure 9. Theoretical efficiency (speed range of 22.25-22.33 knots).**
Computational efficiency curves expected values are, for the first speed range (figure 8), 58.47% and 56.70%, with the difference of -3.03%. Respectively, in the second case (figure 9), values are 59.65% and 57.78% including a difference of -3.13%. In the third case (figure 10), the values are 59.87% and 59.20%, and the difference is -1.11%. The negative change in computational efficiency follows the increasing scale of shaft power and energy consumption.

3. CONCLUSIONS

Methods based on mass data analysis provide statistical approach for analysing complex problems. Chow-Liu tree augmented Naïve Bayes is computationally efficient and reliable framework for analysing mass data problems especially in cases that include incomplete information. This method has been used successfully in such a problems and, based on the research work carried out in the “COMPLETE” project, it seems that the method is applicable for analysing the effect of the biofouling on ship dynamics as well. The results presented in this paper show that there is noticeable change (about 3%) in shaft power data when sailing in the same speed range. This is also confirmed by the similar changes in energy consumption and computational efficiency curves. The magnitude of the change follows the expected rate of the biofouling effect on ship resistances using monthly cleaning interval during the summer time in the Baltic Sea region. However, results shown in this paper require more analysis in order to increase their reliability. “COMPLETE” project offers good opportunities to reach this aim as the mass data has been collected during long-term periods.

References:

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CONCLUSIONS

Methods based on mass data analysis provide statistical approach for analysing complex problems. Chow


SESSION 5. MARITIME BUSINESS AND LOGISTICS
A DEFI-BASED MODEL FOR MARITIME TRADE FINANCE

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Abstract.

While trade finance has been recognized as a key element in international trade, there is a persistent gap between supply and demand. On the other hand, distributed ledger technology (DLT) has given birth to the decentralised finance (DeFi) phenomenon, promising to revolutionize banking and the whole financial sector. This paper enquires whether a DeFi-based business model could address the trade finance gap problematic. To this end, it presents a sketch of a DeFi trade finance business model, showing how it could address the reasons behind the trade finance gap, while at the same time developing a broader meaning of the DeFi concept itself.

Keywords:

Trade finance, letter of credit, decentralised finance, distributed ledger technology, business model innovation.

INTRODUCTION

Trade finance—and in particular its traditional instrument, the letter of credit (LC)—aims to protect exporters and importers alike from the risk of non-completion. Without an LC, many international maritime trade transactions would be too risky to undertake. Lack of access to trade finance, therefore, translates into lost trade opportunities (Ahn et al., 2011).

The importance of trade finance for international maritime trade and economic development has gained increased attention in the last few years. International organizations have observed once and again the persistence of a huge gap between supply and demand of trade finance—currently estimated at US$ 1.5 trillion—(ADB, 2017; WTO, 2016), with negative consequences for trade, most particularly for small and medium enterprises (SMEs), and for emerging and frontier economies (AfDB, 2017). Causes behind this huge trade finance gap are various and complex. However, the main reasons usually mentioned by practitioners are the negative impact of regulations, insufficient liquidity in local banks, high transaction costs/low profitability, and lack of
trust issues (e.g. LC applicant insufficient creditworthiness, low country reputation, difficult contract enforcement, etc.) (ICC, 2017).

Among the proposed answers to this problem are changes in banking regulations and compliance (making them risk based), and expansion of credit supply through multilateral banks and export credit agencies (ECA) (ICC, 2018). At the same time, during the current decade, there has been a significant surge (and success) of fintech firms. Moreover, in the last few years, blockchain-based decentralised finance (DeFi) has attracted attention as a non-conventional way of coping with financial needs.

Against this background it is thus valid to ask whether DeFi could be an alternative solution for the trade finance gap (WEF, 2018); and if so, how could such a solution be designed and implemented. This research study aims to provide a preliminary answer to this question by sketching an innovative, DeFi-based business model for trade finance.

Section 2 presents the theoretical background on the trade finance problematic, as well as on the topic of financial intermediation and business model innovation. Section 3 explains the research methodology. Section 4 discusses decentralised finance, offering a new conceptual approach. Section 5 presents a preliminary sketch of a business model for a decentralised, DLT-based trade finance system. Section 6 offers an ex-ante, preliminary evaluation of the model. Finally, Section 6 presents conclusions, limitations and suggestions for future research.

1. THEORETICAL BACKGROUND

The trade finance gap problem and its potential answer in the form of DeFi can be approached from diverse theoretical perspectives: management science, legal studies, micro and macroeconomy, etc. This reflects its complex nature, with causes and consequences spanning several areas. In this section, we shall begin by referring to the reasons behind the gap as exposed in policy discussions.

Afterwards, the problematic and its likely solution will be analysed against the conceptual background provided by the theories of financial intermediation and of business model innovation. In the process, we shall also approach the novel concept of decentralised finance (DeFi) from a new perspective.

1.1. CAUSES OF THE TRADE FINANCE GAP

Several causes for the persisting trade finance gap has been observed in policy discussions. These causes may be divided into supply-related (affecting the capacity of banks to provide capital for transactions) or demand-related (referred to the importing and exporting firms that transact with each other). Table 1 classifies the causes along this division criteria. In some cases, however, the same cause can be considered both as supply and demand related. Each cause is treated under the light of policy discussions and academic literature.
Figure 1. Classification of trade finance gap causes.

<table>
<thead>
<tr>
<th>Trade finance gap causes</th>
<th>Supply-related</th>
<th>Demand-related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased capital ratio requirements in banking regulations (e.g.: Basel III)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Regulatory due-diligence requirements (e.g. KYC)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Minimal non-bank capital</td>
<td></td>
<td>X</td>
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<tr>
<td>High processing costs</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Document verification problems</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Insufficient knowledge about trade finance</td>
<td></td>
<td>X</td>
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<tr>
<td>Firm related high level of risk</td>
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<td>X</td>
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<tr>
<td>Country related high level of risk</td>
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<td>Insufficient size of transactions</td>
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1.1.1. SUPPLY-RELATED CAUSES

In the wake of the 2008/9 financial crisis, and its negative repercussions in the following years (e.g.: the sovereign debt crisis in some European countries), financial regulations were stiffened (Walker, 2011; Etürk, 2016). Among several areas covered by new banking regulations, two main ones stand: capital requirements and due-diligence procedures.

The Dodd-Frank Act in US, the Regulation (EU) Nº 575/2013 in the EU, and the Third Basel Accord (Basel III) on a global stage, increased the capital requirements for banks. These measures, aimed at lowering excessive risk taking by financial institutions in the previous years, had the negative effect of lowering profitability and decreasing liquidity for trade finance, as observed repeatedly in policy discussions (AfDB, 2017; ICC, 2017, 2018).

Consequences of capital requirements regulation on the level of financial supply, have been extensively studied in the financial literature, particularly in the context of discussions about the relationship between banks liquidity and their risk taking (Adrian and Shin, 2010; Horvath et al., 2014; Berger et al., 2016; Kahn et al., 2017). More recently, a couple of ECB workpapers analyse the short-term effects of capital requirements on credit supply: Mendicino et al. (2019) observe that, in the short run, rising capital requirements may have contractionary effects on credit supply and economic activity (what they name “transitional costs”), even if they generate positive effects in the long run by reducing systemic risk taking. Likewise, Behn et al. (2019) find a material impact of capital requirements on the supply of loans, though the effect is moderated by bank’s initial balance sheets, with banks that are closer to the minimum
capital requirements been more likely to reduce lending. These constraining effects of higher capital requirements and limited bank liquidity have also been pointed out in the specific case of trade finance (Ahn et al., 2011; Auboin, 2011; Auboin and Blengini, 2014)

Due-diligence regulatory requirements, particularly those related to “Know your customer” (KYC) and anti-money laundering (AML) have also been correlated with constraining credit supply, based on results from banks’ surveys (Auboin and Di Caprio, 2017; ICC, 2017, 2018). A necessary balancing between financial integrity and financial inclusion, with a risk-based approach to KYC and AML has thus been proposed (Gelb, 2016; ICC, 2017, 2018).

Other supply-related causes for the trade finance bank has been mostly pointed out in policy reports (AfDB, 2017; ADB, 2017; ICC, 2017, 2018; WTO, 2016). These include, an insufficient involvement of non-bank investors in the secondary market; high-processing costs, especially for document verification, due to the still mostly paper-based nature of letters of credit; and insufficient knowledge about trade finance by local banks in emerging and frontier economies.

High processing costs are related to both supply-side and demand-side considerations for trade finance. For banks, higher processing costs mean lower profitability of trade finance instruments overall, which makes them to limit their credit supply in favour of other, less complex financial assets.

1.1.2. DEMAND-RELATED CAUSES

Demand-related causes for the trade finance gap are those that originate in the importing and exporting firms that require trade finance for their transactions. These can be taken as the answer to the following two, more specific questions: 1) what motivates the rejection of letter of credit applications? And, 2) what limits importers/expo rts to seek trade finance in the first place?

Di Caprio and Yao (2017) observe three types of drivers for trade finance rejections: country-related, firm-related, and bank-related. The country-related reasons include high political and economic risk, underdeveloped finance system, and low contract enforceability. Niepmann and Schmidt-Eisenlohr (2014, 2017) find that in countries with higher risk and lower contract enforceability, letters of credit are used more than documentary collections.

Bank-related rejections are those that take place among bank’s themselves, more specifically, between the exporter’s (confirming) bank and the importer’s (issuing) bank. This aspect is closely related with country risks and is manifest in the ongoing decrease of correspondent bank relationships, as global banks move to lower risk economies (Di Caprio and Yao, 2017; ICC, 2017). This phenomenon, admittedly, is more related to the supply-side of trade finance, but it is grounded in the economic environment where the importing firm is located.

Firm-related reasons for trade finance rejection are mainly due to insufficient collateral and creditworthiness issues, reflecting information asymmetries that limit credit availability (Stiglitz and Weiss, 1981). This affects predominantly small and medium
enterprises (SME), for which is then increasingly difficult to join global supply chain networks.

Besides actual rejections, the demand-side of the trade finance gap is also affected by the high processing costs of instruments like letters of credits (LC), which include a fixed cost component for document handling and screening. The practical implication is that LCs become economically viable only for transactions that surpass certain size threshold (Niepmann and Schmidt-Eisenlohr, 2014). This, again, primarily affects SMEs, which on average engage in lower size transactions than large corporations (WTO, 2016).

1.2. FINANCIAL INTERMEDIATION

The traditional role of banks is to act as financial intermediaries, taking deposits from individuals (households) and channelling them to economic agents requiring capital (firms). This function has been justified by a theory of financial intermediation based on transaction costs (Scholes et al., 1976), asymmetry of information (Brealey et al., 1977; Andolfatto and Nosal, 2009), risk management and participation costs (Allen and Santomero, 1998, 2001).

This traditional role, however, has undergone important changes in the last three decades. First, as observed by Allen and Santomero (1998), banks have concentrated in risk management activities, and the decrease for their clients of what the authors denominate “participation costs”, i.e. the cost of ‘learning how the market works, the distribution of asset returns and how to monitor changes through time’ (p. 1481). In other words, the main value adding role performed by banks has not been as financial buffers between depositors and borrowers, but as risk managers and financial knowledge providers.

Technological changes have also significantly affected the role performed by banks. During the last two decades, with the surge of electronic marketplaces, a disintermediation process has taken place (Nellis et al., 2000; Chircu and Kauffman, 2001; Pati and Shome, 2006; Lima and Soares de Pinho, 2008), with some authors describing an intermediation/disintermediation/reintermediation cycle (Chircu and Kauffman, 1999, 2000), where some traditional intermediaries, after being disenfranchised as a consequence of technological innovations, have found new ways to compete by leveraging these innovations. Financial disintermediation has been noticed in several fields, notably P2P lending (Bruett, 2007; Berger and Gleisner, 2009) and virtual currencies (Pflaum and Hateley, 2014).

Following the “functional perspective” of the financial system (Merton, 1995; Allen and Santomero, 1998), these trends could be understood as a sort of financial intermediation reengineering. The same underlying functions are performed in different ways and by different players as technology and economic forces evolve, generating new business models.

1.3. BUSINESS MODEL INNOVATION

During the last decade, business model innovation has been defined and explained by different (and competing) paradigms and schools (Gassmann et al., 2016). One of them, the Activity System school (aka IESE/Wharton school), defines a business model as a set of activities, resources and capabilities (held within the firm or across its boundaries), that allow a firm to create value and appropriate a share of it (Zott and Amit, 2007, 2010). Therefore, a modification in the distribution of these activities, resources and capabilities
aimed to generate and appropriate economic value, would traduce into business model innovation (BMI).

From a different perspective, the Recombination school (aka St. Gallen school) understands a business model as a “recombination of patterns” for answering 4 key questions about a business: who is the customer? what is the supplied value? how is this value created and distributed? and why is the business profitable? (Gassmann et al., 2016). One of the core tenets of this school is that most of business models are built out of repetitive patterns, whose recombination amounts to BMI (Frankenberger et al., 2013). BMI should be, therefore, a problem-solving undertaking where a business uses existing knowledge and technologies to generate and distribute value in innovative ways.

Delving into the afore described theoretical background, this paper has two main research objectives. First, to discuss and understand the concept of decentralised finance under the framework provided by the concepts of financial intermediation and business model innovation. And second, to sketch a model for a decentralised finance system that could provide a solution, if only partial, to the trade finance gap problematic. These objectives will be dealt with in sections 4 and 5, respectively. Previously, however, the research methodology is discussed in the following section.

2. RESEARCH METHODOLOGY

The present study follows the Design Science Research (DSR) paradigm, frequently used in the Information Systems discipline (March and Smith, 1995; Hevner et al., 2004). The goal of DSR is twofold: solving a practical problem and generating theory, both through the creation of an IT artifact (Beck et al., 2013).

The IT artifact itself can be a construct, model, method or instantiation, and its creation follows two general stages: design/building and evaluation (March and Smith, 1995; Hevner et al., 2004). Though traditional DSR suggests a sequenced procedure (first design/build, then evaluate), recent literature have questioned this structure as too rigid. It is observed that evaluation can be parallel and intermingled with the design stage (Beck et al., 2013; Venable et al., 2016), as well as that several design/evaluation iterations should be performed as the artifact is developed.

DSR begins by identifying a problem to be solved: in this case, the trade finance gap. A potential answer to this problem (among many) is aimed at through the development of a model (a business model). The model is sketched in line with the decentralized finance paradigm, closely related to distributed ledger technology (blockchain).

The second general stage of DSR is the evaluation of the proposed artifact. The evaluation needs to cover two aspects, which correspond to the twofold goal of DSR: whether the artifact is useful in addressing the perceived problem, and whether the creation of the artifact generates new knowledge.

A full evaluation of an artifact should include its instantiation, i.e. the functioning artifact operating in the real world. For the research here undertaken, a full evaluation would imply an assessment on whether an instantiation of the proposed model effectively
addresses the reasons behind the trade finance gap. In other words, a full DSR evaluation would require for an actual artifact to be already in the market.

However, as literature on DSR has observed, the evaluation of the artifact is conducted through several iterations, which cover not only its final instantiation, but also its preliminary design/blueprint in terms of models. In this sense, a distinction is made between *ex-ante* and *ex-post* evaluations (Sonnenberg and Vom Brocke, 2012; Venable *et al.*, 2016). *Ex-ante* evaluations are made over the artifact’s model before it is instantiated.

Given that the objective of this paper is to design and propose a new business model for trade finance, the assessment to be presented in Section 6 constitutes an *ex-ante* evaluation of the corresponding blueprint. It represents the first step in the DSR which should be completed when an actual instantiation of the model is developed and introduced in the market (as a new system, or even as a startup). At that final stage, an *ex-post* evaluation can be conducted.

### 3. WHAT IS DECENTRALISED FINANCE (DEFI)?

The term “decentralised finance” has been used with differing meanings in academic and policy discussions. It has been associated in the past with the concept of fiscal decentralization or “fiscal federalism” (Oates, 1994; Wibbels and Rodden, 2006), as well as with the spatial decentralisation of financial markets and how this might influence flows of capital to SMEs (Klagge and Martin, 2005). In more recent years, however, the expression is being used in relation to crypto-currencies, and even more specifically with the so-called DApps of the Ethereum blockchain platform. Most of the uses of the expression, including its associated abbreviation (DeFi) are to be found in blockchain related websites like *Cointelegraph*, online publishing platforms like *Medium*, or initial coin offering (ICO) whitepapers. Its use in academic papers, however, is almost non-existent, something that reflects the novelty of the topic.

Without denying the clear relationship between what is referred as “DeFi” and blockchain technology-based systems, we consider that this use of the term is too narrow. Correspondingly, in this section we discuss 4 alternative (but complementary) uses: DeFi as *disintermediation*, as *decreased concentration*, as *unbundling*, and as *alternative* finance.

#### 3.1. DEFI AS FINANCIAL DISINTERMEDIATION

One of the virtues for which Bitcoin and blockchain have been hailed is that they would allow individuals to transact with each other without recurring to banks. Some of these discussions are ideologically dressed in anarchic or libertarian colours, where banks (especially central banks) are at the root of all evils in the economy and society (Hayes, 2018; Schmid, 2019). In more concrete terms, it is observed that one of the virtues of Bitcoin and distributed ledger technology (DLT) is that it allows for considerably faster processing of payments, clearance and settlement: a $T+15$’ system instead of the annoying $T+2$ or $T+3$ —the latter of which in any case, as Lipton (2018) observes, has a series of practical advantages.
Besides payments, other financial functions traditionally performed by banks are being disintermediated (with or without the technological help of DLT): loans (P2P lending systems), and risk management (AI-powered credit scoring). In other words, some of the factors behind the justification for banking intermediation (asymmetries of information, transaction costs, risk management, participation costs) (Allen and Santomero, 1998), are being coped with through technological and business model innovation. This allows for the performance of those functions by entities different than banks or in a purely P2P basis. This disintermediation element is present in DeFi, understood in a more encompassing way than simply as blockchain-based finance.

3.2. DEFI AS DECREASED CONCENTRATION IN THE FINANCIAL SYSTEM

As mentioned above, the term decentralized finance has been used to refer to capital markets that are geographically less concentrated (Germany) than others (UK) (Klagge and Martin, 2005). This level of spatial concentration in finance has its institutional, monetary and infrastructure counterparts. A financial sector can be more or less institutionally concentrated (trade finance, for instance, is very highly concentrated: according to the ICC (2018), 90% of trade finance in the world, by transaction value, is provided by only 13 banks). Money creation is more or less concentrated between central banks and commercial banks (by virtue of fractional banking) in the monetary circuit (Lipton and Pentland, 2018). Financial ledgers are controlled by banks and central banks; they are purportedly being democratised by Bitcoin, where the ledger is being controlled by peer-nodes (in reality, there is a big concentration among a few Chinese mining pools) (Lipton, 2018; Cong et al., 2019).

DeFi is therefore to be also understood as a process of decreasing spatial, institutional, monetary or infrastructure concentration. Bitcoin would be a good example of decreased concentration in the spatial (access to Bitcoin has mostly no geographic limits), institutional (digital exchanges trading it have swarmed everywhere), and infrastructure senses. It is far less clear whether, with a few mining pools driving the increase in supply, Bitcoin is an example of monetary de-concentration.

3.3. DEFI AS UNBUNDLING OF FINANCIAL FUNCTIONS

According to the above-mentioned functional perspective, over long periods of time, financial functions have been more stable than financial institutions: ‘Institutions have come and gone, evolved or changed, but functional needs persist while packaged differently and delivered in substantially different ways’ (Allen and Santomero, 1998: 1466). Traditionally, banks have been the institutions that have performed these functions, as a one-stop place for most of financial services.

The Fintech revolution that has been taking place during the last decade (Gomber et al., 2018) has brought the “unbundling” of financial services. This business phenomenon is closely related with the disintermediation of some of these functions, but it is not identical with the latter. Disintermediation refers to coping with problems related with financial functions (like transaction costs or asymmetries of information) without a bank or other intermediary. Unbundling refers to the provision of those functions by specialized players (fintech firms).

Rather than relying in a single a bank as the unique solution for their financial needs, individuals and firms are increasingly picking up different services (payments, micro-loans, mortgages, investment) from separate fintech companies or so-called “shadow”
banks (Lee and Shin, 2018). The unbundling of functions is thus another element in our broad DeFi concept.

3.4. DEFI AS ALTERNATIVE FINANCE

One of the most salient phenomena brought about by blockchain technology, most particularly by the Ethereum platform smart contract-based ERC-20 digital tokens, is that of “initial coin offerings”, better known simply as ICOs (Tasca et al., 2018). During the second-half of 2017 and until the middle of 2018, all kind of startup projects, claiming to develop the next blockchain disruptive use case, tried to raise capital by selling so-called “utility” or “use” tokens, under a sort of pre-sale of services business model. However, by the second half of 2018 the amount of raised capital had substantially decreased, a trend that continued throughout 2019.

Despite the overwhelming number of failed ICOs (many of them outright scams or Ponzi schemes), token-based alternative financing has been recognized as a potentially powerful tool that could lead to a new economic paradigm, from centralized platforms and business models to decentralised ones (Tasca, 2019). Apart from its current use in startup funding, token-based issuing events (now re-christened IEOs: “initial exchange offerings”, or STOs “security token offerings”), might work as well as tools for deploying secondary markets for securities. In this line, European jurisdictions like Switzerland and Malta have already created legal classifications of tokens that include classes that would clearly fall under the well-known Howey test for identifying securities. ICOs, IEOs and STOs can be understood as tools for alternative finance, defined as ways of financing different than traditional bank and market finance channels (Allen et al., 2012). This characteristic of being capable to provide an alternative source of finance is the last element in our DeFi conceptualization.

The former elements are meant as badges to identify instances of decentralised finance, and do not have to be all present for a financial system, method or tool to be considered as such. The purpose is not to offer a complete and clear definition of DeFi. Rather, the objective in highlighting these elements is to show several aspects where DeFi can be more effective and efficient than traditional finance in addressing the trade finance gap and in coping with financial needs, particularly those of SMEs in emerging and frontier economies.

4. A DECENTRALISED TRADE FINANCE MODEL DESIGN

In this section we present a basic design for a decentralised trade finance model. Our objective is not to present a detailed and formalised model, but rather a general sketch that could answer the question: “how would a DeFi trade finance model look like?”. The section is divided into two sub-sections, describing first the design pillars behind the model, and then sketching the model itself.

4.1. DESIGN PILLARS

4.1.1. BUSINESS-PROCESS-AS-A-SERVICE (BPaaS)

The concept of Business-Process-as-a-Service (BPaaS) has been coined in the context of cloud services (Wang et al., 2010), being an extension of the traditional cloud services stack of Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), Software-as-a-

An important feature of the BPaaS model is its firm boundaries-crossing structure. One the one hand, BPaaS is not simply an additional layer over the traditional cloud stack, entirely allocated to the cloud provider. Rather, it spans the provider, the consumer and third parties in between (Barton and Seel, 2014). On the other hand, BPaaS can be configured by mixing services from different providers into a single business process structure, which is in turn offered to clients by the firm as its own service (Bourne et al., 2015).

4.1.2. DISTRIBUTED LEDGER TECHNOLOGY (DLT)

Few technologies, if any, have generated more attention than distributed ledger technology (blockchain) in the last years. Without descending into technological details, DLT provides a distributed database or ledger, where any event that validly modifies the state of a system can be registered and, after being so registered, cannot be modified. For an event to modify the system in a valid way, the event has to be congruent with the last state of the system.

DLT provides the infrastructure pillar for a decentralised finance model, as valid transactions performed by any economic player taking part in a business process, would be reflected in an accurate rendition of that process’ state. For financial instruments that carry certain complexity, like a letter of credit (LC), DLT can provide the infrastructure for a system where all relevant parties would have an accurate representation of the current state of the LC life cycle.

4.1.3. TOKENIZED SECURITIZATION

The final pillar for the proposed model is given by a method for sourcing capital: issuing securities as digital tokens. In particular, the R3 blockchain platform Corda (Brown, 2017) is proposed to function as an infrastructure over which a secondary market could be developed. The choice of Corda over other blockchain platforms, like Ethereum or Fabric, is due to its adequacy and higher potential of becoming a standard for financial systems. It is significant, in this sense, that the SIX Group, the Swiss Stock Exchange operator, is developing the announced SIX Digital Exchange using Corda as the blockchain platform (Allison, 2019).

Figure 1 shows a basic depiction of the formerly described pillars, with their respective DeFi function for the model.
4.2. THE BUSINESS MODEL

In order to present the model, we shall cover in turn the DeFi elements reflected in each pillar, showing how the financial function is provided and contrasting it with the traditional business model for trade finance.

4.2.1. THE DISINTERMEDIATION ELEMENT

International trade can be described in general terms as three inter-dependent flows: physical flows (merchandise/commodities), information flows (EDI, XML, documents), and financial flows (letters of credit, documentary collections, cash advances, etc.). Trade finance instruments like LCs can be described, more specifically, as an inter-dependent flow of documents and money.

Figure 2, taken from Malaket (2016), depicts the traditional process flow for a documentary letter of credit.

The system works in a series of pair-based relationships: importer/exporter, importer/issuing bank, issuing bank/advising (confirming) bank, advising (confirming) bank/exporter. For each of these relationships, information (including documents) and money is exchanged. The validation and authentication of documents is done through the intermediation of the issuing bank and the advising (which can also be confirming) bank: the advising bank has to trust the issuing bank, and the exporter has to trust the advising bank as to the authenticity of the LC.
Figure 3 shows the same documentary LC workflow, processed through a DLT platform, in this case, R3’s Corda.

**Figure 4. Documentary letter of credit workflow with DLT-based solution.**

DLT allows for this trust to be disintermediated and deposited in the platform itself. From the very first step of applying for an LC, the importer might use a frontend application where relevant parameters (port of load, port of destination, sale price, etc.) are stored in the platform. Documents themselves are not to be stored in the platform, but rather their relevant parameters (represented in the hashed lines in figure 4). This way, several of the authentication and verification functions performed by banks, that address the information asymmetry problem, are delegated (disintermediated) to the DLT platform.

**4.2.2. THE ALTERNATIVE FINANCE ELEMENT**

In the traditional model for LCs, the delivery vs payment (DvP) dilemma is solved by bank guaranteeing payment against a compliant presentation of documents. The system works through a forward relay of information and documents, and a backwards relay interchange of documents for money, as depicted in figure 4 (dashed lines represent information flows, dotted lines represent financial flows).

**Figure 5. Forward and backwards relays in documentary letter of credit.**

In the forward relay, the importer applies for an LC; the issuing bank transmits the LC to the advising/confirming bank, which in turn confirms the authenticity of the LC (advises it) to the exporter. Then, in the backwards relay, the exporter presents relevant documents (BL, BE, and other documents like commercial invoice, certificate of origin, etc.) to the advising/confirming bank and receives payment; the advising/confirming bank forwards
the documents to the issuing bank and gets reimbursed; and the issuing bank delivers the
documents to the importer against reimbursement. The exporter gets paid by the
advising/confirming bank either with funds from the bank itself, or by funds obtained
through the negotiation of the LC in the secondary market.

Figure 5 depicts a modified version of the system (excluding the forward relay), showing
how alternative finance comes into place.

**Figure 6. Alternative finance system.**

In the alternative finance system, the backwards relay interchange of documents for
money works in a similar way. The novel element is provided by the tokenization of the
LC, in order to expand its tradability in the secondary market. In other words, the LC
becomes a digital asset with embedded intrinsic value (Tasca, 2019), in this case
represented by the right to collect principal and interest from the importer, behaving very
much like a bond.

LCs can be securitized either as single units or by fractioning them in sub-units, much
like mortgage-backed securities (MBS). Each unit or sub-unit would be represented, as a
digital asset, by a tradable token. For most LCs, securitization will require their slicing
into smaller sub-units, given that the average value of an LC is considerably high.

**4.2.3. THE UNBUNDLING ELEMENT**

As mentioned above, BPaaS has a firm boundaries-crossing structure that can be
configured by mixing services from different firms into a single value proposition offered
to the clients. For trade finance, BPaaS allows to unbundle financial services currently
concentrated in the banks (e.g.: document verification, creditworthiness assessment,
negotiation in the secondary market, etc.), such that these would be provided by different
firms, achieving coordination through a DLT platform.

Figure 6 shows a possible configuration of this unbundling, where issuing and
advising/confirming banks outsource certain services to specialized entities. Document
digitization and verification could be done by a frontend application provider. Risk
management could be provided by a global bank with extensive knowledge in trade
finance. And the source of capital would be digital exchanges, setting and monitoring
secondary markets.

**Figure 7. Configuration of unbundled services for trade finance.**
In this configuration, issuing banks retain their relationship with importers, and advising/confirming banks with exporters. But several services needed for the effective execution of the LC workflow are outsourced to more efficient entities.

5. EVALUATION

5.1. PRELIMINARY CONSIDERATIONS

Gregor and Hevner (2013) present a framework for evaluating DSR projects, composed of three maturity levels, as shown on table 2 (reproduced from their research essay).

Figure 8. Design Science Research Contribution Types.

<table>
<thead>
<tr>
<th>Contribution Types</th>
<th>Example Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>More abstract, complete, and mature knowledge</td>
<td>Level 3. Well-developed design theory about embedded phenomena</td>
</tr>
<tr>
<td>More specific, limited, and less mature knowledge</td>
<td>Level 2. Nascent design theory—knowledge as operational principles/architecture</td>
</tr>
<tr>
<td></td>
<td>Level 1. Situated implementation of artifact</td>
</tr>
</tbody>
</table>

The contribution intended by this paper is situated in Level 2 of the framework: it presents principles (decentralisation elements) and architecture (pillars) for developing a decentralised trade finance business model. The artifact, at this stage, consists in the sketch model presented in Section 5, plus the discussion about a theoretical construct (decentralised finance) contained in Section 4.

This ex-ante evaluation will cover two areas: practical assessment and theoretical contribution.

5.2. PRACTICAL ASSESSMENT

The practical assessment of the artifact, represented by the business model, amounts to answering a simple question: is it useful? A question that in this case can be rendered more explicitly as: does the model addresses the problems behind the trade finance gap?
Following the classification in Section 2, the usefulness of the model in addressing supply-related problems and demand-related problems is considered in turn.

5.2.1. ADDRESSING SUPPLY-RELATED PROBLEMS

The Basel III capital requirements and minimal non-bank capital investments, while having different origins (regulatory and economic), generate an important problem behind the trade finance gap: insufficient liquidity. This problem is addressed by the DeFi trade finance model through the alternative finance element: the development of a tokenized/securitized secondary market.

KYC/AML requirements, being related to regulatory issues, are not addressed by the model. High-processing costs and document verification problems are closely related. The still paper-based nature of the whole process has been identified as one key reason behind high processing costs. Most document verification issues arise out of archaic procedures and tasks. The digital transformation enhanced by DLT, in particular by the immutable registration of relevant parameters in a distributed database, would significantly reduce incongruencies between documents (LCs, BLs and BEs), which are the source of many delays and additional costs.

This increased efficiency provided by DLT would cover the whole lifecycle of the LC, from its issuance to its securitization, including execution, clearing and settlement of securities, as explained by Pinna and Ruttenberg (2016).

Finally, the unbundling of financial services would allow local banks who do not have sufficient knowledge about trade finance, to receive assistance from specialized providers in matters such as creditworthiness assessment and secondary market negotiation. Global banks who currently concentrate most of trade finance could provide creditworthiness assessments for LCs to be issued or confirmed by local banks in emerging and frontier markets, without taking part in the financing. This would decrease the institutional concentration of trade finance providers.

5.2.2. ADDRESSING DEMAND-RELATED PROBLEMS

High processing costs (partially caused by inefficient document verification procedures) increase SMEs’ transaction costs. In turn, this high transaction costs elevate the transaction-size threshold above which is economically viable to use an LC. All these problems would be addressed by DLT-based digital transformation, as already explained.

The insufficient knowledge about trade finance by importers and exporters can be similarly addressed through the unbundling principle. For instance, a specialized frontend application service could guide the importer in the process of applying for an LC, and the exporter for making a compliant presentation under UCP 600 rules.

Firm-related level of risk reflects an asymmetry of information problem. A DLT-based system would help SMEs with good track record to signal its creditworthiness more easily to banks with whom they do not have previous experience. Indeed, all the relevant information about previous LCs would be accurately and immutable registered in a distributed database.

Country-related level of risk is not addressed by the model.
Table 3 presents the problems, the way they are addressed by the model, and the corresponding DeFi element.

**Figure 9. Addressing trade finance gap problems with DeFi.**

<table>
<thead>
<tr>
<th>Trade finance gap causes</th>
<th>Addressed by</th>
<th>DeFi element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased capital ratio requirements in banking regulations (e.g.: Basel III)</td>
<td>Additional capital from investors in tokenized secondary market</td>
<td>Alternative finance</td>
</tr>
<tr>
<td>Regulatory due diligence requirements (e.g. KYC)</td>
<td>Not addressed by the model</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Minimal non-bank capital</td>
<td>Additional capital from investors in tokenized secondary market</td>
<td>Alternative finance</td>
</tr>
<tr>
<td>High processing costs</td>
<td>Digitalization of processes</td>
<td>Disintermediation</td>
</tr>
<tr>
<td>Document verification problems</td>
<td>Digitalization of processes</td>
<td>Disintermediation</td>
</tr>
<tr>
<td>Insufficient knowledge about trade finance by local banks and by importers or exporters</td>
<td>Financial services provided by specialized firms or global banks / Reduced participation costs</td>
<td>Unbundling / Decreased concentration</td>
</tr>
<tr>
<td>Firm related high level of risk</td>
<td>Reduced information asymmetries</td>
<td>Unbundling</td>
</tr>
<tr>
<td>Country related high level of risk</td>
<td>Not addressed by the model</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Insufficient size of transactions</td>
<td>Digitalization of processes</td>
<td>Disintermediation</td>
</tr>
</tbody>
</table>

5.3. THEORETICAL CONTRIBUTION
The theoretical contribution aimed at by this paper is twofold. On the one hand, it discusses the term theoretical construct of “decentralised finance”, identifying previous usages and its current narrow meaning under the “DeFi” abbreviation, while developing a broader meaning. This is done by making explicit several elements implicit in the notion of decentralization, namely: disintermediation, decreased concentration, unbundling and alternative finance.

On the other hand, the paper uses these elements in order to sketch a business model that addresses a real-life problem, in this case, the trade finance gap. This application looks to generate prescriptive knowledge or, following the theoretical taxonomy by Gregor (2006), theory for design and action.
6. CONCLUSION

This paper has addressed a practical problem, the trade finance gap extensively discussed in policy circles, by inquiring whether a solution could be found in decentralised finance (DeFi). To this end, it has presented a theoretical background, including the academic and policy treatment of the trade finance problem, as well as literature about the concepts of financial intermediation and business model innovation. Then, it has discussed the DeFi concept, offering a broader meaning, based on specific elements. These elements in turn have been used in the design of a DeFi business model that would address the trade finance gap. Finally, a preliminary evaluation of the model and the theoretical contribution has been offered.

Several limitations are present in this paper. First and foremost, it represents a preliminary stage in the DSR process, where only a model is presented: it does not include methods or an actual instantiation. Second, all the data presented is obtained from secondary sources, also due to the early stage of the research. Also, the discussion is limited to documentary letters of credit, leaving out several other important trade finance instruments like documentary collections (DC) or standby letters of credit (SLC).

This opens opportunities for future research. A separate DeFi business model for DCs or SLCs could be designed. Also, more detailed analysis of the application of DLT to specific business processes related to trade finance can be conducted. For example, how information gathered during the origination phase of an LC and registered as relevant parameters in a DLT platform, could be useful for securitization processes in the secondary market.

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TRACKING RADIOACTIVE MATERIALS IN SEA TRANSPORTATION
BY RFID TECHNOLOGY

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Abstract:

The demand for radioactive materials has been increasing over the last five decades, and therefore it is to be expected that the need for radioactive materials transportation shall also increase. The Radio Frequency and IDentification (RFID) technology has already made progress in this field and become the most widespread way to track and trace radioactive cargo. The easy installation, simple and fast data transfer from the sensor through RFID transponder, along with compactness and quality of the sensors provide a safe and easy way of using this technology in transport of the radioactive materials. A variety of sensors, such as temperature, radiation, speed, earthquake, (Differential) Global Positioning System (D)GPS, etc., are the key, but not the only one part of the complex system that is responsible for safe transportation of radioactive goods. A large number of parameters that must be monitored at the same time, as well as the simplicity of the system, are strengthened by using the appropriate RFID software. By means of this software, the operator has insight into the condition of the radioactive material inside the container without the risk of exposure to radiation, and without compromising the safety and security of the data exchange at any time. By using the latest-generation crypto tools, security has been guaranteed.

Keywords:
radioactive materials, sea transportation, tracking and tracing, RFID technology.

INTRODUCTION

Today nuclear power provides 10% of the world’s electricity. Due to the clime change, 80% of all electricity will need to be clean and low carbon by 2050 [1]. Therefore, nuclear capacity should be considerably increased in order to meet climate goals. Russia, India and China are currently leaders in expanding nuclear power production. For instance, China has nine reactors under construction now. Finland, United Arab Emirates, Belarus, Bangladesh and Turkey are also building new reactors. Currently, in total 450 nuclear power reactors operate worldwide.

Plans for increasing nuclear capacity are always connected with huge and high-risk investments. Small modular reactors make these plans more feasible and allow combining
nuclear power with renewables, i.e., sources of energy that are not depleted by use, such as water, wind or solar power. The environmental consciousness is generally rising and it becomes evident that energy need could not be satisfied in the future by sole use of coal or natural gas. Besides, for producing electrical power, nuclear energy is used for variety of research, industry, agriculture, and medicine purposes.

With increase of nuclear capacity worldwide, it is to be expected that the need for radioactive materials (RAM) transportation will increase. Thereby, sea transportation will undoubtedly play an important role in satisfying irradiated nuclear fuel, plutonium and radioactive waste transportation requirements in the upcoming period [2].

In this research article, we will be focused on literature review in the field of RAM transportation by means of sea, road and rail transport (Section 2). Particular emphasize will be given to tracking RAM cargo during its transportation or transshipment. An overview of the ARG-US project achievements, when it comes to tracking and tracing RAM in road and rail transportation, will be given (Section 3). After that, an attempt to conceive a similar model of RAM tracking in sea transportation will be done (Section 4). At the end, some conclusion remarks and directions for further research work in the field will be given (Section 5).

1. LITERATURE REVIEW

There is a scarcity of research articles on nuclear cargo transportation, which are available online. Below are presented some of the articles, which have been found after an extensive web search. Legislative framework of maritime transportation of irradiated nuclear fuel (INF), plutonium and radioactive wastes together with widely expressed concern that an accident may occur to a ship carrying such cargo has been studied in [2]. The same study reviews the legal issues associated with the right of emergency access to a foreign seaport by a ship transporting nuclear materials. It also considers whether seabed characteristics should be assessed in determining the routing of nuclear cargo ships, bearing in mind that ocean floor topography and sea water depth will be crucial in determining whether recovery of nuclear materials would be practicable in the event of sinking of a ship. The description of ship carrying nuclear cargo construction requirements has been given in [3]. This paper presents INF Code requirements due to the ship’s construction, fire safety measures, electrical power supply, cargo stowage and segregation, emergency planning and security measures. World Nuclear Transport Institute (WNTI) has published a fact sheet on the transport of nuclear fuel [4]. This study gives relevant data on the nuclear fuel cycle, front-end operations, fuel fabrication, reprocessing, transport packaging, sea transport, purpose-built vessels, etc. A model of response in the case of radioactive cargo transportation in Japan has been presented in [5]. The authors have given in this reference an overview of the tracking system for radioactive material transport including sensor unit, communication network, central monitoring center and sub-terminals, which provide trend viewer, abnormal situation detection, current situation and next step during the shipment. The authors of the references [6;7;8] have given description of applying Radio Frequency IDentification (RFID) technology in nuclear material management. They have provided prototype tag design and production, prototype application software including graphical user interface and preliminary test results in terms of read range, sensor performance, memory read/write, seal sensor, battery life, etc. It is worth to mention within the context that reference [9] gives a general insight in RFID technology and its applications. The authors of the reference [10] have dealt with mathematical modeling and simulations, based on special
tran-function theory, in estimating temperature of plutonium during its transportation. The authors of [11] have investigated efficiency of detectors for intercepting illicit trafficking of fissionable material in container cargo in maritime transportation. They have suggested tagged neutron inspection system in addition to container content X-ray scan, etc.

2. TRACKING RAM IN ROAD AND RAIL TRANSPORTATION

In 2008 Argonne National Laboratory (Chicago, Illinois, USA) Packaging Certification Program (PCP) team has developed RFID tracking and monitoring system for the management of RAM packages during storage and transportation [12]. This system, called ARG-US, is composed of appropriate hardware modification, application software, secured database, protected web access, and irradiation experimental measurements. The B fissile material drums (models 9975, 9979 and ES-3100) certified by US Department of Energy and US Nuclear Regulatory Commission have been used for testing the prototype. The demonstration of the system successfully integrated Global Positioning System (GPS) for vehicles and railway wagons positioning, including their RAM cargo, satellite and cellular General Radio Package Service (GPRS) wireless communications, the RFID tags attached to the RAM drums, and Geographic Information System (GIS) technology in geo-fencing purposes [13], etc. The RFID tags and GPS technology in combination with GIS enable dedicated software to trigger a response when a mobile device enters or leaves certain geographical area. The RFID in combination with GPS generate an alarm in the case of an incident with the RAM drums. Figure 1 gives an overview of the ARG-US prototype and associated field experiment. The fifty authorized stakeholders across the country of Illinois (USA) have observed the demonstration via secured internet access.

Figure 1. a) ARG-US sensors’ unit sealed at each RAM drum (Source: [13]) Scheme of ARG-US RFID monitoring and tracking RAM drum packages during storage and transport (Source: [12])

Firstly, experiments have been made with road transportation of a vehicle with 14 RAM drums along the route Chicago (Illinois) to Augusta (South Carolina). Sensor data were updated every 10 minutes, while several incidents of seal (i.e., loosening the drum bolts) and shock sensor violations were observed. At two mountain spots lost of satellite/cellular connection has been noticed. In addition, an incident with low battery level at sensors’ unit attached to the RAM drum has been indicated (Figure 2).
The RAM drum marked yellow indicates a potential danger since battery is low at the moment. A drum marked red means serious danger, while a drums marked green indicates that everything is in order and there is no danger of an incident. The system tracks the drums in road transportation in close to real time. After these experiments in transportation of RAM cargo, a series of experiments at Argonne (Chicago, Illinois, USA) radiological facility has been realized across the RAM drums storage areas. Two layers of network for tracking and tracing stored RAM drums have been set: a multi-sand wired one as the first layer based on Ethernet, and the second one based on wireless network. Blink sensors have been used as wireless sensors that communicate only upstream with the Remote Area Modular Monitoring (RAMM) infrastructure nodes. They enable fast connection to the existing wireless sensor network (WSN). A digital video camera, or optical sensor, has been also incorporated into the RAMM platform. More about these second term set of the ARG-US experiments can be found in references [13;14;15].

Due to the lack of research articles when it comes to tracking RAM drums as single items in sea transportation, we have used the experiences from the ARG-US project realization to propose a model for RAM cargo tracking in marine transportation. Prior to the presenting the model, we have given a short overview of some structural requirements that ships for transportation of nuclear cargo have to comply with, in order to ensure safe RAM transport.

3. A MODEL FOR TRACKING RAM IN SEA TRANSPORTATION

The International Maritime Organization (IMO) has introduced the elective Code for Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on Board ships, or so-called INF Code, in 1993 [3;4]. This Code complements International Atomic Energy Agency (IAEA) Regulations. The INF Code has been adopted in 1999 and become mandatory in 2001. It covers ship design, construction and equipment. It also included
advanced safety measures for ships carrying spent fuel, Mixed Oxide (MOX) fuel and vitrified high-level waste. The requirements for ships carrying nuclear cargo are as follows:

- Double hull around cargo holds, plus high resistant structures between hulls;
- Hull’s firm anti-collision construction;
- Double safety-required equipment for navigation, communication, cargo control and monitoring, electrical and cooling systems, so that the second system could be used in the case of need;
- Satellite navigation, tracking and tracing, so that the ship automatically transmits it position in close to real time to a control center;
- Extra fire detection and fire fighting equipment including a hold flooding system, so that all holds could be completely flooded, while the vessel remains its buoyancy;
- Twin engines, rudders and propellers which operate entirely independently;
- Bow thrusters to provide higher level of maneuverability at slow speed, etc.

These purpose-built vessels have been used to transport fissile materials between Japan and Europe (United Kingdom and France). They are owned by Pacific Nuclear Transport Limited (PNTL), TN International, and a Japanese consortium. PNTL is the most experienced company for transportation of nuclear cargo at world scale. Up to now, it has covered more than five million miles without an accident. These ships usually have crew that is about two to three times larger than crew on chemical tankers of a similar size. Besides, navigating and engineering officers commonly hold certificates of competence for a higher rank than the one they serve. All PNTL ships meet the international standards and requirements of the relevant authorities [16]. In Figure 3 are shown main structural areas of a PNTL ship with a transversal cross-section of a nuclear cargo hold.

![Figure 3. Scheme of main structural areas of a PNLT vessel (Source: [16])](image)
Security is a top priority for ships carrying nuclear materials. Shipments must comply with coastal state requirements, as well as physical protection measures developed by the IAEA and IMO. Since in the focus of this paper is tracking and tracking RAM via RFID in sea transportation, we have tried to make a compilation of results and experiences from ARG-US project, and available online literature sources in this domain and propose a framework of an appropriate info-communication model (Figure 4). All PNTL ships have satellite navigation and weather routing equipment, as well as tracking equipment. Such systems enable these ships to follow the safest route and avoid severe weather patterns. Ship’s position is monitored at any stage of her voyage. The voyage monitoring system automatically reports the vessel’s latitude and longitude, speed and heading every two hours. If a message is not received by the report centre within a pre-determined time, PNTL’s emergency response system is automatically activated [17]. If a ship accounts difficulty, trained and fully equipped PNTL emergency team is 24 hours on stand by to offer assistance. All emergency arrangements are in keeping with IAEA regulations [18]. Special monitors in the holds of each PNTL ship would provide information about the status of the cargo to a salvage team.

Figure 4. Model of a nuclear cargo ship’s communication system with manned Report Center (Source: Own)

We have assumed that each ship’s cargo hold is treated as a Remote Area Modular Monitoring (RAMM) sub-system connected with central monitoring system on board refereeing to AGR-US project attainments [6;7;8;13;14;15]. A digital video camera or optical sensor might be incorporated into each RAMM (RAM cargo hold). The RFID active tags attached to each RAM drum’s bolt contains following sensors: temperature, 3-axis digital accelerometer, gamma sensor, neutron sensor, electronic loop seal and rechargeable Li-ion battery. All these sensors are connected with monitoring system via two-layered network, i.e., via wired Ethernet and wireless network for security purposes. Due to [19] ships carrying RAM cargo are fitted with
an automatic voyage monitoring system which transmits detail of the vessel’s position, speed and heading to the Report Center (Barrow, UK) every two hours. These transmissions are preformed automatically and without any intervention of the crew. If a message was not received at the allotted time the Emergency Response System would be activated. Further in [19] is stated: “It is probable that the transmission system would be based on, or similar to, the widely used Inmarsat C communication system which uses geo-stationary satellites positioned over the equator to receive and transmit the data.” As an alternative, one can conjecture that Officers on Watch (OoW) and/or Master should monitor and control cargo holds through back-end info-communication system with the appropriate software architecture and interface. In addition, they might be responsible for regular reporting to the Report Center. If we assume that VHF Data Exchange System (VDES) is used for this purpose, than the reports should be sent via Application Specific Message (ASM) 6 (dangerous cargo indication + following communication) to the land based control-report center. The ASM 6 contains the information as: MMSI, flag, unit of quantity of dangerous cargo, code under which cargo is carried, BC class, IMDG class, and like [20]. Within the context, it is important to emphasize that mandatory reporting from ships is usually encapsulated into ASM, while Maritime Service Portfolio (MSP) cover a number of Vessel Traffic Service (VTS) related and other services [21]. Additionally, possibilities of using Iridium GMDSS [22] should be analyzed in the forthcoming research work in this domain. Apart from the proposed model based on the assumptions, through further research work some efforts should be made to identify exact extraterrestrial communication channel(s) and method(s) of (automatic) reporting, used as a bidirectional link between ships carrying nuclear cargo and ground based (control) report center(s).

4. CONCLUSIONS

The paper proposes a model of communication between a ship carrying nuclear cargo and land based control center in sea transportation. The model is based on the experiences from ARG-US project being realized during ten years period (2008-2018) in Argonne National Laboratory (Chicago, Illinois, USA). Conceiving and designing a model has been supported by PNLT information available on their official website. After an extensive search of the web, it can be concluded that online literature sources in this field are scarce. Further investigation should go in two directions: (a) exploring data transfer between sealed and tagged RAM drums and monitoring system on board ship, and (b) exploring in more detail communications between the ship carrying nuclear cargo and (control) report center ashore. Due to the lack of available information, we can only assume which form of data exchange and which communication channels are used. We have conjectured that ASM 6 reporting method within VDES might be used, but it might be also Inmarsat C, Iridium GMDSS, or some other extraterrestrial communication mode for providing safety and security at sea. This is to be explored in some more detail through the following research work.

References:


IMPLEMENTATION OF A RFID SYSTEM ON SHIPS FOR PASSENGER AND CREW LOCATION

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Abstract:

Alongside the advances made in luxury and comfort in passenger ships over the last few decades, new and modern elements and protocols for the safety of the ship, passengers and the environment have also been established. At present, the major concern is to develop a more specialized security technological framework with the main objective of minimizing risks on board. It is in this area that the present work is carried out with a view to proposing the implementation of a system for locating people on board in real time consisting of the use of tracking bracelets, based on radiofrequency technology. Radio frequency technology is a technology that is now more than 50 years old, and yet it is still a technology with great potential.

Despite being a system that requires a substantial initial investment and costly maintenance, the benefits, in the short and long term, will be reflected in a substantial reduction in the number of incidents that pose a security risk, as well as a more efficient management of resources. The system applies the use of active radio frequency tags installed on the bracelets that will respond to the message transmitted by a transceiver through a series of antennas distributed throughout the vessel. By means of a series of algorithms, these antennas will determine the position of the bracelet and therefore identify the owner passenger. These devices will be operational both in the interior spaces of the ship and on the outer decks. Finally, a procedure is developed for the use of this system focused on respecting at all times the privacy rights of the passengers. As a result, and for moments of crisis on board, an efficient missing passenger location system will be obtained, along with a procedure to ensure its proper use.

Keywords:

Maritime safety, passenger ship, tracking bracelets, radiofrequency technology

INTRODUCTION

Alongside the increase in comfort and convenience that large passenger ships
and mixed ships of the RO-PAX (Roll-on / Roll-off and Passenger ship) type have experienced in recent decades, new and modern elements and action protocols have been established for the safety of the ship, the passengers and the environment.

Today’s demands drive us towards a security framework to minimize risks that is increasingly specialized and supported by technology. More specifically, this consists of radiofrequency technology, which is no longer a new technology, (it has been around now for over 50 years), but which is still a technology in progress with great potential.

The location of passengers by radio waves, using identification bracelets, will lead to an increase in the safety of passengers and crew, especially in the most vulnerable groups and their companions, which will directly and positively affect the reputation of the shipping company.

Passenger location by radio waves, by means of identification bracelets, will provide an increase in passenger and crew safety, especially in the most vulnerable groups and in their companions, having a direct impact on the company's reputation. Despite being a system that requires a substantial initial investment and costly maintenance, the benefits, in the short and long term, will be reflected in a substantial reduction in the number of incidents that pose a security risk, as well as a more effective management of resources.

The growth in the size and complexity of vessels, continually increasing their infrastructures located in the passenger areas, makes it increasingly necessary to verify the flows of movement of people in case of an emergency, to have them located and to be able to distribute them according, for example, to the available means of abandonment that are found on the ship. Also, during the course of an abandonment, it is essential to know where they are going, whether someone is being left behind or if they have to be redirected, allowing decisions to be made in real time and with updated values, all of which is vital for managing the emergency itself, minimizing both personal and material damage [1].

The location of passengers in case of an emergency on board is always an obstacle to the management of the emergency itself, since there will be two determining factors when it comes to managing the existing resources for the resolution of the emergency: on the one hand, human behavior, both that of the passengers and rescuers or the crew responsible for directing the passengers, and on the other the characteristics of the emergency itself and of the ship [2].

The incorporation of new technology is vital for the development of security on board. The security policy, which is normally a reactive policy (accident-regulation), has led to the implementation of various measures to reduce risks both to people, the environment and cargo and to the ship itself. However, it is a fact that risks exist and will exist, as do accidents, and that is why it is necessary to try to reduce them as much as possible to avoid a fatal outcome by applying proactive security policies [3].

To understand the benefits of a real-time location and identification system on board a vessel, we will study the possibilities that a system based on RFID (Radio Frequency Identification) technology provides, which includes the use
of active tracking bracelets that operate in the UHF (Ultra High Frequency) range, in order to manage on-board emergencies, whether search and rescue or passenger management [4]. These bracelets will respond to the message of a transceiver transmitted by a series of antennas distributed throughout the vessel which, by means of a series of algorithms, will determine the position of the bracelet and the identification of the passenger to whom it corresponds.

The inclusion of this system of location and identification by radiofrequency of passengers as a security system can contribute to the better management of crowd control and passenger management in case of emergencies on board, such as for example:

- Management of the disappearance of a passenger. It is essential that the crew know how to manage the report of a disappearance of a passenger, activating the tracking bracelet protocols, achieving a reduction in the response times in the event of a possible fall overboard or the location of a minor who has gone missing.

- Location of missing passengers in case of abandonment: in the case of an emergency signal, the passengers must go to the areas designated as meeting points on the vessel and the crew must check all of these areas to ensure that nobody has been left behind. In real life, however, passengers sometimes stay in areas which the crew have failed to check or the passenger may even hide himself or ignore all of the instructions of the crew, all of which makes passenger location more difficult.

- Identification of passengers with special needs: in the case of a search for missing passengers, it will be of great benefit to the crew that is undertaking the search to know beforehand about any special needs or the physical/psychological conditions of the passengers in order to optimise the search criteria.

There are at present several real-time location systems with different uses but none of which are considered suitable for use on a passenger vessel.

GNSS (Global Navigation Satellite System) systems are global satellite navigation systems, such as the popular American GPS (Global Positioning System), the Russian GLONASS (Global'naya Navigatsionnaya Sputnikovaya System), or the European GALILEO, which are based on the calculation of the position of the user as provided by the signal received from a minimum of four satellites. They have a margin of error of between 3 and 5 metres, which could be a serious problem in the case of the search for and positioning of passengers, who may actually be in adjacent areas, but with different accesses, leading to a delay in their rescue. This is why these systems have been rejected as location systems for persons inside a premise, as in this case, inside a vessel [5].

Another of the systems that are not taken into account for indoor location systems is infrared location, since, in this technology, direct vision is essential, and due to its short range it would be necessary to place an infinity of infrared emitters, without finally achieving the objective of covering 100% of the zones [6].
The system based on the triangulation of the position by means of bluetooth devices around it is a cheap technology and one that can provide an alternative to the problem of indoor location in case of emergency, although at present, it has moved towards a more commercial use, taking advantage of the widespread use of mobile phones: information is sent to consumers when they are close to the product, or they are given directions on how to get to it. For the moment, most of these systems are short range, and their use in matters of security has not been developed, although it is a technology in progress [7].

Like the “beacons” used in bluetooth systems, Wi-Fi beacons make it possible to connect with an access point, which emits a periodic signal indicating its presence. Its study and development has taken place largely in the world of commerce and mobile telephony, where it has made and continues to make significant progress. One problem worth mentioning is the possible interference of two networks that simultaneously emit a beacon, the signal of both becoming unusable, so it would be desirable to use channels that are not heavily occupied, as well as taking into account the multipath of the signal, which must be carefully modelled before the implementation of the system to avoid areas with no signal or very reduced power [8].

Finally, GSM telephone location technology (Global System for Mobile Communications), both because of its inaccuracy, and because the environment is the marine environment, where there is normally no signal from the repeaters, is also considered unsuitable for use as a location system on a ship [9].

In sum, the objectives of this work are to propose the implementation of an efficient real-time location system, indoors and outdoors, on all passenger decks, using radiofrequency technology with a tracking bracelet, as well as develop an appropriate procedure for the use of the system, whose purpose is to provide specific actions and action processes in the event of the disappearance of a passenger and their non-location by the watchkeeping personnel, establishing the prior situation that must occur for the adoption of this procedure and always respecting the privacy rights of the passengers.

As a final result, an efficient system for locating missing passengers is obtained, together with a tool to correctly use this system consisting of an appropriate procedure that will be included in the Ship's Safety Management Manual. The system and procedure that are presented alongside the instructions on its use are designed to provide a new security tool.

1. THE RFID SYSTEM

At present, the systems of location and identification of both objects and people are experiencing a boom and are being widely developed. Our reality opens the doors to endless possibilities, from access to venues without the need to queue to get tickets, or even the fully automated purchase of clothes. Every day new ways of optimizing the resources around us arise, RFID technology becoming the norm, from supermarkets where you no longer have to go through checkout, electronic tolls, assembly lines, luggage management in airports, etc.
An RFID system is a system of remote data storage and retrieval using radio frequency. The operation is simple, as simply by triangulating the signal from different transceivers, it is possible to determine the position of the transmitter. A label containing an identification responds to the request of a sender-receiver, who reads and transmits digitally the information received to the specific application called middleware for interpretation [10].

One of the advantages of RF (Radio Frequency) waves is their ability to penetrate surfaces and obstacles to a certain extent, so that a moderate number of RFID emitters-receivers could cover a larger space than, for example, infrared or ultrasound devices, also avoiding the need for direct line of sight with the label [11].

At times, due to the high propagation speed of the RF waves, the systems are combined with slower wave speed systems such as ultrasound systems, thus further reducing the margin of error when positioning the label. However, the system is not free from possible failures: multipath, reflection, diffraction and attenuation of the signal due to obstacles can cause the signal to fluctuate [12].

1.1 COMPONENTS OF AN RFID SYSTEM

The system is basically composed of the following elements[13]:

- an RFID reader transponder,
- some RFID labels,
- a subsystem of data processing or middleware,
- antennas.

![Figure 1. Diagram of a RFID system.](image)

Source: Study, design and simulation of an RFID system based on EPC. Eduard Samà Casanovas

1.1.1 THE READER

An antenna, a transponder and a decoder form a reader. Also known as an interrogator, its main purpose is to transmit and receive signals by transforming the RF waves of the tags into a language understandable to a computer. The computer sends signals to see if there are labels in its reading range. When it picks up a response signal, it reads the message and transmits it to the data subsystem. There are readers which can edit the message of the tag thanks to integrated programming modules (if it is an editable tag).
These fundamental elements for an RFID system are usually connected to antennas, either fixed or in portable units, and can supply power to passive RFID tags. The vast majority of readers can both read and write the necessary information on the label, so that when it is read it transmits it.

**Figure 2: Examples of modular, portable and fixed readers.**

1.1.2 THE TAGS

The RFID tag, transponder or Tag, is made up of an antenna, a radio transducer and a microchip. It transmits the identification data of the tag through the antenna. Depending on the model, it may have internal memory to store additional data, and depending on the model there are also non-reusable read-only tags or ones with which you cannot modify the message or attach or delete additional data. There is also the write-read type, with the possibility of editing the tag information.

Passive tags have no internal power supply [14] and are activated when they receive the energy of a reader through an electromagnetic wave signal that induces current in the tag antenna, sufficient to power the integrated circuit, generating and transmitting a response. The reading range is usually a maximum of 5 to 10 meters, depending on the size and design of the antenna, the frequency used and the type of tag. One of the disadvantages is that in the vast majority of cases the message transmitted is brief, usually an identification number, it not being possible to expand the storage much more and transmit it.

**Figure 3. Examples of passive tags.**

Sources from left to right: prometec.net and fqingenieria.com

Unlike passive tags, active tags do have an autonomous power supply (usually a battery), and with it they distribute current to their integrated circuits and, via a transmitter, propagate their signal to the reader [15]. Thanks to this, they are capable of transmitting more powerful and reliable signals, with a much greater reading distance than passive tags, with clear responses to weak reception and
in more difficult environments for radio frequency (metal, water ...) so they are more efficient in more difficult environments for radio frequency.

**Figure 4. Examples of active tags.**

![Active tags](image)

Sources from left to right: kimaldi.com, aprender.tdroboteca.co and nextpoints.com

Finally, semi-passive tags are tags that have their own power supply, but unlike the active ones, this battery only feeds the microchip and is not used for the transmission of the message [16]. When transmitting, its operation is basically the same as that of a passive tag, since the energy in the radio frequency is reflected towards the reader that emits it. This design improves the response time and increases the reading range, while also having a reliability comparable to active tags and a longer service life. They may have greater memory capacity as well as additional processing functions (different sensors to determine temperature, humidity ...).

**Figure 5. Examples of semi-passive tags.**

![Semi-passive tags](image)

Sources from left to right: nextpoints.com y vanch.net

1.1.3 DATA PROCESSING SUBSYSTEM OR MIDDLEWARE

The Data Processing Subsystem or Middleware is the specific computer application that processes and stores data [17]. It is a software that allows you to manage the message, being able to extract the useful information received by the reader, filter it and store it in a database, disposing of it when you need it. It plays the role of a translator to the language of the applications interested in the information on the tag. It can also perform the functions of peripheral device management and data routing.
1.1.4 THE ANTENNAS

The reader antennas are responsible for enabling the communication between the tag and the reader. The choice of antenna model and number will depend largely on the area to be covered for tag detection [18] [19]. Another important factor when choosing the antenna is to select the frequency range suitable for its use (figure 6).

![Figure 6. Different models of RFID antennas](source: milesdata.com)

1.2 PROBLEMS WITH PRIVACY AND DATA PROTECTION

In the present era, the world of technology is evolving very quickly. However, changes in the legislation, the adoption of new laws and their entry into force does not come about so quickly. RFID technology is a technology that is growing and must be regulated to avoid the risks to privacy that may arise from its use.

In the case that concerns us, the tags being bracelets that emit a message which can be read by the interrogation network of the ship in the passenger area, and it being clear that the objective is constrained, in the case of an emergency, to search and rescue and crowd control, the system and procedures for implementing the protocol and protecting users must be very clear and specific about the protection of all the data that the tags may contain, since the users will take them with them when they disembark. Likewise, it should also be compulsory to notify the use of RFID technology, by means of signage, to clearly indicate that passengers are being subjected to its use in the different areas of the ship [20].

In any case, the system will remain inactive until its use is required, as in as the case of the disappearance of a passenger, a minor, an elderly person, etc., for crowd control in case of an emergency, or for search and rescue if necessary. Hence, in normal circumstances, there will be no signal from the interrogator and thus no response will be generated from the tag.

Upon disembarking, passengers, at the access to the vehicle decks or the gate, will have an eraser that eliminates the message written beforehand simply by bringing it close to the bracelet, if they wish).
1.3 TESTS WITH RFID TECHNOLOGY

Various tests have been devised for the development of a real-time location system using RFID technology, such as the LANDMARC study [21], which establishes a location procedure with RFID technology in an environment with and without obstacles, increasing accuracy by introducing fixed reference tags to reduce the error margins when applying the position calculation algorithm. Tests have also been performed on indoor ring overlay location based on RSSI (Received Signal Strength Indicator) [22].

2. DESIGN OF A RFID SYSTEM IN A RO-PAX SHIP FOR PASSENGERS LOCATION

Using the RFID system for locating passengers both indoors and outdoors, our aim is to transfer that idea to maritime safety, in a range of situations, which to a greater or lesser extent, occur on board a passenger ship [23].

It is quite a challenge to set up the installation required to make the system viable. However, situations as common as the location of a lost child or the location of a passenger reported by a relative as missing in the middle of the night can be managed quickly and efficiently, avoiding reaching the extremes of having to activate the man overboard protocol. In other words, the existing resources could be optimized, minimizing the reaction time and possible errors that the human factor sometimes entails. It is essential that there is a good coordination between the land offices and the ship, as passengers must come for boarding with the bracelet already programmed with their identification number.

With the establishment of this system and the development of the procedure, a rapid reaction will be achieved to a situation, which, if not resolved, can become an emergency, which would force the deployment of all the measures available on board, such as messages from the general public address system, the organization of search patrols and even notification to the authorities and maritime search and rescue maneuvers.

After activating the system, the tags will respond to the interrogators' signal, sending their unique identifier, combining it with the vessel's database, and a series of calculations that the system performs will determine the approximate place in which the label corresponding to the passenger sought is found. In this way, the person in the best position to locate the passenger can be identified.

The benefits of using RFID technology aimed at passenger location will be reflected in resource optimization, efficient incident management, anticipation of needs and of course a better business reputation and benefits for the passengers, by causing them less disturbance throughout their stay on board.
2.1 CHOOSING THE SYSTEM.

For the theoretical development of the system, its components are chosen based on their performance and characteristics. Optimal conditions are sought to address a hostile environment, as is the case of a vessel with a steel structure.

We start with the choice of frequency, type of technology (active or passive), type of tag, antenna and reader, not forgetting the data processing techniques for real-time location.

The frequency selected is UHF from 860 to 960 MHz. This provides us with a greater reading and data transfer distance. It is at present the band on which the development of RFID technology is focusing. It has a good penetration against conductive and non-conductive materials, although not in liquids.

We will use an active technology tag, with a long-lasting battery (currently more than 10 years), with its own transmitter, which alleviates the power requirement of the readers, with an “Alien H3” chip, with storage capacity of 512 bits, with read and write capability, so that the code can be changed for each new trip. The reading range is 15 meters, with a high transmission speed and the capacity to communicate with other tags.

It is a TOTAL tag (tag-only-talks-after-listening), so it remains at rest until it receives a signal from a reader, at which time it responds using its own energy. The presentation is in the form of a hypoallergenic silicone bracelet, waterproof and of different sizes, with the possibility of printing a logo on it (figure 7).

![Figure 7. Silicon RFID active bracelets.](http://www.primeplasticcards.co.uk)

The reader will be fixed and of universal use. In our tests, it will work in the UHF frequency range, from 860 to 960 MHz, although it can be used in other ranges and adapted to other countries' regulations.

This is an IP67: BL67 modular system reader with the possibility of connecting up to 20 antennas and a reading range of up to 900 tags per second. It will use anti-collision protocols and simultaneous reading.

With respect to the antenna, it will follow the path of the other elements of the system, working in the same frequency range. The model chosen is the IANT217 (Electronics Ltd.) Omni-directional antenna, circularly polarized with a reading range of 15 meters.
On a three-dimensional plane, the irradiation of an omnidirectional antenna is uniform in all directions. It is used if coverage is required in all directions. Its radiation pattern is similar to a donut without a hole. Circular polarization is also used when tag location is unknown.

For the calculation of the position, fixed control tags will be distributed over all of the decks, creating a map that can be stored in a database which has the RSSI levels of certain static tags that are related to the tags we are trying to locate.

It is the dynamics carried out in the LANDMARC study, in which a series of algorithms take into account the levels of RRSI of the non-control active tags in relation to the control ones, that create an approximation of the tag positioning.

The RSSI will depend on the distance of the tag, since this is the strength of the signal received by the reader as a response by the tag. It can be calculated by verifying the emission range of the tag, and by extrapolation to other control tags distributed throughout the ship. Positioning systems based on RSSI can give erroneous values if the signal has suffered path losses due to the physical characteristics of the environment.

2.2 OPERATION OF THE PROPOSED SYSTEM

In the proposed scenario, tag recognition has been established anywhere on the passenger decks and inside the ship by means of at least four antennas, and whenever possible, with an unobstructed view between antenna and tag, thus reducing the chances of error. Even so, an error of approximately one meter is estimated.

Using the analysis tool, it is possible to select the tag which is to be located. Knowing the power with which they emit, the RSSI received by the reader/scan be calculated through the different antennas positioned around it. With this Reading, the radii are calculated with respect to the strength of the received signal, tracing a ring for each of the radii. The superposition of the rings based on RSSI provides an area in which, in theory, the tag which is being sought is to be found (figure 8).

The more different RSSI readings from a tag, the more precise the location, although it is also advisable to use a method of refinement to further reduce the bounded area.
3. DEVELOPMENT OF PROCEDURE FOR PROPER USE OF RFID SYSTEM

Once the RFID system is installed on board, there needs to be a written procedure that systematizes and regulates the use of the system by the crew members, which is efficient and at the same time safeguards the privacy of the passengers.

For the elaboration of this procedure, Chapter IX of the SOLAS (International Convention for the Safety of Life at Sea) of the IMO (International Maritime Organization) dealing with the safety management of ships [24], will be taken as a reference, as well as Chapter 7 of the ISM Code (International Safety Management Code) [25] entitled “Development of plans for on-board operations”.

Following the guidelines of the aforementioned tools, the elaboration of a procedure for locating passengers in real time, which can be integrated into the mandatory International Safety Management Manual (ISMM) on all ships according to the ISM code, is detailed below.

3.1 SEQUENCE OF CONDITIONS REQUIRED FOR THE ACTIVATION OF THE RFID SYSTEM.

The prior conditions indispensable for the procedure to be initiated are as follows:
1º Suspición de la desaparición de un pasajero.

2º Aceptación de las condiciones de uso del sistema de localización de pasajeros, encontradas en una cláusula del contrato de transporte previamente aceptado por el cliente.

3º Aceptación de que en ningún caso se alterará la seguridad del buque o la autoridad del Capitán por la implantación de esta prueba.

4º Entendido de que la activación del sistema es una medida complementaria a las que se detallan en el ISMM.

Para la activación del sistema, la siguiente serie de condiciones debe ser cumplida:

1. Informe de la desaparición del pasajero. Los miembros de la tripulación que se encargan de manejar el incidente deben recibir los datos del pasajero, la hora en que se comunicó la desaparición, así como los datos del informante y cualquier otra información relevante.

2. Anuncios por el sistema de comunicación en áreas comunes para pasajeros: El tipo de mensaje, repeticiones y tiempo de intervalos se determinarán en el manual de servicios a bordo (OBSM).

3. Informe al oficial de guardia: Cuando el pasajero no se ha localizado después de repetidos anuncios por el sistema de comunicación, antes de iniciar cualquier otra acción, el oficial a bordo debe ser informado y luego indicar las medidas a tomar. El oficial a bordo coordinará una búsqueda conjunta por el OBS y puente (sargento de guardia) y escribirá los datos del pasajero, el tiempo del incidente, la posición del buque y cualquier otra información relevante en el cuaderno de incidentes.

4. Búsqueda conjunto puente / OBS: Normalmente el personal a bordo, junto con el sargento de guardia, revisarán los decks de pasajeros uno por uno en coordinación y comunicación con el puente. En el caso de no localizar al pasajero, el sargento de guardia también revisará áreas restrinidas que se considera que el pasajero puede haber accedido sin autorización, como la cubierta de vehículos, áreas para mascotas, etc.

5. Información al capitán: Si el pasajero aún no ha sido localizado, el capitán será informado del incidente.

6. Anuncios por el sistema de comunicación del buque: Se harán dos anuncios por el sistema de comunicación del buque que cubrirán todas las áreas de pasajeros y tripulantes. El tiempo entre los mensajes no deberá exceder cinco minutos.

7. Activación del sistema. Después de completar todo el procedimiento y antes de declarar una emergencia a bordo, el sistema se activará para detectar la ubicación del tag del pulsera del pasajero.

Las condiciones para la activación del sistema pueden ser alteradas según los criterios del Capitán o el oficial de guardia: por ejemplo, el proceso puede ser acelerado si la persona desaparecida es un menor o una persona con discapacidad o incluso si el buque está en medio de una tormenta. Todas estas condiciones se reunirán en
the procedure itself, in the observations section.

3.2 FLOWCHART OF THE PROCEDURE

The main aim of the procedure is to establish a method so that the on-board personnel will perform the task adequately. The right solution to the situations that may arise on-board demands the collaboration and communication between the ship’s command, the officers and the junior officers, as the success of the operations may depend on the good performance of all of the crew. It is thus essential that all participants should have some practice in carrying out their obligations and duties in each situation. The persons responsible for the company on land and on-board will act in accordance with what has been established, as shown in the flowchart in figure 9.
3.2 FLOWCHART OF THE PROCEDURE

The main aim of the procedure is to establish a method so that the onboard personnel will perform the task adequately. The right solution to the situations that may arise on-board demands the collaboration and communication between the ship’s command, the officers and the junior officers, as the success of the operations may depend on the good performance of all of the crew. It is thus essential that all participants should have some practise in carrying out their obligations and duties in each situation.

The persons responsible for the company on land and on-board will act in accordance with what has been established, as shown in the flowchart in figure 9.

Figure 9. Flowchart for RFID system activation.

Source: the authors
4. CONCLUSIONS
Once the system has been completed and the procedure revised, we can conclude that:

1.- It is an efficient indoor and outdoor real-time location system.

2.- It is a system whose use implies prior acceptance by the user, through a clause in the transport contract (ticket).

3.- It is a system that complements traditional searches, increasing reliability and accuracy while reducing response times in most cases. The procedure clearly establishes the guidelines to be followed by the crew to optimize resources in case of disappearance of passengers.

4.- It is a system that does not involve any health risk and does not violate the privacy rights of the passage. It respects the rights of passengers, as the system is not activated unless absolutely necessary.

5.- It is a system that leads to an increase in passenger security, substantially increasing that of the most vulnerable groups (minors, elderly, people with reduced mobility, people with mental disabilities) since it allows an adequate reaction to the needs of the individual if necessary. As a side-effect, it will provide greater peace of mind and security to the companions of these persons.

6.- The procedure developed is a dynamic procedure, which can be altered by decision of the Captain or the officer responsible, if necessary.

7.- With regard to crowd control and directing the passengers in emergencies, using the RFID system, real-time decision making can be made, from avoiding the collapse of a point of abandonment, to redirecting the passengers to the most appropriate evacuation route. It can also be used to create descriptive models of passenger behavior in case of emergency situations.

References:


appropriate evacuation route. It can also be used to redirect passengers to the collapse of a point of abandonment, to create descriptive models for emergency situations. Using the RFID system, real-time information can be transmitted to the systems, allowing for a more efficient decision-making process.

7. The system is not activated unless absolutely necessary. It is an efficient way to ensure the privacy rights of the passage. It r

8. The system clearly establishes the guidelines to be followed by the crew to optimize resources in case of disappearance of passengers. It is an efficient system that mostly vulnerable groups (minors, elderly, people with disabilities) since it allows an adequate level of support and companions for decision making can be made, if necessary.

9. It r

10. It r

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13. It r

CONCLUSIONS

It is an efficient system that provides greater peace of mind and security to the needs of the individual in maritime environments. The captain or the officer can decide if an increase in passenger mobility is required.

References:


International Convention for the Safety of Life at Sea.

NEW INTERNATIONAL GUIDELINES FOR VESSEL TRAFFIC SERVICES. REVISION OF IMO RESOLUTION A.857(20).

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Abstract:

The recognition of the International Maritime Organization (IMO) in 1985 and the publication of the first guidelines was a definitive stage for the Vessel Traffic Services (VTS). However, the last revised version of the Guidelines for VTS was published in 1997, Resolution A.857(20)[1], and has remained in force since then. A hiatus of 22 years has more than justified its urgent review. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) has been working on the current revision of this Resolution through several sessions of the VTS Committee. After the main author’s participation in its last Seminar, this paper analyses changes to be introduced and how VTS Centres will be affected. This paper will examine some of the initial key changes to the system, including new definitions, such as “the VTS provider”, and the resolution’s aims to unify its diverse services within a VTS, leaving behind the three differentiated types: information, organization and assistance. The forecast for the next phase is that the Maritime Safety Committee (MSC) will approve the proposal and the IMO Assembly on its 32nd session, will adopt it by 2021.

Through this process, the new Resolution will be more concise and internationally adaptable, in accordance with our current needs. This paper will deal with the further revision and update of the Resolution that has initiated 4 years ago. Illustrating in one hand the slowness of legislation and the even slower nature of the maritime sector and in the other hand a suggested interpretation of the future requirements that international navigation will pose to the traffic management.

Keywords:

VTS; IMO Resolution; IALA.

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INTRODUCTION

The recognition of the International Maritime Organization (IMO) in 1985, and the publication of the first guidelines via Resolution A.578 (14)[2], was a definitive stage for the Vessel Traffic Services. In 1997, 12 years later, this resolution was revoked and a new one was adopted, the Resolution A.857(20) [1] but there have been no more revisions or modifications published since then. However, the maritime sector has demanded an urgent update.

The Maritime Safety Committee (MSC) and the IALA, through the expertise of the VTS Committee, have been working on the revision since 2018, seeking to provide a clear framework to operate VTS globally and in accordance with our times.

1. BACKGROUND OF THE VTS SYSTEM.

The origin of what is formally understood as a maritime traffic surveillance system dates back to 1946, when the first experiments of combining radar screen equipment with the transmission of radio messages referring to navigation in real time were recorded at the port of Liverpool, UK. The development of radar during the Second World War made it possible to monitor and accurately track maritime traffic, and its civil applicability was first utilized in Douglas, Isle of Man, 1948 (Hughes, 2009) [3]. Months later, in July, more sophisticated equipment was installed in the same port of Liverpool and, by 1950, other ports, including Long Beach, California, and Rotterdam were also provided with this new device.

At that point it was seen as a powerful tool to facilitate operations, reduce delays and increase the efficiency of port traffic flow. Gradually, radars were installed in various European ports such as Amsterdam in Holland, Le Havre in France, Southampton in England and Halifax in Nova Scotia. By the sixties there were centres distributed across Europe and North America and, by the seventies, in Japan. Currently, forms of VTS, although not standard throughout the world, are found in the littorals of all continents in countries including: China, Egypt, Hong Kong, South Africa, all European countries including the Baltic, Atlantic and Mediterranean coasts, the Arabian Peninsula, the Black Sea, the USA and Canada.

Whilst the hardware up to this point was Radar and the marine-band Very High Frequency, VHF, radio provided by VTS centres, the software, meaning guidelines or regulations, did not appear until more than thirty years later.

It has been established that the first official recognition of the VTS system by the IMO was not until 1968. At the time it was the IMCO, Inter-Governmental Maritime Consultative Organization, which adopted, through the Assembly of the Maritime Safety Committee, the Resolution A.158 (ES. IV) [4] and this recommendation was received by ports as a valuable contribution to port safety and its approaches. In this sense, it promoted two points addressed to governments in favour of safety: one which is particularly relevant for oil terminals or dangerous goods; and the second being the use of the ETA, Estimated Time of Arrival, which also helps to manage the arrival of ships. The birth of the principles that have been maintained to support the VTS service can be seen to contribute to safety, increase efficiency and also protect the marine environment, although, in the sixties, it specified only the cases of operations in oil terminals and ports where noxious or hazardous cargoes were loaded and unloaded.
The first guide for VTS came 17 years after initial recognition, when a new Resolution was issued. The IMO Resolution A.578(14) in 1985 [2], in terms of the Guide for VTS, highlighted the need for ships to report ashore when approaching a port and within territorial waters: in narrow channels, in areas of heavy traffic, when dangerous goods are involved or in sensitive areas. In general, operational procedures and VTS planning were outlined. And, most importantly, international treaties concerning safety, the International Convention for the Safety of Life at Sea, SOLAS, were addressed within Chapters IV and V, Communications and Safety, respectively.

The second and last direct resolution of the IMO was in 1997, 12 years later, when the Guide for VTS version was revised through the Resolution A.857(20) [1].


This resolution revoked the first guidelines for VTS version and, generally, it was more extensive and precise, went from having 17 pages to 22. Two annexes were added, some technical criteria concerning VTS and, addressed for the first time, the hiring procedures, necessary qualifications and training of the personnel that operates within the VTS centres.

This was adopted after other important publications, including the first edition of the VTS Manual, came from the IALA in 1993. So the resolution included, for the first time, the IALA Manual as a complement to the guidelines of the resolution itself. Also, the Resolution MSC.43(64) [7], Guidelines and criteria for Ship Reporting Systems, SRS, adopted in 1994, was included.

The main points of the resolution that have been proposed to be changed are those that have been considered over the years obsolete or superseded, overly detailed, unclear, misunderstandings or open to differing interpretation. With these parameters, seven out of ten definitions, according to Annex 1, point 1, will need to be modified.

The Vessel Traffic Service, VTS defined at point 1.1 as: “a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area”.

The Competent authority in 1.2: “the authority made responsible, in whole or in part, by the Government for safety, including environmental safety, and efficiency of vessel traffic and the protection of the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area”.

The VTS operator is defined as: “an appropriately qualified person performing one or more tasks contributing to the services of the VTS”. 1.10 defines Allied services: “services are services actively involved in the safe and efficient passage of the vessel through the VTS area”. 
Within point 2, General considerations for VTS, the services that are rendered by a VTS are described in point 2.3 and three types of services are identified: The Information Service, INS, the Traffic Organisation Service, TOS and the Navigational Assistance Service, NAS.

These services are directly linked to Chapter 4 of the VTS manual of the IALA and, according to Resolution A.857(20), two types of VTS are described: i) Coastal VTS: Control of maritime traffic in a determined area, which includes traffic in Traffic Separation Scheme (TSS), regulated by the IMO, and can be found in Spain, for example, as the Finisterre VTS which controls the Finisterre TSS. ii) Port VTS: Mainly dedicated to port entry and departures. It may be the case that the same VTS centre exercises Coastal and Port control.

3. THE NEW RESOLUTION ON GUIDELINES FOR VTS. 1997-2018.

Since 1997, more than 20 years have passed and, during this time, important matters have occurred. Some of the most important, in relation to the maritime sector and influence on the VTS system, include; the implementation of the Automatic Identification System (AIS) on board ships, the creation of the Safe Sea Net (SSN) [8] and later the European Maritime Safety Agency (EMSA) [9], and the concept of e-Navigation [10] that is increasingly necessary to incorporate the rapid developments of new technologies and their potential use.

Governments, organisations and different stakeholders, within the international maritime domain, have pointed out the need to update the resolution.

IALA, through the expertise of the VTS Committee and a correspondence group (over 30 committee members from 20 organizations, representing competent authorities, VTS authorities, sister organizations and industrial members), has taken a coordinating role in the preparation of a new revised Resolution for submission to the IMO [11].

The first process review was initiated under the work program of 2014 to 2018. In 2016 the VTS Committee commenced the development of an unplanned output proposal for the IMO. In February 2018, a proposal for a new output for a revision of the resolution was submitted to the Maritime Safety Committee in its 99th session, (MSC 99/20/3) [12]. In April 2019, the MSC published the progress on the review via MSC 101/23/11 [13] and, in June, the IALA hosted a seminar at its headquarters on updating the resolution. IMO Member States, IALA members, international organizations and other stakeholders were informed and invited to participate in the draft version. In September IALA held the VTS47th session [14] with the aim of finalizing the review. The VTS Committee will have finalised the draft revision for submission to the IMO-Sub-Committee on Navigation, Communications and Search and Rescue (NCSR), 7th session by January 2020.

In reference to the main points that will be subject to modifications, within the definitions are, in order of appearance: The Vessel Traffic Service, VTS will be implemented by a Government, instead of “a Competent Authority”. This is directly allied to point 2: Competent Authority. The term “Authority” raises semantic bewilderment in confusion over what is formally understood as an "Authority" and the one that is "Authorized" to exercise a function, in this case that of VTS. To avoid translation differences, the body that exercises the VTS service will be called "the VTS provider", a more accurate phrase denotation in a domain of shared sociolinguistics, (the English language). So, the Competent Authority will be the authority made legally
responsible by the Government for vessel traffic services and the VTS authority (point 3) will be the VTS provider which will mean the organisation or entity legally empowered by the Government or Competent authority for the provision of a vessel traffic service. The VTS area means the delineated, formally declared area in which the vessel traffic service provider is legally empowered to deliver the service. The compound expression of “service area” will be separated, with the understanding that the service is already provided in the area and, therefore, is redundant. The subdivision of area into sub-areas or sectors will also be eliminated in this definition the VTS personnel instead of VTS operator (point 1.6), so that the functions do not fall according to the tasks to be performed, but on the qualifications held. In this way, more importance is given to training. The definition 1.10, Allied services, denotes the word “allied” to mean services, other than a vessel traffic service, supporting vessel traffic since safety and efficiency are already part of the functions of a VTS.

One of the most substantial changes will refer to the three types of services that are rendered by a VTS. The INS, TOS and NAS were used to differentiate the degree of interaction of the VTS with vessels and, furthermore, with the type of VTS, since the TOS and NAS services are associated with the Port or Harbour VTS, whilst the INS is with the Coastal VTS. However, these are not being recognised by mariners who are the primary recipients of VTS, nor is the common understanding among VTS experts on the interpretation and the practical use of the three types of services. The word "Service" after each type of service was found to be the cause of current confusion. One of the authorities’ main concerns is that these services are not declared or delivered consistently worldwide, while ships navigate in different VTS areas. VTS are delivering navigational assistance and traffic organisation without declaring the services. The aim is to exclude the types of VTS service in the revised resolution, to harmonise the interpretation and provision of vessel traffic service worldwide and understand that there is, in fact, only one “service” provided by a VTS. The service (not plural) consists of maritime information, monitoring, management and organisation of vessel traffic and navigation assistance [15].

Although Resolution A.857(20) included, for the first-time, guidelines on recruitment, qualifications and training of VTS Operators in Annex 2, in point 1.1.3 [sic.]: The various levels of knowledge and skill required of the operator, and the standard of training necessary to achieve these levels, have never been fully defined on a world-wide basis. At present there are no internationally recognized qualifications for VTS operators, and the approach to recruitment and training varies widely from country to country. So, to mitigate these variances, the existing resolution makes reference to the IALA VTS Manual, however this Manual is only updated every 4 years. In order to avoid the pitfalls caused by a lack of updating, the new resolution will refer to the suite of IALA guidance relating to VTS recommendations, guidelines and model courses that are under continuous review.


Since the review work began in June 2018, more than 15 meeting have been held. The next steps are for approval at IMO MSC 102 in May 2020, and then adoption at IMO Assembly 32 by autumn 2021 with the new resolution published in December.

IALA has developed a complete set of training recommendations, guidelines and model courses that will be ready and effective when the new resolution is published.
As stated above, all the software will be ready and updated, but the hardware of the VTS centres remains the same. Figure 1 shows the main means for a VTS in red colour versus the referring guidelines in orange through the years. GVTS as IMO Guidelines for VTS. After more than 50 years, only radio and radar are considered in the profession of VTS. Although, with the obligatory use of the AIS on board vessels, according to SOLAS Convention, Chapter V Regulation 19 Carriage requirements for shipborne navigational [5], certain ships will have been fitted with an automatic identification system (AIS) not later than 2008. Consequently, this is also observed as an essential tool for the control of the traffic from shore. It is recognised by Resolution MSC.74(69) [16] of 1998 that the AIS should improve the safety of navigation, aiding the efficient navigation of ships, the protection of the environment and the operation of vessel traffic services (VTS). AIS was defined as a VTS tool, that is, from ship-to-shore for traffic management.

**Figure 1. Radar and VHF versus guidelines for VTS.**

In the same way that the AIS device cannot be understood without an ECDIS, a VTS Operator must use an electronic chart, although the technology of integrating the AIS signal into a radar exists. According to figure 3, Annex 2 of the present resolution, the components included are radar, radio, circuit TV, visual, Telex, phone, computers and others. There are no references to AIS, VHF with Data Exchange (VDES) [17], ECDIS or any electronic chart, nor of AIS with satellite signal. The phone is no longer utilised without a system connected to Internet messaging through an app. Geolocations are used as a means to transmit one position near the coast ship-to-shore. The “others” mentioned in Annex 2 may cover this omission of equipment but, in time, it must be rectified by inclusion in the regulations.
The figure 2 shows future means for VTS that some already use versus regulations (Reg.) limbo for them.

**Figure 2. Future means for VTS versus regulation limbo.**


5. CONCLUSIONS.

All these efforts seek to ensure that the resolution serves as an effective instrument, providing a framework to implement VTS globally in a harmonised manner and that it responds to significant global changes since its adoption in 1997. It has been the work, so far, of 24 years. Although the result will be an effective instrument, it is worth noting what this long process has meant. New resolutions, updates and revocations that require so many years to be published, could risk being ineffective.
The present resolution refers to a number of instruments which are now incorrect, obsolete or redundant and requires updating. The document will also benefit from overall rationalisation and restructuring.

IALA has developed a complete set of training recommendations, guidelines and model courses, and so ensuring that details of VTS operations and training refer to the IALA Standards and Guidelines related to VTS, is an advantage. Thus, the IALA appeal formula will facilitate future updates.

The new resolution and guidelines are not foreseen to have a negative impact on VTS technology. Once implemented, the resolution will, however, strengthen the link between the IMO Guidelines and the existing IALA standards on VTS technology.

It should be borne in mind that new challenges are approaching that will have to be addressed. The global maritime fleet continually increases, and the maritime sector needs to unify and standardise procedures and processes optimising connections to the logistic chain between ports. Recognition of the role and increasing position of VTS is necessary since governments are recommended to implement such a service.

Globalisation and the widespread use of the internet are changing global perceptions and strategies. That is why the concept of e-Navigation has emerged. Unmanned vessels and drones will be increasingly common. Satellites bring both detection technology and communications, and all will interact with the VTS system in the near future. Surface picture worldwide maritime traffic, the capability to monitor and analyse wider traffic images, is already tangible.

Finally, environmental awareness has increased proportionally with concerns to protect the planet and increasing measures of marine protection will be required in each new procedural update.

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THE DANUBE WATERWAY TRANSPORT AS ‘EXTENDED LEG’ OF MARITIME TRANSPORT ACROSS SHIP LOCKS – CASE STUDY: SHIP LOCK IRON GATE 1

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Abstract:

The ship locks are most important infrastructural objects for traffic and transport on Danube navigable network. In operational sense they are the obstacles for inland navigation. It means they limit the Danube waterway transport and fleet capacities.

The ship locks in the function of using inland navigation on the Danube River present in first part of this paper. The number of ship locks on the Danube River are following: the Upper Danube (15 dams each with two standardized locks with one lock chamber), the Middle Danube (1 dam with two standardized locks with one lock chamber and 1 dam with two standardized locks each with two lock chambers) and the Lower Danube (1 dam with two standardized locks with one lock chamber). The authors research the individual ship lock capacity for 12 ship locks, mainly on the Upper Danube, depending upon the state of lock chamber and performances of each locks, kind of inland vessels/barge tows and upstream and downstream navigation.

In second part of this paper considers the restoration of Serbian ship locks: Iron Gate 1. The Serbian ship lock on right bank of Danube River operate in pair by the Romanian ship lock on left bank of Danube River. Their capacities analyze depending on the distribution of vessels/barge tows in front of dams and in back of dams (upstream and downstream navigation).

Keywords:

Eco/Co/multimodal transport; Inland navigation and ship locks on Danube River; Ship lock capacity; Ship time passing across ship lock.
1. INTRODUCTION

The basic characteristics of inland waterway transport development from 2010 to 2020 in the Danube Region are following:

- Strengthening and growth of road transport, especially in foreign trade increasing road transport in long distances in competition with other transport modes.
- Stagnation and relative decrease of Danube inland waterway transport in freight transport activities.
- All better results in pipeline transport causing decrease of liquid cargo traffic in Danube inland navigation.

This state follows the infrastructure in all transport modes, in other words, road network and pipelines many faster develop than rail trucks and inland waterways in the Danube Region.

The current transport utilization of the remaining Danube amounts 7 to 10% of its maximum theoretical/potential capacity. The main explanation for it lies in the economic framework conditions in the Danube catchment areas. Additionally, Danube navigation is presently faced with temporarily limited and fluctuating droughts at some sections, which affects its competitive position. Removal of the unfavorable fairway conditions on the Danube would therefore also contribute to the optimized exploitation of Danube's potential. [1]

The relationship between Danube waterway transport and Danube hydrological regime is given by the fact that vessels sail through the fairway built in Danube River and vessels' capacity transport depends on the water depth and width of fairway's sections. In the fact, the relationship between water depth and vessels' loading capacity is direct: the lower water depth, the lower vessels' carrying capacity.

On the other side, the International Commission for the Protection of the Danube River – ICPDR talks about negative effects due to climate change in the Danube River Basin including Danube fairway and Danube waterway transport:

- Measures in the past were not successful and current Danube River Management will not be successful to stop bed level degradation.
- Due to ongoing process to bed level degradation, water depth might decrease up to 0.6 m around 2030.
- Ongoing bed level degradation could have great impact on Danube waterway transport, especially at river locations with fixed layers.
- Sediment deficit in the Danube due to damming and regulation works repeated. The issue of sediment deficit remained open. [2]
It means the Danube infrastructural adaptation strategies have to involve all those physical measures aimed to modify ship locks such as the Iron Gate 1 including other ship locks along the Danube fairway.

The remainder of this paper is organized as follows. The section 2 provides a introduced consideration with a review of ship locks on Upper, Middle and Lower Danube. In the section 3 deals with a average lockage time, mainly on the Upper Danube. The section 4 includes the analysis of lock operations of Serbian and Romanian ship locks Iron Gate 1. In the section 5 cost of lockage is analyzed in frame of the Serbian ship lock Iron Gate 1. The economic analysis: savings after restoration of Serbian lock Iron Gate 1 are presented in the section 6. The section 7 describes the evaluation of air pollution and noise in area of Serbian lock Iron Gate 1 after adaptation (environmental conditions). This paper concludes with the section 8 and future research directions are suggested.

2. SHIP LOCKS ON UPPER, MIDDLE AND LOWER DANUBE

On international Danube fairway across ten riparian countries, from Kelheim, river kilometer- rkm 2414+840 to Sulina, rkm 0.000 (the junction of Danube in Black Sea) built 18 ship locks, from which 14 locks arranged in pairs at hydroelectric power stations (dams) as parallel, symmetrical or asymmetrical, standardized ship locks.

Four ship locks on Upper Danube (German part of Danube) are with one lock chamber for commercial vessels. Two locks have particular lock chamber for recreational vessels (dimensions of chamber: 20x4.0 m). From 18 ship locks 17 are with one longitudinal lock chamber (single step) including access canals on both sides of lock chamber (upstream and downstream direction), pre-berths at ship locks and other equipment for surmount of water height between up and down water levels in the chamber. This height varies between 7 and 17 m excepting Serbian and Romanian ship locks Iron Gate 1. The ship locks Iron Gate 1 are only with two longitudinal chambers (two-step) for surmount of difference of water levels in first chamber (in downstream direction) of 17.5 m and in second chamber of 17 m.

According to the characteristics of Danube fairway (longitudinal fall and velocity of water stream) 15 ship locks arranged on the Upper Danube (5 in German part of Danube and 10 in Austrian part of Danube). There are on average, mutual distance of 24.28 km in Germany and 31.23 km in Austria along Danube waterway. Also, the work of these ship locks depend on common operations, since lockage in one ship lock (for example, first lock in upstream direction) has the impact on the operations of other ship locks in both upstream and downstream directions.

On the Middle Danube built two dams: Gabčikovo (rkm 1819+150) with two ship locks Slovakian and Hungarian locks and the Iron Gate 1 including Serbian lock on right bank (rkm 942+950) and Romanian lock on left bank (rkm 942+950).
On the Lower Danube built one dam Iron Gate 2 with two ship locks the Serbian lock on right bank (rkm 863+000) and Romanian lock on left bank (rkm 863+700). The distance between Iron Gate 1 and 2 is approximately 80 km.

All Danube ship locks presented in the Table 2.1 with locations on the Danube waterway, dimensions of lock chamber, minimum depth on threshold of lock chamber and maximal allowed dimensions of barge tows/convoy.

The total lockage time of vessel/barge tow/convoy encompasses following times: the times of opening and closing lower and upper gates of lock chamber, the enter/exit times of vessels/barge tows/convoy to and from lock chamber, the preparation times with maneuvers for berthing and unberthing to and from lock bollards (in lock chamber) and times of water filling/discharge in lock chamber. [4]

In other words, passing times of vessel/barge tow/convoy through the lock depend upon numerous variables. The states of the lock chamber change as result of the following basic operations:

I. Upstream direction
(1) Closing of the gates at the lower lock head.
(2) Filling the chamber with water.
(3) Opening of gates at the upper lock head.

II. Downstream direction
(1) Closing of the gates at the upper lock head.
(2) Discharge of water from the chamber.
(3) Opening of the gates at the lower lock head.

<table>
<thead>
<tr>
<th>Name of ship lock</th>
<th>Distance from Sulina in rkm</th>
<th>Dimensions of lock chamber</th>
<th>Minimal depth on threshold, m</th>
<th>Maximum allowed dimensions of barge tow</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAD ABBACH</td>
<td>2397+170</td>
<td>190</td>
<td>4.00</td>
<td>185 11.40</td>
</tr>
<tr>
<td>REGENSBURG</td>
<td>2379+680</td>
<td>190</td>
<td>4.00</td>
<td>185 11.40</td>
</tr>
<tr>
<td>Location</td>
<td>Distance</td>
<td>Width</td>
<td>Depth</td>
<td>current</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>-------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>Geisling</td>
<td>2354+290</td>
<td>230</td>
<td>24</td>
<td>4.00</td>
</tr>
<tr>
<td>Straubing</td>
<td>2324+330</td>
<td>230</td>
<td>24</td>
<td>4.00</td>
</tr>
<tr>
<td>Kachlet</td>
<td>2230+330</td>
<td>230</td>
<td>24</td>
<td>2.50</td>
</tr>
<tr>
<td>Jochenstein</td>
<td>2203+330</td>
<td>230</td>
<td>24</td>
<td>5.22</td>
</tr>
<tr>
<td>Achach</td>
<td>2162+670</td>
<td>230</td>
<td>24</td>
<td>4.61</td>
</tr>
<tr>
<td>Ottensheim</td>
<td>2146+820</td>
<td>230</td>
<td>24</td>
<td>3.97</td>
</tr>
<tr>
<td>Abwinden</td>
<td>2119+540</td>
<td>230</td>
<td>24</td>
<td>4.39</td>
</tr>
<tr>
<td>Wallsee</td>
<td>2095+060</td>
<td>230</td>
<td>24</td>
<td>4.29</td>
</tr>
<tr>
<td>Ybbs-Persenbeug</td>
<td>2060+420</td>
<td>230</td>
<td>24</td>
<td>4.15</td>
</tr>
<tr>
<td>Melk</td>
<td>2038+060</td>
<td>230</td>
<td>24</td>
<td>3.41</td>
</tr>
<tr>
<td>Altenworth</td>
<td>1980+110</td>
<td>230</td>
<td>24</td>
<td>4.69</td>
</tr>
<tr>
<td>Greifenstein</td>
<td>1949+200</td>
<td>230</td>
<td>24</td>
<td>4.15</td>
</tr>
<tr>
<td>Freudenau</td>
<td>1921+050</td>
<td>275</td>
<td>24</td>
<td>4.87</td>
</tr>
<tr>
<td>Gabčikovo</td>
<td>1819+150</td>
<td>280</td>
<td>34</td>
<td>5.00</td>
</tr>
<tr>
<td>Iron Gate 1</td>
<td>Right Bank</td>
<td>310</td>
<td>34</td>
<td>5.00</td>
</tr>
</tbody>
</table>
### 3. AVERAGE LOCKAGE TIME ACROSS SHIP LOCKS ON UPPER DANUBE

The total lockage time has been measured in vessel/barge tow from moment of reducing speed (lighten power of main engines) in front of the ship lock to the moment of full power of vessel (main) engine(s) on the second side of lock in both directions of navigation (upstream and downstream). The measures performed in the period 1978-1984 within all three systems of transportation technology on Danube River:

- Push towing system.
- Pull towing system
- Self-propelled barge including combinations with pushed and pulled barges.

The Danube cargo fleet is presented in Fig. 1 depending on the Danube transport technology [5].

**Figure. 1. Types of freight ships/barge tows in Danube navigation.**
(a) Pushed barge tow with push boat;

(b) Pulled barge tow with pull boat;

(c) Self-propelled barge or freight motor ship;

(d) 1 – Self-propelled pushed barge with pushed barge in tow;

2 – Self-propelled pulled barge with pulled barge in tow.

The total lockage time of push/pull barge tows and self-propelled barge could calculate as follows [3]:

\[ t_{up} = t_{um} + t_{px} + t_p + t_{px}' + t_{im} \]  … (3.1)

where

- \( t_{up} \) = total lockage time, min;
- \( t_{um} \) = enter time of vessel/barge tow/convoy in lock chamber with maneuvers, min;
- \( t_{px} \) = prepared time of vessel/barge tow/convoy for lockage (connecting of vessel/barge tow/convoy for bollards on chamber’s walls) and time of closing of lower/upper gates in depending on navigable direction, min;
- \( t_p \) = filling/discharge time of lock chamber with water, min;
- \( t_{px}' \) = prepared time of vessel/barge tow/convoy for exit from lock chamber (untie of vessel/barge tow/convoy from bollards on chamber’s wall) and time of opening of lower/upper gates in depending on
navigable direction, min;

\[ t_{\text{im}} = \text{exit time of vessel/barge tow from lock chamber with maneuvers to establish full power of vessel engine(s), min.} \]

The waiting time of vessel/barge tow/convoy in front of ship lock and in lock chamber has been particularly measured. These times do not directly include in total lockage time although they belong to total lockage time.

Total lockage time for 11 ship locks on Upper Danube based on the measures in each ship lock according to the Eq. (3.1) presented in the Table 3.1 depending on the direction of navigation, types of vessel/barge tow and total [3].

**Table 2 – Average lockage time across some ship locks on Upper Danube.**

<table>
<thead>
<tr>
<th>Name of ship locks</th>
<th>Average lockage time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>GEISLING</td>
<td>45.00</td>
</tr>
<tr>
<td>KACHLET</td>
<td>62.33</td>
</tr>
<tr>
<td>JOCHENSTEIN</td>
<td>49.80</td>
</tr>
<tr>
<td>ACHACH</td>
<td>45.33</td>
</tr>
<tr>
<td>OTTENHEIM</td>
<td>36.80</td>
</tr>
<tr>
<td>ABWINDEN</td>
<td>39.46</td>
</tr>
<tr>
<td>WALLSEE</td>
<td>44.69</td>
</tr>
</tbody>
</table>
The data in Tables 1 and 2, could use for different analyses depending upon research interest. We have considered the ship lock operations for 11 ship locks in row from Geisling (rkm 2354+270) to Greifenstein (rkm 1949+200) in the length of 405 km on Upper Danube in Germany and Austria. In the meantime, new ship locks have been built which don’t include in this research.

The preparation of pulled barge tow in front of ship lock and in lock chamber requires more time and more works of ship crew than at push-towing system.

All times such as: enter time of barge tow in lock chamber with preparation for lockage, water filling/discharge of lock chamber, exit time of barge tow from lock chamber/ship lock area are random variables. Obviously, these time periods are under impact of many factors as natural, techno-technological, traffic and others which man cannot control (water levels, waiting time of vessels/barge tows, size of barge tow/convoy, etc.).

### 4. ANALYSIS OF LOCK OPERATIONS OF SERBIAN LOCK IRON GATE 1

The Serbian and Romanian ship lock Iron Gate 1 (rkm 944+950 – rkm 941+200) are parallel, two ship chambers in row and pair, by alternation changes the direction of lockage each seven days or each the Monday in month at six o’clock. One of them take on vessels/barge tows for downstream direction until second lock take on vessels/barge tows for upstream direction.

As a rule, the both ship locks aren’t do if one of them is in capital remount or during serious repairs and different failures. In this case, whole vessel/barge tow flow take on one ship lock in both directions (upstream and downstream).

The data of the Department for lock operation and monitoring of Serbian ship lock refers to only to lock operations without vessel/barge tow operations in lock [6], as shown in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>YBBS</th>
<th>PERSENBEUG</th>
<th>MELK</th>
<th>ALTENWORTH</th>
<th>GREIFENSTEIN</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>54.33</td>
<td>73.14</td>
<td>43.28</td>
<td>56.50</td>
<td>42.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Flexible</td>
<td>34.00</td>
<td>43.50</td>
<td>37.85</td>
<td>51.90</td>
<td>38.70</td>
<td>48.95</td>
</tr>
</tbody>
</table>

Table 3 – Lock operations without vessel/barge tow operations in lock area.
The data in Tables 1 and 2, could use for different analyses depending upon research interest. We have considered the ship lock operations for 11 ship locks in row from Geisling (rkm 2354+270) to Greifenstein (rkm 1949+200) in the length of 405 km on Upper Danube in Germany and Austria. In the meantime, new ship locks have been built which don't include in this research.

The preparation of pulled barge tow in front of ship lock and in lock chamber requires more time and more works of ship crew than at push-towing system. All times such as: enter time of barge tow in lock chamber with preparation for lockage, water filling/discharge of lock chamber, exit time of barge tow from lock chamber/ship lock area are random variables. Obviously, these time periods are under impact of many factors as natural, technological, traffic and others which man cannot control (water levels, waiting time of vessels/barge tows, size of barge tow/convoy, etc.).

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As a rule, the both ship locks aren't do if one of them is in capital remount or during serious repairs and different failures. In this case, whole vessel/barge tow flow take on one ship lock in both directions (upstream and downstream).

The data of the Department for lock operation and monitoring of Serbian ship lock refers to only to lock operations without vessel/barge tow operations in lock area [6], as shown in Table 3.

<table>
<thead>
<tr>
<th>Time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-30</td>
</tr>
</tbody>
</table>

<p>| Enter time of vessel/barge tow/convoy in Serbian lock Iron Gate 1 and connecting vessel/barge tow for bollards on chamber walls |</p>
<table>
<thead>
<tr>
<th>Lower section of double gate on middle head</th>
<th>Working gate on upper head</th>
<th>Plate plugs on upper and lower head</th>
<th>Segment’ s plugs on middle head</th>
<th>Double gate on lower head</th>
</tr>
</thead>
<tbody>
<tr>
<td>In dropping</td>
<td>In raising</td>
<td>8-10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>10-12</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Filling/discharge time of lock chambers with water (equalizing water levels between lock chambers) |
|----------|----------------|
| 15 |

| Disconnecting time of vessel/barge tow/convoy from chamber’s bollards, transit time of vessel/barge tow in upstream/downstream Chambers and connecting vessel/barge tow/convoy for chamber’s bollards |
|----------|----------------|
| 20-30 |

| Disconnecting time of vessel/barge tow/convoy from |
|----------|----------------|
| |

---
chamber’s bollards and transit time of vessel/barge tow/convoy to lock Berths (in upstream/downstream directions) | 20-30
---|---
Total | 126-165
Total in hours | 2.1-2.75

We calculated the total lockage time for vessels/barge tows or convoys from the start of damping ship engine(s) or reduce speed in front of ship lock to the full power of ship engine(s) on the other side of lock in alternations of upstream and downstream navigation. The waiting time of vessel/barge tow at lock anchorages and lock chamber and time of formation of barge tow did not measure in official departments of Iron Gate, although these times are the part of total lockage time.

The vessels/barge tows differ according to sizes and structure. It has the impact to the lock capacity and waiting time of vessels/barge tows at lock Iron Gate 1, as shown in Fig. 2.

Figure. 2 – Maximum possible dimensions of barge tow/convoy on the Danube waterway according to UNECE waterway classes (Fairway Rehabilitation and Maintenance Master Plan – Danube and its navigable tributaries, Version 13, November 2014, p.9)
Graphical presentation of upstream and downstream lockage of vessel/barge tow/convoy across Serbian lock Iron Gate 1 was composed by the data of Department for lock operations and monitoring and the sample on lock operations from 2013, as shown in Fig. 3.

Fig. 3 – Graphical presentation of upstream and downstream lockage of vessel/barge tow/convoy across Serbian lock Iron Gate 1 (Radinlović, Maraš, Milović, 2017, p. 14)
Legend:

GB = Upper Basin

DB = Lower Basin

$l'_{ui}$ = enter/exit distance of vessel/barge tow in lower basin;

$l''_{ui}$ = enter/exit distance of vessel/barge tow in upper basin;

$l_{pr}$ = transit distance of vessel/barge tow between two chambers (from first to second chamber);

$t_{pr, dv}$ = lockage time in both directions;

$t_{pr, j}$ = lockage time in one direction.

Operations
Two-way lockage
1,6 = enter;
2,4,7 and 9 = technical operations in lock chambers;
3,8 = transit from first to second chamber;
5,10 = exit.
One-way lockage
6,8 = technical operations in lock chamber;
6,8 = transit from first to second chamber;
9 = exit.

Technological diagrams approximately present an average upstream and downstream lockage including particular lock operations for ship lock Iron Gate 1 and particular lockage for vessels/barge tows/convoys, as shown in Figs. 4. and 5.

Figure. 4 – Average downstream lockage time across Serbian lock Iron Gate 1 with two chambers in row (Radmilović, Maraš, Milović, 2017, p.14)
### Operations and Time, min

<table>
<thead>
<tr>
<th>No.</th>
<th>Operations</th>
<th>Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Entry time of vessel/barge tow</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>1 Distance from signal to upper chamber</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 Connecting to bollards</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Working gate on upper head</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>1 Closing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 Plate plugs</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Water discharging time of upper chamber</td>
<td>15</td>
</tr>
<tr>
<td>4.</td>
<td>Opening time of double-gate on middle head-segment plugs</td>
<td>15</td>
</tr>
<tr>
<td>5.</td>
<td>Transit time of vessel/barge tow to lower chamber, disconnecting/connecting for bollards</td>
<td>25</td>
</tr>
<tr>
<td>6.</td>
<td>Closing time of double-gate with plate plugs</td>
<td>8</td>
</tr>
<tr>
<td>7.</td>
<td>Water discharging time of lower chamber</td>
<td>15</td>
</tr>
<tr>
<td>8.</td>
<td>Opening time of double-gate on lower head</td>
<td>12</td>
</tr>
<tr>
<td>9.</td>
<td>Disconnecting time of vessel/barge tow from bollards and passing across lower lock canal</td>
<td>25</td>
</tr>
</tbody>
</table>

Total downstream time:

1) Serbian lock Iron Gate 1
2) Lockage time for vessel/barge tow/convoy

**Fig. 5 – Average upstream lockage time across Serbian lock Iron Gate 1 with two chambers in row** (Radmilović, Maraš, Milović, 2017, p. 15)
If the duration of a complete lockage cycle (both directions) takes 273 minutes or 4 hours and 33 minutes, average free-flow waiting time is already 45 minutes per vessel assuming a uniform arrival pattern (30 min per vessel in both the busy period and the quiet period of the day plus 15 min due to possible congestion).

For instance, 10 620 540 tons of cargo and 7063 vessels have passed across Serbian lock Iron Gate 1 including vessels without cargo (empty vessels) in 2016. These vessels are quite concentrated on certain hours of the day, 70% of the daily passages are concentrated in 12 opening hours, whereas the remaining 30% of the arrivals are distributed over the other 12 hours. This leads to total waiting time due to congestion:

\[
0.7 \times 7063 \times 15 / 60 = 1236 \text{ hours for 2016},
\]

which can be valued against on average value of 74 Eur. This study calculated on a value of 78 Eur per vessel per hour for container shipments and 74 Eur for non-container shipments [7]. It means the waiting time costs in 2016 for Serbian lock Iron Gate 1 thus amount to

\[
1236 \times 74 = 91464 \text{ Eur per year}.
\]
The weakness of this method is in the valuation which does not take into account the composition of the types of vessels/barge tows, although the share of large vessels is much higher than small vessels [6].

Based on the analysis of lock operations in both locks Iron Gate 1 (Serbian and Romanian) through number of lockages, number of vessels across locks, freight tons of locked vessels and cargo throughput across locks Iron Gate 1 from 1970-2016, the results are following:

**SERBIAN LOCK IRON GATE 1**

- Average number of vessels per one lockage ……………………. 5 vessels
- Participation of freight tons in cargo tons ……………………. 48.75%
- Average amount of cargo per one lockage ……………………. 6180 tons
- Average amount of cargo per one locked vessel ……………………. 1236 tons
- Usage of permitted water area of lock chamber per one lockage …. 37%

**ROMANIAN LOCK IRON GATE 1**

- Average number of vessels per one lockage ……………………. 5 vessels
- Participation of freight tons in cargo tons ……………………. 51%
- Average amount of cargo per one lockage ……………………. 5991 tons
- Average amount of cargo per one locked vessel ……………………. 1198 tons
- Usage of permitted water area of lock chamber per one lockage …………. 37%

**COMMON WORK OF BOTH SHIP LOCKS IRON GATE 1 (SERBIAN/ROMANIAN)**

- Average number of vessels per one lockage ……………………. 5 vessels
- Participation of freight tons in cargo tons ……………………. 49.85%
- Average amount of cargo per one lockage ……………………. 6086 tons
- Average amount of cargo per one locked vessel ……………………. 1217 tons
- Usage of permitted water area of lock chamber per one lockage …………. 37%

The estimation of participation of empty vessels according to the total number of locked vessels changes between 30% and 40%.

The evidence of stoppages of Serbian lock Iron Gate 1 in period from 2010 to 2019. shows that the Serbian lock had longer periods without work.
5. COST OF LOCKAGE IN SERBIAN LOCK IRON GATE 1

This cost includes following items: maintenance cost (current and capital maintenance, repairs, rehabilitation and others according to the specifications) and operation cost (consumption of electrical energy in Serbian lock through consumed amount of water in MWh; consumed electrical energy in work of lock equipment in MWh and gross salaries of workers) in time period from 2013 to 2016. [6]

The structure of employees in the Department for lock operations and monitoring of Serbian lock is following:

- Deputy of Director for exploitation of hydro power station and lock Iron Gate 1.
- Lockmaster into the shifts.
- Electricians into the shifts.
- Experts for hydraulics into the shifts.

The Department for maintenance charges to current and investment maintenance of lock.

According to the Technical Sector of Hydroelectric power station the maintenance cost increases with degree of 15% per year and operation costs with degree of 5% per year because of old age equipment and lock (47 years) [6].

Based on the statistical analysis of average price of lockage in Serbian lock, the price has approximately determined for period from 2013 to 2016. In this calculation two alternatives have been developed. In first alternative the maintenance and operation costs did not include investment costs until second alternative encompasses the costs as whole (maintenance, operation and investment costs):

- First alternative – average price of lockage across Serbian lock Iron Gate 1 and standard deviation:
  \[ T_{sr,pr} = 479.18 \text{ Eur per one lockage for considered period 2013-2016.} \]
  \[ S = 306.66 \text{ Eur per one lockage.} \]

- Second alternative – average price of lockage across Serbian lock Iron Gate 1 and standard deviation:
  \[ T_{sr,pr} = 806.21 \text{ Eur per one lockage for considered period 2013-2016.} \]
  \[ S = 476.80 \text{ Eur per one lockage.} \]
These results could conditionally receive since the pattern is restrict in time period (very short) and maintenance cost have had large deviations from 582 000 Eur and 703 lockages in 2013 to 104 000 Eur and 1644 lockages in 2014. [6].

Addition costs mainly depend on the duration of adaptation and rehabilitation of Serbian lock. In this period vessel’s traffic in both directions will be accepted by Romanian lock Iron Gate 1. Average number of lockages for both locks is approximately 3250 lockages per year from 1970 to 2016 year. In former work the Serbian lock have had largest number of lockages in 1973 (3102) and Romanian lock in 1970 (4230). By the survey of number of lockages could see that this number decreases and each lock could receive whole vessel’s traffic in both directions, for example, one of them in capital remount.

The addition cost could determine when Romanian lock only works by same methodology. For example, 21 562 315 tons of cargo and 14 248 vessels have been passed across Romanian lock Iron Gate 1 including empty vessels in 2016. If the duration of a complete lockage cycle in both directions takes 273 minutes or 4 hours and 33 minutes (Fig. 4. and 5) same as in Serbian lock Iron Gate 1, average free-flow waiting time for both directions could approximately assume 70 minutes per vessel from which 25 minutes due to congestion.

Under same assumptions, these vessels are quite concentrated on certain hours of the day, 70% of the daily passages are concentrated in 12 opening hours, whereas the remaining 30% of the arrivals are distributed over the other 12 hours. This lead to total waiting time due to congestion:

\[
0.7 \times 14248 \times 25/60 = 4156 \text{ hours per year},
\]

which can be valuated against on average value of 74 Eur per vessel-hour for non-container shipments [7]. It means the waiting time costs in 2016 during the adaptation of Serbian lock Iron Gate 1 are following:

\[
4156 \times 74 = 307 544 \text{ Eur per year},
\]

or 300-320 thousands Eur, if the adaptation lasts one year.

6. ECONOMIC ANALYSIS: SAVINGS AFTER RESTORATION OF SERBIAN LOCK IRON GATE 1

The savings refer to:

- Saving in trip time or voyage time of vessels
- Saving in operative costs of shipping companies.

Based on available data the saving in trip time of vessel should determine after the adaptation of Serbian lock. According to official data of Technical Sector of Serbian part of Iron Gate 1 did not exist difference between upstream and downstream lockage time. Their estimations of average lockage time in one direction is 100 minutes only for lock operations.
in conditions before the adaptation. By the adaptation of Serbian lock Iron Gate 1 the
lockage time decreases and returns on 90 minutes. This will have the impact on lock
capacity and number of lock stoppages.

For 46 years the Serbian lock have had 1646 average number of lockages per year
(maximum 3102 lockages in 1973 and minimum 207 lockages in 1995) and the Romanian
lock have had 1639 average number of lockages per year (maximum 4230 in 1970 and
minimum 244 lockages in 1999).

The saving in trip time of vessel could simply determine on annual level for average
number of lockages per year and average saving time at one lockage (upstream or
downstream) for vessel in Serbian lock as [5]:

\[ 1646 \text{ lockages} \times (100 - 90 \text{ minutes}) = 16460 \text{ minutes or 274.33 hours or 11.43 days}. \]

The calculated savings are incomplete and rough estimations since the calculation don’t
include many and complex variables such as: duration of lockage time for most often types of
vessels/barge tows, annual opening hours of lock, uneven arrivals of vessel/barge tow at
Iron Gate 1, priority of service, etc.

According to the number of locked vessels in the period 1970-2016, average number of
locked vessels per year is 8500 vessels including empty vessels in both directions in
Serbian lock.

Average free-flow waiting time for both directions approximately assumed 45 minutes per
vessel (30 minutes per vessel in both the busy and quiet period of day and 15 min due to
possible congestion). After adaptation of Serbian lock the average free-flow waiting time of
vessels for both directions approximately assumed 25 minutes per vessel (15 minutes per
vessel in both directions and 10 minutes per vessel due to possible congestion). The
assumption is that these vessels quite concentrated on certain hours of the day, 70% of daily
passages are concentrated in 12 opening hours, whereas the remaining 30% in other 12
hours. This leads to total waiting time of vessels due to congestion:

- Before adaptation of Serbian lock:
  \[ 0.7 \times 8500 \times 15/60 = 1487.5 \text{ hours per year} \]

- After adaptation of Serbian lock:
  \[ 0.7 \times 8500 \times 10/60 = 991.66 \text{ hours per year} . \]

Now, average cost of vessel waiting time per lockage by average price of 74 Eur per vessel-
hour for non-container shipments:

- Before adaptation of Serbian lock:
  \[ 1487.5 \text{ vessel-hours/year} \times 74 \text{ Euro/vessel-hour} = 110 075 \text{ Eur/ year} \]
After adaptation of Serbian lock:

991.66 vessel-hours/year x 74 Eur/vessel-hour = 73 383 Eur/year, and

Cost saving for shipping companies:

110 075 – 73 383 = 36 692 Eur/year.

7. EVALUATION OF AIR POLLUTION AND NOISE IN AREA OF SERBIAN LOCK IRON GATE 1 AFTER ADAPTATION

Environmental cost at the Serbian lock Iron Gate 1 comes from the damages producing vessel emissions in air, water and soil. The Serbian lock area includes the space in the length of 14 km alongside Danube fairway, from rkm 949 (position of first traffic signal for entrance of downstream vessels/barge tows in Serbian lock area) to rkm 935+700 (position of first traffic signal for entrance of upstream vessels/barge tows in Serbian lock area).

Air pollution refers to the emissions of polluters from vessel engine(s) such as: CO₂ (carbon dioxide), NOₓ (nitrogen oxides), SOₓ (sulfur oxides), PMₓ,ᵧ (particulate matters, diameter from x to y) and NMVOC (Non-methan volatile organic compounds). Their emissions mainly depend on the kind of fuel which use the Danube vessels. Most frequent fuel on Danube vessels is diesel oil. For this type of fuel, the air pollution will be evaluated within Serbian lock area in length of 14 km and average locked vessels per year of 8500 vessels in period 1970-2016.

We assumed that one quarter of 8500 vessels are motor vessels such as: pushboats, pulltugs, self-propelled barges, passenger ships including cruise ships and recreational boats and yachts having in mind that average number of vessels per on lockage equals to 5 (Section 4.).

Main and auxiliary vessel engine(s) are medium- and high-speed diesel motors with following characteristics: different old age, different powers, different outfitting and fuel consumption. The fuel consumption depends upon engine power, production year of engine, number of kilometers in navigation, usage of carrying capacity, size of barge tow, etc. Empty barge tows have less fuel consumption and emissions also.

The determination of emissions is connected by average power of main engines, specific type of diesel fuel (ship diesel oil with low sulfur content to a maximum of 10 ppm) and average diesel fuel consumption per kg/vessel-km. Average fuel consumption of diesel oil has been established of 38.63 l/vessel-km by comprehensive analysis and working evidence in sample of pushboats (nominal power from 360 kW to 2100 kW) with push barges, cargo motor vessels or self-propelled barges (nominal power between 600kW and 1300 kW) which passed across Serbian lock Iron Gate 1 during 2013.

As mentioned, we assumed that one quarter of total number of locked vessels are motor vessels. It means from total number of locked vessels per year of 8500 vessels 2125 vessels have been motor vessels.

Average fuel consumption in Serbian lock area in length of 14 km is following:
Now, total fuel consumption in Serbian lock area is following:

\[
2125 \text{ vessel/year} \times 540.82 \text{ l/vessel} = 1149242 \text{ l/year} \quad [6].
\]

The actual engine power and diesel fuel consumption per kg/vessel-km for all types of the Danube vessels are not precisely known since precise and comprehensive data on the engine composition of Danube fleet are not registered on the Danube Region level. For these reasons, the bottom-up approach has been applied to local inventories based on the interviews with ship owners and by means of consistency check with fleet registers by the Authority for Determination of the Seaworthiness in Serbia [8].

The EMEP/EEA (European Monitoring and Evaluation Programme/European Environment Agency) air pollutant inventory guidebook and more precisely the International navigation, national navigation, national fishing and military (shipping) [9], were considered as reference for emission estimate at inland navigation across Serbian lock Iron Gate 1.

Emissions from inland navigation across Serbian lock could be estimated at different levels of complexity. In paper [9 pp. 12-29], are expressed three tiers of increasing complexity as: “‘Tier 1’ method using default emission factors only, ‘Tier 1’ emission factors assume an average technology for fleet.” This approach for navigation uses the general equation to be applied for the different NFR (Nomenclature for Reporting Source Category Code) codes [9 p. 12]:

\[
E_i = \sum_{m} (FC_m \cdot EF_{i,m})
\]

… (7.1)

where:
- \( E_i \) = emission of pollutant \( i \) in kilograms;
- \( FC_m \) = mass of fuel type \( m \) sold in the country for navigation (tons);
- \( EF_{i,m} \) = fuel consumption – specific emission factor of pollutant \( i \) and fuel type \( m \) (kg/tons);
- \( m \) = fuel type (bunker fuel oil, marine diesel oil, marine gas oil, gasoline).

The applied factors for calculation of emissions from inland navigation at Serbian lock have adopted by European Environment Agency. They presented in Table 4.

**Table 4 – Emission factors for vessels using diesel oil.**

<table>
<thead>
<tr>
<th>Polluter</th>
<th>Emission factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>3200</td>
<td>kg/t goriva</td>
</tr>
</tbody>
</table>
S = percentage sulfur content in fuel: 0.1% from 1 January 2010 for inland waterway vessels and ships at berth in Community ports.

Based on the data on emission factors (Table 4) and Eq. (7.1) evaluated amount of pollutants’ emissions presented in Table 5.

**Table 5 – Annual emissions of air polluters from vessels in Serbian lock Iron Gate 1 area.**

<table>
<thead>
<tr>
<th>Polluter</th>
<th>Emission factor, kg/t diesel fuel</th>
<th>Correction factor</th>
<th>Total amount, tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ – carbon dioxide</td>
<td>3170</td>
<td>1000</td>
<td>3643</td>
</tr>
<tr>
<td>NOₓ – nitrogen oxides</td>
<td>78.5</td>
<td>1000</td>
<td>92.21</td>
</tr>
<tr>
<td>PM₁₀ – particle matters with diameter of 10 microns</td>
<td>1.5</td>
<td>1000</td>
<td>1.72</td>
</tr>
<tr>
<td>SO₂ – sulfur dioxide</td>
<td>0.0002</td>
<td>1000</td>
<td>0.000229</td>
</tr>
<tr>
<td>VOC – Volatile organic compounds</td>
<td>2.7</td>
<td>1000</td>
<td>3.1</td>
</tr>
<tr>
<td>Total amount</td>
<td></td>
<td></td>
<td>3740.03</td>
</tr>
</tbody>
</table>

The estimation of ecological efficiency for inland navigation system at Serbian lock area and the process of measure of carbon footprint mainly depend upon gather data. In this case gathering data don’t exist that we have to receive this evaluation as very crude estimation in view of precisely.

The basis of this calculation can be found on the TREMOVE data. The TREMOVE model is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model covers passenger and freight transport and covers the period 1995-2030. TREMOVE distinguishes 21 types of inland waterway transport vessels, namely 3 types of vessels (cargo, tanker and pusher) and 7
sizes (from under 250 ton until over 3000 ton). Air pollution costs from vessel emissions presented in Table 6 for most common types of vessels [7].

Table 6 – Emission costs for most common types of vessels (Eur per vessel-kilometers).

<table>
<thead>
<tr>
<th>Type of vessel</th>
<th>Rural area</th>
<th>Urban area (300000 inhabitants)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SO₂</td>
<td>NOₓ</td>
</tr>
<tr>
<td>Dry cargo, 400-650 t</td>
<td>0.03</td>
<td>0.34</td>
</tr>
<tr>
<td>Dry cargo, 1500-3000 t</td>
<td>0.09</td>
<td>1.28</td>
</tr>
<tr>
<td>Tanker, 450-600 t</td>
<td>0.02</td>
<td>0.34</td>
</tr>
<tr>
<td>Tanker, 1500-3000 t</td>
<td>0.14</td>
<td>1.98</td>
</tr>
<tr>
<td>Push barge, 400-650 t</td>
<td>0.12</td>
<td>1.67</td>
</tr>
<tr>
<td>Push barge, 1500-3000 t</td>
<td>0.12</td>
<td>1.67</td>
</tr>
</tbody>
</table>

Based on the emission costs for tanker (1500-3000 t) we calculated annual total cost of emissions in Serbian lock area as rural area, as shown in Table 7.

Table 7 – Annual emission costs from vessels in Serbian lock area.

<table>
<thead>
<tr>
<th>Polluters</th>
<th>Total amount, tons</th>
<th>Annual vessel-km</th>
<th>Costs, EUR/t</th>
<th>Cost EUR/vessel-km</th>
<th>Total, EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>3643</td>
<td></td>
<td>87.00</td>
<td></td>
<td>316 941</td>
</tr>
<tr>
<td>NOₓ</td>
<td>29750</td>
<td></td>
<td></td>
<td>1.98</td>
<td>58 905</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>29750</td>
<td></td>
<td>0.45</td>
<td></td>
<td>13 387.5</td>
</tr>
<tr>
<td>SO₂</td>
<td>29750</td>
<td></td>
<td>0.14</td>
<td></td>
<td>4 165</td>
</tr>
<tr>
<td>VOC</td>
<td>29750</td>
<td></td>
<td>0.005</td>
<td></td>
<td>1 487.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>394 886</td>
</tr>
</tbody>
</table>

Under an assumption that 2125 motor vessels passed across Serbian lock area in length of 14 km, it means these vessels achieved:

2125 motor vessels x 14 km = 29750 km per year [6].
The CO₂ emission factor for diesel oil fuel has been taken by the Report of German refineries [10]. The calculation yields CO₂ emission factor of 3170 kgCO₂/ton fuel (pushers, pull boats and freight motor vessels and 2995 kgCO₂/ton fuel (cruise passenger ships).

The valuation of CO₂ emissions was adopted by the literature [11]. Extrapolating the cost values back to 2011 prices, results of 87 Eur per ton CO₂, which is the most recent estimate for all EU countries for period to 2020.

The noise with low frequency, such as in the Danube navigation at hydropower of Iron Gate 1, is low in comparison with noise producing road traffic in City of Kladovo and their surroundings. The City of Kladovo with surroundings has about 20000 inhabitants, only the Kladovo about 9000 inhabitants. The urban part of Kladovo get away about 10 km from hydropower Iron Gate 1 with ship locks. The determination of total costs of noise in/out borders of Kladovo must be connect with number of inhabitants under the impact of noise. This depends on level of urbanization in Kladovo area. We will assume that inland navigation in area of ship locks produces low cost of noise, since few peoples live alongside of Danube banks in this case.

8. CONCLUSIONS

There is no straightforward answers to the question about the decision support factors and best adaption measures to face the impacts of low water periods on the Danube waterway transport (DWT). However, the behavior of the actors in the DWT market suggests that customers are the ones under more pressure to adapt, particularly Danube shipping companies (and ship owners). Noticeable impacts are expected to occur on the Danube hydrological regime due to changes on water discharge, changes on river morphology and water temperature. Changes on Danube water discharges show direct consequences on efficiency, safety and reliability of Danube waterway transport. High discharges will cause traffic problems and low water discharges will limit loading capacity and will increase grounding risk.

The level of urgency for adapting differs between Danube shipping companies, shippers and forwarders, with one side, and the official institutions for management and maintenance of Danube fairway, with second side. The adaption strategies and measures could be: strategy of new Danube vessels’ design, logistics measures and Danube infrastructural strategies for maintenance of fairway and river management, including Serbian and Romanian locks Iron Gate 1.

The Danube shipping companies adapt on different ways as follows:

- Waiting time of higher water levels
- Lightering/reloading of cargo from vessels to minimize its draft
The Danube shipping companies adapt on different ways as follow: Serbians and infrastructural strategies for maintenance of fairway and river management, including could be: str maintenance of Danube fairway, with second side. The adaption strategies and measures and forwarders, with one side, and the official institutions for management and.

The level grounding risk. traffic problems and low water discharges will limit loading capacity and will increase efficiency, safety and reliability of Danube waterway transport. High discharges will cause water temperature. Changes on D hydrological regime due to changes on water discharge, changes on river morphology and companies (and ship owners). Noticeable impacts are expected to occur on the Danube customers are the ones under.

8. CONCLUSIONS

There is no straightforward answers alongside of Danube banks in this case. This depends on level of urbanization in Kladovo about 9000 inhabitants under the impact of noise. The City of Kladovo with surroundings has about 20000 inhabitants. The urban part of Kladovo get away about 10 km from surroundings. The noise with low frequency, borders of Kladovo must be connect with number of inhabitants under the impact of noise.

The project of restoration and adaption of Iron Gates 1 understand high level of quality of lockages in both directions, savings in operation and maintenance costs, cost savings for shipping companies, increasing of reliability and safety of inland navigation with less stoppages and vessel waiting times at locks and lock chamber.

References:


SESSION 6. HUMAN ELEMENT
**FATIGUE DUE TO ON BOARD WORK CONDITIONS IN MERCHANT VESSELS**

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**Abstract:**

Several publications point to the human error like the fundamental cause of the practical whole of the accidents. Inside these accidents, the fatigue has been identified like a recurrent cause, already was as first cause or like an important factor that produces the human error. Investigations carried out during the course of these years have shown that the chronic fatigue problems, the problems related to the stress and other problems of the health are associated with the conditions of work on board. On board, the fatigue related to the work depends directly on the characteristics on the work environment that the worker is exposed and, specifically, to the type of demands imposed by the task.

With the aim to define in an objective way the levels of fatigue associated with the tasks and related aspects of the engineering department crew on board merchant vessels, a survey on workers of this department was conducted. The results showed a high level of complexity in the work performed due to the tremendous physical and mental needs required to perform the typical tasks on board these vessels.

**Keywords:**

Fatigue; Ship; Accident; Human Factor; Work Conditions.

**INTRODUCTION**

Several publications [1,2] have implicated human errors as the fundamental cause of numerous maritime accidents. This type of error is one of the more critical taxpayers’ factors being 80 percent of them [3]. In this sense, the European Platform of Information on Maritime Accidents (EMCIP) [4] investigated the incidents and accidents that occurred on board European vessels during 2011–2014 and found that 67% of these incidents occurred due to human errors.

Among these errors, fatigue was identified as a recurrent cause, usually the first cause or an important factor that leads to the production of other human errors [5,6,7,8]. Further investigations during the course of years [9,10] has revealed that chronic fatigue issues or
problems related to stress and other health conditions are associate with the work environment on board maritime vessels [11].

Fatigue can be defined as a decrease in the capacity of answering or action of a person, due to the resting of our organs [12]. Fatigue can manifest in distinct forms, although it can be differentiated into three major groups:

- **Physiological symptoms**: these symptoms are characterized by the presence of changes associated with a decrease in the capacity to make certain efforts.

- **Conductual symptoms**: these symptoms are associated with the deterioration of the level of performance or through the apparition of physical expressions, such as a yawn. It is necessary to undertake studies on the tendency to assume a greater level of risk when the degree of fatigue increases [13].

- **Subjective symptoms**: these symptoms refer to the perception by the workers of their feelings of discomfort or pain (physical fatigue), difficulty in keeping the eyes open or remaining awake (fatigue related with dizziness), or difficulty in concentration, to take decisions, and to think rapidly (mental fatigue) [14].

At the same time, fatigue can be induced by diverse factors such as long periods of physical or mental activity, insufficient rest, environmental conditions (level of noise, illumination, temperature, etc.)[15] and the organisational conditions under which the work is performed (structure organization, style of supervision, labour climate, etc.). The level of stress generated by the characteristics of the task, by the environmental conditions and the characteristics of the organization in which it develops the activity [16], often interferes in the way a worker processes information, although the interference is always accompanied by degradation of the level of performance [17].

Regarding fatigue in relation to work, it depends directly on the characteristics of the work environment that the worker is exposed to and, specifically, to the type of demands imposed by the task on the worker. The most important factors of the task that are related to the possible apparition of fatigue could be the following [18]:

- **Physical load**: the relation existing between the physical load and the apparition of fatigue when the worker is in a situation of continuous muscular work until reaching the point of exhaustion.

- **Mental load**: when the workers are subjected to situations of overloaded mental tasks, fatigue may occur, which in turn affects the performance of the worker negatively.

- **Physical environment**: factors such as the level of noise, vibrations, illumination, and temperature can act as a risk factor for the worker’s health.

- **Moment of the day and the level of deprivation of dream**: the circadian rhythms affect the level of performance as well as the degree of drowsiness that a person suffers from. The performance associated with work could be the product of a series of actors that interact among themselves (the demands of different tasks, the specific shift system and the individual differences). The main causes of somnolence are the age, general health, quantitative requirements, job satisfaction, fatigue during the night shifts—which had a
greater general level of fatigue among workers than during the day shift[19] —and the quality of the dream[20].

- **Psychosocial conditions of the work**: the psychosocial conditions of the task, such as the worker’s level of commitment, roles, interpersonal and team relations, career progression in the enterprise, the supervisory style, and even the loss of interest in work are related to the occurrence of fatigue.

In consequence, based on previous statements, the present paper aims to determine the real working conditions in merchant ships in accordance with the type of vessel, the engine room automation level and the type of navigation, between other parameters.

2. MATERIALS AND METHODS

To analyse the work environment in a vessel and to examine the possible causes that produce fatigue among personnel on board, it is important to understand the concept of the International Maritime Organization (IMO). The IMO is a skilled organisation of the United Nations that is responsible for the security and protection of navigation and to warn regarding sea pollution from vessels. The IMO constitutes the Assembly, which is a body of work that is evaluated by committees and subcommittees, with the Committee of Maritime Security (MSC) being the oldest and, in case of fatigue, the most influential personnel.

On 4 November 1993, the IMO adopted the Resolution A.772(18) “Fatigue Factors in Manning and Safety”, which defined fatigue as a decrease in the human performance [21], decrease in the reflections as well as a decrease in the capacity to conduct rational trials. The IMO used this factor to tackle the question of fatigue and the hours of rest.

On the other hand, during the sixty-eighth period of MSC sessions, the International Confederation of Free Trade Unions (ICFTU) presented the results of a survey regarding the hours of work, which was prepared by the members of the National Union of the United Kingdom (National Union of Marine, Aviation and Shipping Transport Officers) (NUMAST), some of which are given below:

- The ship’s crew on board have a greater volume of work, which increases the workload on an individual, thereby resulting in fatigue.

- The coastal navigation presents greater fatigue that the oceanic ones, because the realization of scales in port is more frequent.

- The organisation of the work and the structuring of the resources govern by forms elaborated does too many years.

- The countries with less-developed maritime tradition presented with more problems related to fatigue.

- The crew members considered that the major reason for the fatigue on board was insufficient crew.
After this survey, the ICFTU presented a MSC study on fatigue, conducted by the International Federation of Workers of the Transport (ITF) in front of the sixty-ninth period of sessions. This study was based on the answers of 2,500 marines belonging to 60 nationalities who loaned services on board from 63 ships of distinct pavilion [22]. The major reasons indicated by this study were the intensity of work hours and the insufficient rest time in the maritime sector.

Fatigue is not only relevant to the immediate and negative consequences of the action of a fatigued crew, but also with respect to the health and the quality of life of the worker [23].

Regarding the international regulation on the necessary personnel on board of a fuselage, the Resolution A.1047(27) [24] states “Principles of Minimum Safe Manning”, which revokes to the resolutions A.890(21) “Principles of Safe Manning”, and to A.955(23), “Amendments to the Principles of Safe Manning”, which establishes the guidelines for the application of the relative principles to the minimum endowment of security which guarantee that a fuselage has a sufficient and efficient endowment to guarantee the crews’ security and protection.

The minimum endowment of security of a fuselage was established taking into account all pertinent factors, including the following:

- The size and type of the ship;
- The number, power and type of main and auxiliaries engines units;
- The level of automation of the fuselage;
- The construction and equipment of the vessel;
- The maintenance methods employed;
- The load to transport;
- The frequency of the scales in the ports, the length and nature of the trips made;
- The zone(s) of navigation, routes of the vessel and operations undertaken; and
- The measure of activities performed during training on board.

Regarding the number of hours of work and rest of personnel on board in ships, there exist two agreements: the International agreement on the norms of the degree and the guards of the people of sea [25], amended in 2010, and the Maritime Labour Convention [26].

The STCW is the international norm that regulates the minimum numbers of hours of rest; these rules are applicable to the officials and sailors that form a part of the guards of navigation, the guards of machines or guards whose functions are committed or designated to security, prevention and protection. The minimum numbers of hours of rest to the sailors and officials to whom these committees are assigned are 10 hours during a period of 24 hours and 77 hours during a period of 7 days. Thus, at most, in two periods, one person is likely to have a minimum 6 hours of rest. The interval between two consecutive periods is thus, at most, 14 hours. When a worker has to be traceable at all times (as is the case in the spaces of machines without permanent endowment), he or she enjoys a compensatory rest period if they worked during the rest period.
At the same time, the MLC [26] treats man-hours and rest hours for people at sea. One of the differences with the STCW roots in that, it establishes only the hours of rest, whereas the MLC[26] establishes that the maximum man-hours cannot exceed 14 hours during a period of 24 hours or 72 hours during a period of 7 days; there is no exception that allows a period of rest of 70 hours during a period of 7 days to (maximum) 2 weeks. The MLC [26] recognizes that the man-hours of workers at sea equal that of other workers, which is 8 hours, with a weekly rest day; the days of rest correspond to the official holidays. This not being an obstacle allowed the members to form a collective agreement to establish normal man-hours that are no less favourable that that proposed by the Agreement.

Subsequent to the survey presented by the ICFTU during the sixty-eighth period of sessions of the Committee of Maritime Security, this same Committee, in their seventy-first period of sessions, tackled the question of fatigue and assessed directions required to consider the IMO performances [27] and elaborated, in their seventy-fourth period of sessions, guidelines for modules of each part involved in the safety aspects of the ship.

The aim of these guidelines was to gather information regarding adaption to a practical format involving all aspects involved in the security of the ship.

The guidelines were composed of destined modules, each for one part of interest, as detailed below:

- Module 1: Fatigue.
- Module 2: Fatigue and the Ratings.
- Module 3: Fatigue and the Ship's Officers.
- Module 4: Fatigue and the Masters.
- Module 5: Fatigue and the Training Institutions and Management Personnel in charge of Training.
- Module 7: Shipboard Fatigue and the Naval Architects.
- Module 8: Fatigue and the Maritime Pilot.
- Module 9: Fatigue and Tugboat Personnel.
- Appendix: Fatigue related documentation.

During the proposal of amendments to the Guidelines on fatigue that appear in the annex of the circular MSC/circ.1014[28], it was established that a tool be used to evaluate fatigue, such as a program based on the operational needs in vessels and fatigue studies that allow anticipation of their possible effects.

The said tool would be required to mainly identify the programs of work shifts that can cause fatigue with the aim to improve their conditions. There are unforeseen situations that may modify the shifts, such as illnesses of the crew, technical problems and meteorological
conditions. We have to analyse the programs of shifts that in practical situations contribute to the determination of possible fatigue effects.

Åhsberg et al. [29] developed an instrument for perceiving fatigue in a work evaluation, designated on the likes of the Swedish Occupational Fatigue Inventory (SOFI), which integrates five dimensions of fatigue, namely, fault of energy, physical tiredness, physical discomfort, fault of motivation and somnolence, as defined below:

- **Fault of energy**: this dimension refers to the general feelings of decrease in the strength.
- **Physical tiredness**: it collects the general feelings of the body resulting from dynamic work and signs of metabolic exhaustion.
- **Physical discomfort**: a dimension that describes corporal feelings resulting from a load of static work.
- **Fault of motivation**: it refers to the feeling of neither being engaged with the work nor being excited about it.
- **Somnolence**: it collects the feelings of somnolence.

The validation was performed through a series of experimental studies and descriptive characters, with a careful observation of the command of some dimensions on others in as a function of the work type evaluated. Originally, the SOFI [29] was composed of 25 expressions, five for each dimension, with the scale of assessment of 11 points.

In their first experimental study, Åhsberg and Gamberale [30] analysed fatigue generated by two types of physical work. Their second experimental study [31] identified the dimensions of fatigue preferably associated with a certain form of mental work. In order to analyse the effect of shift system on fatigue perceived by SOFI, workers were engaged in rotating shifts [32]. Finally, the SOFI was administered to people that developed this activity in five professions with totally different work load [33].

The instrument was later revised [33], and the number of expressions in each dimension was reduced to four, such that the questionnaire finally consisted of 20 elements, and the answer scale was changed to 1–7 points.

In Spain, an investigation was conducted to check the reliability and validity of SOFI in the Spanish population [34]. The results obtained showed that the Spanish adaptation of the SOFI was a valid and reliable instrument to evaluate fatigue related to work from a multidimensional perspective in the Spanish population.

The resultant adaptation to the Spanish language includes 15 expressions related to physiological answers (cognitive, motor and emotional aspects), through which the five basic dimensions of fatigue (fault of energy, fault of motivation, somnolence, physical unrest and physical effort) can be measured. The reliability of the instrument was satisfactory, and the examination of the convergence gave important results. This adaptation constituted an extremely notable product, taking into account the previous errors in suitable tools to measure the fatigue level related to work in the context of the Spanish language.
Next, a modification [35] of the SOFI Spanish version was developed, called as SOFI Spanish Modified version (SOFI-SM) which allowed evaluation of a new dimension called as emotional fatigue or irritability. The irritability in this version refers to a dimension that describes the feelings of irritation, nervousness, anger or irascibility.

The original version of the SOFI requires that the participant describe in 11-points scale, with “0” indicating minor extension and “10” indicating major extension. However, in this survey, the scale was reduced and the questions were classified on the scale of Likert [36]; this scale builds according to a series of items that indicate a positive or negative attitude, with each item possessing five possible answers ranging from value 1 to 5, where “1” indicates a strong disagreement and “5” indicates total agreement.

It is interesting to point out that it is necessary to develop these subjective methods of evaluation of labour fatigue for maritime ships considering the dearth of literature on the same [37].

Based on these comments, and in a similar way than the previous studies of MSC study of fatigue, a survey about fatigue on board merchant ships was done. Like in these previous studies, this survey was organised in 25 questions. Eight of the questions are related with descriptive aspects like the type of vessel and other seventeen questions were related to the fatigue level like, for instance, the engine room automation level, the type of navigation, working hours, and sleeping hours. As an up to date of the previous methodology, an original point of view was incorporated into our methodology. In this sense, it was employed the social media, “Facebook” using the page on Marine Engineering. This new procedure lets us to improve the time and agility needed to analyse this kind of database of responses obtained. What is more, it is interesting to highlight that, as it is well known, Facebook is a social networking that, once developed and administrated by the authors, more than 4900 marine engineers in different merchant vessels were connected and let us to respond the survey in a reduced time period of five days.

3. RESULTS AND DISCUSSION

As it was explained before, a survey of the engineering department crew on board merchant vessels was conducted to understand their levels of fatigue in association with their respective tasks and related aspects. In particular, this poll was conducted through the social media, “Facebook” using the page on Marine Engineering. As a result, the survey was filled in 108 merchant ships reaching what it can be considered as a representative participation level, as we can see in Figure 1. In this sense, it is interesting to highlight that the mean, the median and the mode of the numerical punctuation obtained from each question showed similar values for each variable analysed, which can be identified with a normal distribution centred in the average value. What is the same, a no compensation between extreme values will not offer us, in this case, a non-representative average scale value.

If we now start the analysis of the obtained results, it was obtained in Figure 2 that the rank or positions of the respondents who answered the poll. At the same time, with regard to the age of the respondents who participated in the survey, 70% are in the range between 25-45 years.

The most usual turns within the population polled have been other different that the proposed in the poll, followed for the unattended machine type. This conclusion is reflected in Figure 3.
The fast technological development and the reduction in the number of crew members in the vessels’ engineering department have contributed to the greater workload on the crew [38], in addition to seeing altered the tasks to make[39].

As seen in Figure 4, the level of automation of the machines on which the crew worked were either half or more than half. On a scale of 1 to 5, 31.5% of the crew answered 3 and 30.6% answered 4 with reference to the machine automation level. On the scale of 1 to 5, the value 5 indicates total accordance; therefore, 30.6% value indicates sufficient agreement.

Figure 5 shows the type of navigation. A detailed analysis of the responses revealed that 56.5% of the personnel sailed on vessels that make trips near the coast and hence “coastal navigation”, while 42.6% sailed in vessels that moved away from the coast and hence “oceanic navigation”.

The relation to the demand corresponding to a particular job post was also noticed with reference to the physical load, mental load, motivation, job requirements, and insufficient staff.
Figure 3. The percentage-wise segregation of work shifts of the crew members.

Figure 4. The engine room automation level at the maritime vessels.

Figure 5. The type of navigation made by the respondents.
Figure 6 shows that the greatest percentage of answers for the first question, “My position requires physical effort” is 3 (corresponding to 33.3% of respondents). This observation indicates that his work position requires a medium level of physical effort, whereas the answer given in terms of percentages (31.5%) indicate that the respondent considered that his position required a high level of effort.

Figure 7 shows the corresponding percentages of responses to the questions: “I feel fatigued when I initiate my work day” and “I feel fatigued at the end of my work day”. The most common answer in the first case, with 36.1% of the results, corresponded to a medium level of fatigue (3/5); 10.2% of the respondents felt extremely fatigued at the start of the work every day. Comparing this data with the highest percentage registered in the second question, where 48.1% of the respondents ensured feeling extremely fatigued at the end of every day indicates recovery during the rest hours.

In Figure 8, the answers given to the questions, “I have enough time to perform my tasks” and “I can rest in the middle of my work” the majority of the respondents are enough agree with this affirmation, at the same time that they put of self-evident that it is possible to make these works.

This figure also evidences the high collaboration among the members of the engineering department. According to the answers given by the respondents of the ICFTU, although the number of crew members were insufficient, there was a strong commitment to help each other among them.

**Figure 6. “My position requires physical effort” and “My position requires mental effort”.**
Figure 7. “I feel fatigued when I initiate my work day” and “I feel fatigued at the end of my work day”.

Figure 9 shows the workers’ perception of their work as highly complex due to the need for retaining a lot of information and the pressure felt due to the time limitation, which produces a lot of stress and fatigue by the end of a work day. Previously, they agreed on having sufficient time to perform work, but our results showed that performing the task within the tight deadlines produced extreme pressure.

Figure 10 shows that 69.4% of the respondents considered that their companies respected their period of sailing/holiday. Because of the diversity in the responses, and depending on the type of navigation (oceanic or coastal) and the time of stay in port, can present greater ease to go down the ship during the rest days.

Figure 8. “I have enough time to perform my tasks”, “I can rest in the middle of my work” and “There is collaboration in the works of other mates”.

Figure 10 shows that 69.4% of the respondents considered that their companies respected their period of sailing/holiday. Because of the diversity in the responses, and depending on the type of navigation (oceanic or coastal) and the time of stay in port, can present greater ease to go down the ship during the rest days.
HUMAN ELEMENT

Figure 9. “I realise that my work influences the pressure by the time”, “I am accustomed to handling complex situations” and “I am required to memorize a lot of information”.

Figure 10. “My company respects my sailing periods and holidays”; “I may go down the ship in my rest day”.
Table 1 shows the mid-results of the answers obtained from the respondents. The term UMS refers to an unattended machine (Unattended Machinery Space). In this type of guards, the engineer crew team work in spaces of engines (room and control) during the schedule from 08:00 AM to 12:00 PM and 01:00 PM to 05:00 PM. During this period, only one engineer remains in charge of the alarms until 08:00 AM on the following day and goes down to make a round at the end of the afternoon.

Appreciable differences indicate that oceanic navigation personnel felt more fatigued that the coastal ones, although in both the cases, fatigue existed.

In oceanic navigation, the machine was more automated, which is justified because the vessels are more modern. According to the Society of Small and Average Dockyards of Reconversion (PYMAR), the report of activities of the sector of naval construction of 2014 [40] suggests that the improvement in the world-wide contracting of vessel constructions could only be appreciated in two groups: passage vessels and gas tankers. However, this increase has little weight on the contracting of gross tonnage. The greater percentage of ships delivered during this period correspond to 31.2% of general load vessels, followed by container vessels with 20.5% and tank ships with 14.5% loads; in any one of these cases, the major type of navigation were long distance.

We can thus note that oceanic navigation crew is more motivated than the coastal ones, although coastal navigation crew can go ashore in their rest day and are provided more respect for their sailing periods and holidays. Considering all these points, it can be said that greater motivation is related directly with vessels being more modern. A detailed analysis obtained results by rank on board and the type of navigation (Figure 13).

Comparing by ranks and the type of navigation, the Chief Engineers’ polled differed in several answers, for instance, the oceanic navigation chief engineers were in total accordance with the affirmation “I am accustomed to handling complex situations”, which corresponded to the value of 5 on scale versus that of value 4 for the coastal navigation ones. This greater habit to treat complex situations among the oceanic navigation chief engineers justify the condition, as they are required to put in greater effort than the coastal navigation ones. A similar trend was observed for the requirement to memorize a lot of information. On the other hand, the oceanic navigation engineers do not consider their engine room automated, unlike the coastal navigation, and they do not have sufficient time to perform their works.

In both the cases, the chief engineers begin their work after the same level of rest, but end up with different level of fatigue, with it being higher in the coastal chiefs, because of the greater number of manoeuvres they have to undertake.

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q01</td>
<td>Time in the rank (years)</td>
<td>2-5</td>
</tr>
<tr>
<td>Q02</td>
<td>Age (years)</td>
<td>35-45</td>
</tr>
</tbody>
</table>
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Figure 11. Average results of the survey.

Figure 12 shows a comparison of the average results obtained, depending on the type of navigation, in accordance with the results of the ICFTU, which indicate greater fatigue exist in the coastal navigation than in the oceanic navigation.

**Figure 12. Average results by the type of navigation.**

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Coastal</th>
<th>Ocean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q01</td>
<td>Time in the rank (years)</td>
<td>2-5</td>
<td>2-5</td>
</tr>
<tr>
<td>Q02</td>
<td>Age (years)</td>
<td>35-45</td>
<td>35-45</td>
</tr>
<tr>
<td>-----</td>
<td>------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Q03</td>
<td>Turns</td>
<td>Others</td>
<td>UMS</td>
</tr>
<tr>
<td>Q04</td>
<td>My position requires physical effort</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Q05</td>
<td>I have enough time to perform my work</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Q06</td>
<td>I realise that my work influences the pressure by the time</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Q07</td>
<td>I can rest in the middle of my work</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Q08</td>
<td>I am accustomed to handling complex situations</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Q09</td>
<td>There is collaboration in the works of other mates</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Q10</td>
<td>My position requires mental effort</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Q11</td>
<td>I am required to memorize a lot of information</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Q12</td>
<td>My company respects my sailing period and holidays</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Q13</td>
<td>The machine is automated</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Q14</td>
<td>I feel fatigued at the end of my work day</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Q15</td>
<td>I feel fatigued when I initiate my work day</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Q16</td>
<td>I may possibly go down the ship in my rest day</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Q17</td>
<td>I feel motivated in my work</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

On the other hand, oceanic chiefs feel more motivated than the coastal ones, which influences the apparition of fatigue in them.

In the case of the Second Engineer – 1st Assistant Engineer, they matched in a greater number of answers that the Chief Engineers. The engineers in the coastal navigation believe that they work under more pressure than an oceanic navigation engineer, because the time to make reparations is limited. On the contrary, Chief Engineers in the coastal navigation rated question “I am accustomed to handling complex situations” with a 5, while the oceanic navigation engineers rated with a 4; this difference can be because the former are more accustomed to working quick and are always ready to start a new trip. In both the cases, the crew begin their day with equal amount of rest. However, the oceanic navigation engineer feel more fatigued at
the end of a day than coastal navigation ones. The motivation level in the Second Engineers in oceanic navigation is greater than that in coastal navigation.

**Figure 13. Mid-results by the type of navigation and position on board.**

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<thead>
<tr>
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<tbody>
<tr>
<td>Q01</td>
<td>2-5</td>
<td>+ 10</td>
<td>2-5</td>
<td>2-5</td>
<td>1-2</td>
<td>2-5</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>Q03</td>
<td>Others</td>
<td>Others</td>
<td>Others</td>
<td>UMS</td>
<td>4:00-8:00 &amp; 16:00-20:00</td>
<td>UMS</td>
<td>Others</td>
<td>Others</td>
</tr>
<tr>
<td>Q04</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Q05</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Q06</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Q07</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Q08</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Q09</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Q10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Q11</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Q12</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Q13</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Analysing the case of the Third and Fourth Engineers, the coastal ones felt that their work required more physical effort, as compared to that perceive by the oceanic ones. The Third-Fourth Engineers in the coastal navigation system were totally in accordance (5 grade) with the affirmation “I feel that my work influences the pressure on my by the time”, whereas those in the oceanic navigation system agree (4 grade). In addition, the coastal engineers answered with neutral punctuation (3) to the affirmation “I get sufficient time to perform my work”, whereas the oceanic ones showed total agreement with the affirmation. On the other hand, the answers given by the coastal engineers mark with a high punctuation the fact that their work requires mental effort and demands memorisation of a lot of information, whereas in the answers given by the oceanic ones, the punctuation was somewhat lower, although the latter ones are accustomed to handling complex situations, the answer is one point more that the given for the coastal ones. Regarding the level of fatigue at the end of the day, the coastal ones felt more fatigued that the oceanic ones as well as reported worse rest conditions. Finally, as reported in previous cases, the level of motivation in oceanic navigation engineers was more than that in the coastal navigation ones.

Finally, a rough analyses of the case of the Subordinates showed that the responses of the Third and Fourth Engineers differed a lot. The costal ones perceived their work as requiring greater physical effort as compared to that perceived by oceanic ones. The coastal Subordinates answered with a neutral (3 grade) to the affirmation “I have sufficient time to perform my work”, whereas oceanic ones agreed with the affirmation, which indicates that the level of pressure by the time was more in oceanic Subordinates than in coastal ones, what can be due to the fact that, although usually there is time to perform tasks, often the need is to resolve an issue as fast as possible. Focusing on fatigue, the coastal Subordinates start their work being more tired and finish it the same way as compared with the oceanic ones. In both the cases, the motivation for the work is the same, with neutral answer (3 grade).

4. CONCLUSIONS

As per the guidelines of IMO [27], stress, like fatigue, is associated with places on board a vessel. Our survey results reflected the high level of complexity in the works performed in the engineering department.

On the other hand, the level of effort necessary to perform the task is also higher, because the typical tasks on board a vessel requires tremendous physical and mental intervention.
Notably, the time allotted to realize a task is restricted, which produces tremendous pressure to complete a task within a fixed schedule. Cumulatively, our observations suggest that the workers showed high levels of fatigue (Table 1), which seemed to be associated with the stress produced from the work conditions. Considering the strict requirements and the high complexity of the tasks on maritime vessels, it seems best to manage the tasks through active and well-managed collaboration among the resources on the vessels, allowing time for rest for everyone and thereby distributing the work load and the related stress uniformly in order to combat fatigue.

References:


[22] International Transport Workers' Federation. *Lucha contra la fatiga, la seguridad de los buques requiere de una dotación realista*. 2006


EVOLUTION OF MARITIME ACCIDENTS IN SPANISH FISHING

Alfredo, Torné, Antonio, Isalgué, Francesc Xavier, Martinez (presenter).

Barcelona School of Nautical Studies. Universitat Politècnica de Catalunya, Spain

Abstract:

During the last years, we have studied the Spain’s maritime accidents that occurred in fishing and the causes that produced them from 2000 (year of starting of the CIAIM reports) to June 2016. It was decided to study this problem because there is observed a large number of accidents compared to other sectors such as building construction or metallurgy. We have been studying all of maritime accidents occurred from 2000 to 2016 including merchant vessels, fishing vessels and others. The study shows that the fishing vessels obtained the most important number of accidents and number of persons’ casualties. Having said that, we have considered it appropriate to observe the evolution of maritime accidents, especially in fishing vessels, that have occurred since June 2016 to the present separately, and its causes.

In some cases, it can only be counted as a number and the causes that produced them cannot be taken into account since some recent investigations are still ongoing. This paper aims to analyze whether despite the measures that have been implemented during these years in the field of training professionals in the fisheries sector, the relatively high number of accidents persists. The results obtained are of vital importance in the evaluation of the measures applied to the problem of the large number of accidents in fishing and also in the preparation of future measures that must be proposed in the direction of reducing the effects on people, resulting from the accidents occurred in fishing.

Keywords:

fishing, accidents, security.

INTRODUCTION

Fishing was in the past and remains today one of the important productive sectors of Spain, 388,386 tons at December 31 2018. This important sector develops, and is divided into 4 main modes, Siege, Drag, Longlines, Minor Arts and a fifth that encompasses all other less important modes. From the point of view of value, according to the Spanish Ministry of Agriculture [1], the products of fishing represented 1,056,643,78 (thousand Euros) in 2018 [2]. If we observed the circular about fisheries 966 published by the Food and Agriculture Organization of the United Nations that this Organization (FAO), this Organization estimate that 15 millions of “fishers” engaged in fisheries in the world, and approximately 98% work in vessels less than 24 meters in length.[13].

Besides being an important industry in Spain, it is also characteristic for the large number of accidents recorded. The accident rate in the fisheries sector worldwide has been the subject of
study and concern for different countries, including Spain. Levels of fishing accidents fired alarms because they are above many sectors of our society, including construction. [3,4]. The same problem is observed in United States. Time ago, in U.S. the investigators comes observing the accidents in the fishing industries, and we look the problem is important. In 1998 published an report about this problem and conclude: “Fishing has consistently ranked as the most deadly occupation since 1992”.[15]. The similar conclusions were obtained in France or Ireland.[16,17]

For years, organizations from several countries launched various actions aimed to reducing the high accident rate that was collected in inshore fisheries. These measures, even today in continuous development, address specific issues on the construction of ships, control and prevention of the values of the ship's stability, training and awareness of fishermen, among others [5,6]. The different measures implemented by the different countries for analysing the accidents and the proposal of actions to reduce them, comes to the specific organizations, such as the Marine Accident Investigation Branch (MIAB) in the United Kingdom, or the Dutch Safety Board in Netherlands, and others [14,15].

The different lines of action against accidents have resulted in the creation of programs that control at all times the stability of the ship, rules to avoid types of undesirable vessels from a constructive point of view, talks in brotherhoods to educate the fishermen on the risks and training in the use and operation of equipment and safety on board [10]. All these actions have significantly reduced accidents in fishing, however accident figures remain still high, much higher than the construction sector [7,8]. In the circular 966, the FAO explained the problem and says that: “about 24.000 fatalities occur worldwide per year”. The problem exist and this is global. Specific organizations in some countries make recommendations to reduce accidents, but at the moment, they are not very effective.

In order to specify the scope of the problem, an investigation by the authors was started in 2016, with the aim of determining the causes of maritime accidents that occurred and were published from 2000 to 2016. This period of accidents, we call it "first period". Then we wanted to look at how the accidents have behaved further on, opening a new period of published maritime accidents that runs from 2016 to 2019, called the "second period".

The first period for the analysis of accidents published by the CIAIM (Maritime Accident and Incident Investigation Commission of Spain) [11] that was carried out in this research, was between 2000 and July 2016. The publication of the various accidents occurs in a scattered manner and in some cases the accidents are published the following year. This fact is understandable because in some of the cases it is difficult to determine the causes with the information available. For the study of different reports about accidents in fishing industries, in Spanish we have the CIAIM. In other countries different organizations do the same work: analizy the maritime accidents, U.K (the MIAB), Netherlands (DSB), France (Ministry of ecology), Ireland (HSA), …

On the other hand, because of the expansion of the publications on time makes it necessary to determine a deadline for the inclusion of accidents in the database, since otherwise, we would never complete it and we would not be able to go to the analysis phase. We also understand that from the deadline we set in 2016 to the present, there have been other accidents that we want to analyze as an addenda to the first analysis. We are interested in the evolution of the events that happened, regarding the first phase of the study and at the same time we are aware that the
volume of accidents is not high very high in a short period of time, but it can show us if the problem persists or how it behaves over time.

That said, fishing vessel accidents that occurred and have been reported from July 2016 to November 2019 have been a total of 27, in which 31 vessels have been involved. We analyze only this part, since they are exclusively accidents that have occurred or have been involved, fishing vessels. It is also important to determine in which case the accidents occurred. Before going into detail with the analysis of the 31 crashed vessels we will observe the distribution by fisherman.

1. METHODS

1.1 GEOGRAPHIC DISTRIBUTION

The first of the data analyzed is the geographical area in which the accidents occurred, to compare it with the previous data.

In the accidents that occurred (2016-2019), we observe that most of the accidents occurred in the Cantabrian-northwestern fishing grounds (maritime zone of Galicia, Cantabria, Basque country and Asturias). Specifically, they were a total of 31 affected vessels, distributed in the following fishing vessels, Cantabrian-Northwestern 22 (70.97%), Mediterranean 7 (22.58%), Gulf of Cadiz 1 (3.23%), Canary 0 (0%), North Atlantic 0 (0%) and International Waters 1 (3.23%).

In the first phase of the accident study in (2000-2016), the percentage of accidents that occurred in the different fishing grounds were 197 distributed as follows, Cantabrian-northwestern 103 (52.28%), Mediterranean 46 (23, 35%), Gulf of Cadiz 15 (7.61%), Canary 6 (3.05%), North Atlantic 9 (4.57%) and International Waters 18 (9.14%).

If we compare the two periods, it can be seen that the Cantabrian-northwestern fishery is still the geographical area with the highest number of accidents and has even increased in percentage of total. We think it would not be correct to claim a rise of 20% between analyzed periods, as some of the accidents that occurred in that same period have not yet been announced, but that is the area with the highest number of accidents. Next is the Mediterranean zone and then with much less accident follow other fishing grounds. Then we can say that the most recurrent place in a fishing accident is the fishing zone Cantabrian-northwestern.

1.2 MODALITIES

The data analyzed in this section are those concerning fishing modes. In the 2016-2019 period, the mode with the highest number of accidents or affected vessels are the minor arts, with 11 affected vessels making up 35.48% of the total, followed by the trawling mode with 8 affected vessels that suppose 25.81%. Then with lower percentages of affected vessels are the fence, and the longline.
In the analysis of fishing vessel accidents from 2000 to 2016 recorded in the northwestern Cantabrian fishing boat, the following data were collected: Of the 103 fishing boat accidents recorded, 66 occurred in the minor arts mode, with 64.08% of the total, followed by trawling with 14 vessels that account for 13.59% and finally with quantities of smaller affected vessels, longline, steering wheels and fishing auxiliaries.

The conclusion that can be drawn comparing the data in the Cantabrian-northwestern fishing shed is that the mode with the highest accident rate is still that of the minor arts.

1.3 THE DEPTH

The depth was one of the data analysed previously in an article published in [18], in which it was observed that most accidents occurred between 0 and 10 meters, in particular the largest number between 5 and 10m of depth, and followed by the strip 50+ m. It should be added that the strip of 50 m or more pools a great amount of depths, further enhancing the real importance of the number of affected vessels in shallow water.

On the other hand, if we look at the accident data published between 2016 and 2019, we can see that even the number of vessels affected at shallow depths has increased its ratio. In the worst case, we might consider some unpublished accidents from the same period, but in any case it can be said that most accidents occur in shallow water and the dynamics in the latest data analysed confirm this data.

Looking at the two periods analysed, it is confirmed that most accidents occur near the coast and we also see that the largest number of accidents followed by those occurring at shallow depths occur far from the coast or at much greater depth, being the intermediate zone the one with the lowest incidence. That said, at this point it is appreciated that the shallow waters are home to a larger number of affected vessels or the same thing, which would be that the vessels at the time of the accident were in shallow places.

1.4 THE TIME THE ACCIDENTS HAPPENED

This was also one of the data analysed in the previous article [18], which we expected to find that accidents occurred when it was dark and the results of the analysis showed that they followed this rule if they did not occur more or less homogeneously or attending to the stripes in which the vessels carried out their fishing. We have to recall that most of the vessels affected are of the minor arts mode.

Of the 103 accidents that took place in the Cantabrian Bay, most proportion occurred between 04:00 and 12:00. We also appreciate that the hours before or afterwards also collect quite a few accidents, observing relative homogeneity.

The statistic dates show the hour of the accident is normally aleatory, but some cases are far of the standard deviation, approximately 30% of total.

In the 2016-2019 study period, the accident data regarding the time that they occurred are quite similar and follow the same pattern very closely. We observe, as in the period 2000-2016, a
great homogeneity and also a decrease between 20:00 and 24:00, perhaps due to fishing reasons most of the vessels are in port. Therefore, at this point we can conclude that the time of the accident also follows the same dynamics as in the 2000-2016 study period.

1.5 CASUALTIES, DEATHS AND MISSING PERSONS

Perhaps this data is the most important of this investigation, since the object of it is in the study of accidents and the proposal of measures aimed at reducing maritime accidents and therefore of people injured, missing and deceased. One of the reasons that aroused our curiosity at the beginning of this thesis was the great accident rate shown by the fishing sector. The data [18] that showed the accidents in the Cantabrian from 2000 to 2016 were: in 103 accidents 23 people injured, 59 dead and 21 missing. It can be seen that the accident rate persists.

When studying the accidents of the 2016-2019 period we want to determine if the accident rate remains high despite the measures and recommendations taken in this sector. In this period 31 vessels were affected and 3 injured, 7 dead and 5 missing were collected as data. It is true that there seems to be a slight decrease of dead plus missing people referred to the number of accidents, but it is difficult to assess whether the trend is real or blurred by statistics, up or down from previous work [18] with so few sample accidents, but it is undeniable that in just 3 years they have lost their lives 12 people, this is absolutely negative data to be taken into account. At the same time these data encourage us to continue in the search for knowledge of the events and to the proposal of measures.

1.6 SHIP DAMAGES

Damage to the ship is also a relevant fact since it shows us how accidents are, if so violent and fast, if the ship sinks slowly, if it fully refloats, etc. When analysing the data of the Cantabrian Calador for the 103 ships that were affected [18], we observe that the great majority resulted in the total loss of the ship or the accident ended up in the sinking of the ship that was later refloated. For a ship to declare a total loss, the event must be violent. On the other hand, if the event has been of another nature, the ship sinks and then can be refloated later with some damage.

In the 2016-2019 period, we observe that the affected vessels in the fishing sector follow the same pattern than in 2000-2016. Most of the affected vessels are declared in total loss, followed by sinking. Therefore, we can conclude that accidents remain essentially of the same characteristics as in the 2000-2016 period.

1.7 METEOROLOGICAL DATA. WIND FORCE AND WIND DIRECTION

The meteorologist was one of the first hypotheses we argued at the beginning of the previous accident investigation [18]. With hardly very few data of the maritime accidents, we are induced to think that the accidents were due to the fact that the ships were small and that when they
moved away from the coast, with strong winds, they made them tip over and gave rise to the accidents. No further from reality, in fact were not right at all. The accidents that occurred between 2000 and 2016, mostly happened near the coast and the study of the meteorological variables on the day of the accident, show us that the wind was not high, even more, as the force of wind increases the accidents decrease. Therefore, neither the direction nor the force of the wind seems to be the cause of the accidents.

The data recorded in the accidents that occurred in the 2016-2019 period show very similar data to those collected in the 2000-2016 period. We see that the largest number of affected vessels is between 0 and 15 knots of wind force. Therefore, they follow the same norm as far as wind force is concerned, understanding that wind force is not the cause of accidents.

1.8 CAUSE OF ACCIDENTS

Finally, a fact of interest is the cause that caused the accident. We believe that knowing the cause and studying all the variables within our reach, we can come up with proposals to reduce these accidents. The most common cause of accident on the affected vessels (103) in the Cantabrian in the 2000-2016 period was that of overturning (capsizing) above all others, followed by embarking water, operational accidents, flooding and boarding.

The data related to the 31 vessels affected in the 2016-2019 period show us that the most common cause among them remains the overturn (capsize), followed by boarding, embarking water, operational and fire. When observing the data, we can affirm that as regards the event, the overturning is still the most common. At the same time we wonder: overturn? If the wind conditions suggest that it is unlikely to tip over. So what is the overturn due to? We will investigate it in the open thesis on this subject.

2. CONCLUSIONS

Once the accidents of the periods (2000-2016) and (2016-2019) have been analysed, and then compared them to each other, in terms of geographical distribution by drawer, the one with the highest accident rate remains that of the Cantabrian - Northwest. Compared data shows that over time accidents continue to be majorities in the area of Galicia and Cantabrian.

As for the modalities, in the study of accidents of the period (2000-2016) the modality that includes more accidents was of minor arts. In the current period (2016-2019) minor arts remain the modality that includes a greater number of affected vessels.

Another of the data that we consider relevant in comparing fishing accidents is depth. The results of the comparison are clear, most of the vessels affected at the time of the accident were at low depths, between 0 and 10 m. This data is the same trend as in the study of accidents between 2000 and 2016.

As for the time slot in which the accidents occurred, in the period 2000-2016 the data were very homogeneous and coincide with the hours in which the vessels were fishing. In any case, there was a decrease in accidents between 4:00 PM and 12:00 PM the next day. In the 2016-2019
period the data is quite similar and homogeneous. There is a decrease between 12:00 and 24:00 the next day. The major accident rate is between 00:00 and 12:00.

The people killed in the accidents between 2000 and 2016 were 59, which added to the 21 missing, make a total of 80 people killed. In the current period of less than 3 years, 7 deaths have been collected, which together with the 5 missing, make a total of 12 deaths in the 31 vessels affected. There is no doubt that the sector has a high accident rate, despite the measures taken [6,7,8,9] and the recommendations [12] made to reduce the number of deaths.

Regarding the damage done to the ships, we observe that in the period 2000-2016 most of the accidents resulted in the total loss of the ship and the sinking. In the 2016-2019 period, the data shows the same trend. The first result is total loss followed by sinking.

As for the meteorology, specifically the force of the wind, in the 2000-2016 period most of the accidents occurred with wind forces between 0 and 15 knots. This data is all the fee of what we estimate as hypothesis at the beginning of the investigation. In the 2016-2019 period, the data is practically the same, most accidents are recorded between calm and 15 knots of wind, and if the intensity of the wind increases, the accidents decrease.

As for the type of event, in the accidents that occurred in the 2000-2016 period, the cause that picked up the most accidents was that of overturning (capsizing), followed by other causes to a lesser extent. If we look at the 2016-2019 period, the most frequent cause is still the boat overturning, followed by other diverse causes.

The problem of fishing accidents in Spain is defined more or less in this way; The geographical area that registers the greatest number of accidents and victims in them is the North-west of the peninsula. The large number of accidents coincide in the data influencing them being nearly the same we had from the ongoing investigation [18], they are related to the depth of the water under the keel and to factors related to maritime conditions. Relatively good meteorological conditions existed in the majority of accidents.

The measures to be proposed on this problem to reduce the number of victims revolves around training of crews, revision of current safety regulations, and others aimed at avoiding the capsizing of boats. These could be automatic stabilization systems or other similar systems that avoid loss of stability.

Finally, in order to predict what the probability of accidents will be repeated, we have drawn up a graph where we have located the accidents that have occurred and we have crossed them over time. The result has been a straight, "very straight" line that suggests that the probability of accidents happening again the same way as previously is very high. Therefore the problem, despite the efforts, persists and there is no evidence that it is solved.

References:


SKILLS BEYOND THE SEAS PROJECT

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Abstract:

The Maritime Sector is currently facing a paradox and difficult situation of a current shortage of young seafarers. This paper demonstrates a methodology for designing two tools that will provide seafarers and MET (Maritime Education and Training) students with a detailed list of their hard and soft skills and suggest pathways to onshore occupations where these skills are needed.

This methodology has been developed by the “Skills Beyond the Seas” Erasmus + project, which brings together five partners from four EU (European Union) countries who are closely linked to the seafarers, MET target groups and youth and are experts in qualification and skills analysis. They are jointly: a) analysing and identifying transferable hard and job-specific skills that are held by four seafarer qualifications, using ECVET (European Credit system for Vocational Education and Training) principles of knowledge, skill and competences, b) identifying onshore jobs and careers that utilise these transferable skills, c) developing a SkillsPath Tool that provides the target groups with options of career moves, and, d) developing an Informal Skills Scanner that identifies and assesses soft skills.

Keywords:

skills portfolio, soft and hard skills, transversal skills, onshore employment, career pathways.

1. INTRODUCTION

The Maritime Sector is currently undergoing immense changes and finds itself in a paradox situation. On the one hand experts state that there is a high demand for seafarers:

"The employment demand in the Maritime Sector is set to more than double by 2030 … but the maritime workforce is aging and young people are no longer attracted to maritime careers" (EU Commission SWD (2017) 130final).
"Whether in traditional or emerging maritime sectors, businesses cannot find the desired workforce, skills and profiles and stakeholders are recommended to increase attractiveness to its rapidly evolving needs" (Executive Agency for Small and Medium-sized Enterprises, Study supporting a possible network of maritime training academies and institutes in the Mediterranean sea basin, 2016).

"... in OECD countries as estimated by ISF/BIMCO (Baltic and International Maritime Council), the shortage of officers shows a gap of 45,000 between supply and demand for officers, and of 145,000 for ratings." (EU Commission, MOVE/C1/2010/148/SI2.588190).

On the other hand they agree:

The unmanned remote or autonomous ship is on the horizon and related policy discussions are high on the agenda of the International Maritime Organisation (IMO), EU institutions such as DG Mare, DG Move and the European Maritime Safety Agency (EMSA) and most European and National Maritime stakeholders and interest groups. The roadmaps indicate that the first remote controlled commercial ship could hit the water by 2020, in only 2 years time (Rolls Royce white paper “Remote and Autonomous Ships”, 2016).

EMSA estimates that there are 254,000 seafarers in the EU (EMSA, Seafarers statistics in the EU, 2014) and between 25,000 and 35,000 students in Maritime Education and Training (MET). All of them will be affected by the current technological developments.

1.1 THE PROBLEM

Whilst currently there is still an urgent need for young people to enter into the professions of seafarers and overall numbers are significant, their future employment and career perspectives are very uncertain and unclear. This uncertainty especially affects young seamen and maritime trainees and makes it a difficult decision for youth to enter this sector. It thereby hinders them to enter into highly valuable VET (Vocational Education Training) which offers them learning outcomes that can be used far beyond sea-going professions.

1.2 THE OBJECTIVES

For active seafarers and students in MET across the EU, who all need a perspective for their future, the project Skills Beyond the Seas offers the much-needed information and guidance for mid- to long-term career planning. For disadvantaged youths it provides support to enter into a diverse sector and thereby gain social inclusion.

The tools developed by the project will provide the users with a detailed list of their hard and soft skills, highlight the transferable skills sets and suggest career pathways to other occupations where these skills are needed.
1.3 TARGET GROUPS

a) Active Seafarers

b) Students of Maritime Education and Training (MET)

c) Disadvantaged Youth

d) MET providers, Maritime qualification Experts, Selected Onshore Qualification Experts, Employment Agencies, Job Centres and Job Recruitment organisations.

1.4. ACTIVITIES

The Skills Beyond the Sea project is undertaking the following activities:

a) developing a methodology to analyse and identify transferable hard and job-specific skills that are held by seafarers, using the ECVET principles and Learning Outcomes,

b) identifying onshore jobs and careers that utilise these transferable skills (from the obvious university lecturer or shipping company office job to more obscure positions like land surveyor, manager, etc.), using data and information provided by the European Skills, Competences, Qualifications and Occupations Classification (ESCO) and experts evaluations,

c) developing a SkillsPath Tool that provides the Target Groups with options of career moves,

d) developing an Informal Skills Scanner that identifies and assesses soft skills held by seafarers in order to widen their skills portfolio and support their career opportunities, using partly Europass skills frameworks for the assessment.

The project is carried out by a consortium of 5 partners from 4 European Countries:

1.) Sea Teach SL (Coordinator) based in Mallorca, Spain
2.) Universitat Politècnica de Catalunya, based in Barcelona, Spain
3.) University of Rijeka, Faculty of Maritime Studies based in Rijeka, Croatia
4.) Turk Loydu based in Istanbul, Turkey
5.) Danmar Computers based in Rzeszow, Poland
2. INNOVATIVE OUTPUTS

The Skills Beyond the Seas project is developing two new and innovative tools which will provide employees and learners in the maritime industry with future pathway guidance to onshore occupations, tailored to their individual skills sets.

It is innovative in the sense that it combines hard skills matches with personal soft and non-formal skills matches, thereby providing the user with a new comprehensive and individual Transferable Skills Profile. The two tools to be designed are

1) the SkillsPath Tool, and

2) the Informal Skills Scanner.

2.1 THE SKILLS PATH TOOL

The SkillsPath Tool will offer an innovative approach that interprets a range of onshore occupations and delivers a multi-layered skills matching system for seafarers, boosting their job mobility. The SkillsPath Tool will operate from a comprehensive dataset of onshore professions, careers, jobs and occupations generated by the project, detailed into their skills and competence components.

The listed onshore jobs, totalling at least 50 separate occupations, will range from related marine jobs to wider but fundamentally compatible career opportunities and sectors. The problem of an industry becoming overtaken by automation and the gradual replacement of traditional skills held by a human workforce by Artificial Intelligence (AI) is not exclusive to the shipping sector and therefore the unique SkillsPath Tool has huge potential to be adapted and utilised for use in other industries such as automotive, aeronautical, transportation and manufacturing.

The SkillsPath Tool will deliver comprehensive career pathway guidance and skills matches for seafarers through the identification of their knowledge, skill and competences which are compatible with other onshore professions, in a cross-sector matching system. This process will facilitate job and cross-sectoral mobility of existing seafarers and provide encouragement to young people and graduates considering this career path, that this sector has a high skills transferability potential and isn’t a ‘limiting’ choice.

By harnessing the ECVET framework of knowledge, skill and competence to provide a standardized cross-sector compatibility framework for seafarers, the SkillsPath Tool will determine levels of: relevance, suitability, appropriateness and commonality to other adjacent careers onshore. It will provide the user with an overall ‘Transferable Skills Profile’ that will incorporate both specific hard skills matches and integrate informally acquired competences. This integration of soft skills will utilise the Informal Skills Scanner to complement the seafarers’ transferable skills profile.
The SkillsPath Tool is being developed in the following stages:

Stage 1: Standardized Skills Breakdown Methodology

To ensure that the cross-matching of knowledge, skill and competence between the Seafarer qualification’s and onshore professions is compatible, allowing the software systems to deliver appropriate and results, the partners have development of a standardized methodology for this skill breakdown. For this they used the International Maritime Organisation’s (IMO) qualifications and curricula for Seafarers as a base and standardized these competence data.

Stage 2: Onshore Job Skills Extraction

To translate the competence requirements for onshore jobs into a format that matches the seafarer’s competences and allows for effective matching between the two, onshore job-related experts are being used to identify, rate, verify and agree on competences of the onshore job they are evaluating through a skills, competence, knowledge matrix.

Stage 3: Development of SkillsPath Tool

To house the multi-layered data set the SkillsPath Tool will be made available through an online platform interface. Built to integrate digital native functionality and interactive systems, the software tool will facilitate the comparison and cross-matching of the knowledge, skill and competence datasets identified in the previous stages. Dedicated servers will host the datasets. User interaction will involve the creation of profile accounts which allow specific personal enquiries. These accounts will provide the functionality to interact, save, view and edit the individual user’s ‘hard skills profile’ and find links to additional qualification and skills extensions.

2.2 THE INFORMAL SKILLS SCANNER (ISS)

To further expand the skills portfolio of seafarers and to broaden their career opportunities, the project will develop the Informal Skills Scanner (ISS). This innovative tool adds the personal perspective to the users Hard Skills Profile. This integration of hard and soft skills sets within and outside this sector has not been delivered before in this form.

Whilst many validation tools of soft and non-formal skills exist, as listed in the “European inventory on validation of non-formal and informal learning” [5], these have never been integrated into a comprehensive skills matching tool with the aim of delivering the user with career pathway guidance based on his/ her entire skills set.

The Informal Skills Scanner will test and assess the user for their soft and non-formal skills that have transversal characteristics, using a combination of new
Whilst the IMO standards largely regulate the hard competences and qualifications of different ranks of seafarers, individuals working in this sector also possess a significant variety of valuable soft and non-formal skills. Realising this potential through an assessment and recognition process will unlock valuable additional skills that can be used in related and adjacent careers. The Informal Skills Scanner will work in conjunction with the SkillsPath Tool to give the individual user a comprehensive ‘skills profile’ that makes their entire skills set visible and in addition offers wide but tailored recommendations for future career pathways.

The ISS distinguishes itself by concentrating on higher soft skills compared to the basic competences such as Reading and Numeracy, since it can be safely assumed that these are present in the Target Group of seafarers. The types of skills that the ISS will target and assess will be soft skills that have transversal characteristics such as: Communication skills, Team working skills, Organisational skills, Interpersonal skills, Sense of initiative and entrepreneurship, Management skills, Problem solving skills, Leadership skills, Decision making skills and Customer service skills.

The Informal Skills Scanner is a software tool that offers assessment criteria in terms of: scenario what if’s, effective operation of a team, response to an issue, managing change, additional duties, reaction in stress situations, dealing with personal and cultural differences, etc. These criteria will offer insights into the individuals’ level of transversal skill competence and generate results into a ‘Soft Transversal Skills Profile’. To effectively test and assess these skills, the tool will be loaded with

a) a rich database that provides a large variety of questions and scenarios, and

b) an algorithm that ensures the constant rotation of test questions and scenarios to avoid repetition even when the test is repeated several times.

The project recognises that potential users might also possess skills such as language skills or digital skills that have been acquired in a soft or non-formal way. It will therefore assess these in form of a self-assessment that is using the “Common European Framework of Reference for Languages” (CEFR) for language skills and the “European Digital Competence Framework for Citizens” for digital competences. Both assessment methods are also used in Europass and are therefore compatible and well recognised.

The Informal Skills Scanner will incorporate national and cultural differences and thereby incorporate an EU dimension in its applicability and validity thanks to the data collection process and test scenarios that will use input from multiple EU partner countries.

The Informal Skills Scanner will be developed in the following stages:

Stage 1: Methodology
The project partners developed a questionnaire that asked experts to identify the most common and recognised soft and non-formal skills and skill-sets of the seafarers. From the results, which are published in the following chapter of this paper, a database of soft skills was formulated.

Stage 2: Developing and programming the Informal Skill Scanner

In the next stage, the partners are now developing the question-database of these soft skills and the language and digital competence frameworks into the Informal Skill Scanner and are deciding its configuration for the most effective and user-friendly display. The software will then be programmed accordingly and the database entered.

3. RESEARCH RESULTS SO FAR

3.1 SUMMARY OF RESEARCH RESULTS FOR INFORMAL SKILLS IN SEAFARERS

The project partners of Skills Beyond the Seas agreed in undertaking a survey to find out which soft skills should be used in the ‘Informal Skills Scanner’. A sample of 122 experts, from different countries, and representing professionals from different maritime companies, organizations or institutions completed successfully the survey.

Data were collected through the use of a structured questionnaire, a copy of which is provided in the Appendix. The length of each survey was about 15 minutes. The questionnaire consists of several major parts to assess the following: nationality, type of institution/company/organization, size of the institution, and rating some transversal skills.

3.1.1 METHODOLOGY

The partners first collated a list of 17 transversal skills that are common in seafarers. This list was then presented to the partners’ maritime experts who rated the skills for importance and this rating led to the reduced list of 10 skills to be surveyed by the questionnaire responders.

Participants of the questionnaire were asked to specify the organisation they were working for and to rate by priority some transversal skills for different ranks. soft skills are those skills that have been learned often unintentionally and in a daily informal setting (family, leisure, work) and are transferable to a wide range of occupations and sectors.

The results were deep analysed using two software: Excel and SPSS. A statistical toolset was applied (average, standard deviation, Pearson correlation coefficient) in order to see the results from different points of view according to the survey answers (By nationality, by size of the organization, by type of institution or as a whole).
3.1.2 RESULTS BY COUNTRY

Professionals from a total of nine countries took part in the survey. The country with more participants was Spain with a total amount of 33, followed by Croatia (27), Poland (25), Turkey (24), and Germany (5). The number of participants of the other countries was not significant compared to those previously listed, however they were considered in the results as a group called ‘other’.

![Figure 1. Number of professionals by country.](image)

a) Officers of the watch

When analysing the results by countries, some similarities between regions can be found. Spain and Germany tend to rate in the same direction, being ‘Adaptability to change’, ‘Cope with pressure’ and ‘Teamworking skills’ the most important. On the other hand, eastern countries (Turkey, Poland and Croatia) have a different view, since ‘Follow procedures’, ‘Cope with pressure’ and ‘Team working skills’ were the top 3 skills.

For Spanish and Croatians, ‘work under pressure’ is the most important skill, while for Germans is the ‘adaptability to change’. Turkish rate as top1 ‘team working skills’ while Polish professionals prefer the ability of ‘Problem solving’. This indicator is useful to understand the job requirements in each country.

Another useful indicator is to analyse the average of each country. If the result is bigger than 4, soft skills should be considered as ‘Very important’ when applying for a job in that country. The results are as follows: Germany (4,22), Spain (4,17), Poland (3,98), Croatia (3,94) and Turkey (3,91).
b) Master and chief engineers

When interpreting the results table, higher education and a higher position requires more transversal skills. In most of the cases, ratings are above 4 and some skills have an average of >4.5. Turkey got the highest average (4,45), followed by Germany (4,38), Spain (4,34), Croatia (4,31) and Poland (4,12).

‘Leadership skills’ was rated as top 1 for all the countries except for Poland where ‘Problem solving skills’ was the most important. ‘Problem solving skills’ was also high rated in all countries, obtaining an average of 4,62, as well as ‘Cope with pressure’ (4,57).

3.1.3 RESULTS BY TYPE OF INSTITUTION

Figure 2. Number of professionals by type of institution.

a) Officers of the watch

In the analysis of the results by the type of institution, Research institutions, Maritime Schools and Maritime Universities follow the same pattern, being ‘Cope with pressure’ and ‘follow procedures’ the most important skills. It is interesting to analyse the results of the professionals working for a Maritime association: they ranked ‘Willingness to learn’ in the first place, however a total of three skills remained in the second place; ‘teamworking skills’, ‘cope with pressure’, and ‘adaptability to change. Last, but not least, Shipping companies found ‘Teamworking skills’ the most important followed by ‘Cope with pressure’.
b) Masters and chief engineers

In reviewing the results of the opinion on master engineers by type of the company/organization, ‘Leadership skills’ seem to be the most important skill for professionals (above 4.6) in all cases except for Research Institutions that ranked it as the least important. ‘Work under pressure’ and ‘problem solving skills’ were ranked as #2 and #3 in all cases. For maritime institutions and shipping companies soft skills are almost essential (with an average above 4.4), while for the rest, they are considered as really important (averages from 4.01 to 4.3).

3.1.4 RESULTS BY SIZE OF THE COMPANY/ORGANIZATION (NUMBER OF EMPLOYEES)

Figure 3. Distribution of professionals by size of the company.

![Pie chart showing distribution of professionals by size of the company](image)

a) Officers of the watch

‘Teamworking skills’ is the most important soft skill for Micro and Small companies followed by ‘Work under pressure’ and ‘apply quality standards’. Medium sized and large companies ranked ‘Cope with pressure’ as #1 skill followed by ‘Apply quality standards’ and ‘Teamworking skills’. Finally, Medium-large companies found that ‘cope under pressure’, ‘teamworking skills’ and ‘willingness to learn’ were the most important abilities.
b) Masters and chief engineers

Whilst the average range of ‘Officers of the watch’ scored between 3,9 and 4,1 (considering soft skills as important), the average of Master and chief engineers was 0,3 points higher in all cases (4,2 the lowest and 4,5 the highest). Small, medium-sized and medium large companies considered ‘Leadership skills’ as the most important, followed by ‘cope with pressure’ and ‘problem solving skills’. On the other hand, micro companies ranked ‘Teamworking skills’ as top one, followed not so far by ‘leadership skills’ and ‘problem solving skills’. Large companies top 3 was as follows: ‘Cope with pressure’, ‘apply quality standards’ and ‘leadership skills’.

4. GENERAL RESULTS ANALYSIS

When analysing the general results, we decided to rank each skill according to what professionals considered as High Importance and Essential (HI&E). In addition, an average of all ratings was calculated to give us a general view of users opinion. The results were as follow:

a) Officers of the watch

‘Coping with pressure’ was rated as ‘HI&E’ 113 times, followed not so far by ‘Teamworking Skills’ (107) and ‘Apply quality Standards’ (103). ‘Willingness to learn’ (94) and ‘Time management’ (93) completed the top 5.

Figure 4. Skills considered as 'HI&E' for Officers of the watch.
When analysing the averages, same results were found, but ratings were a bit different. ‘Coping with pressure’ occupied the first position again with an average of almost 4.4 followed by ‘teamworking skills’ (4.35) and ‘Apply quality standards’ (4.23). The results of the other two skills could be considered as important but not essential since they were in the limit of 4 or even below.

Figure 5. TOP 5 Skills for Officers of the watch (Average).

When evaluating the rest of the skills, it is clear that ‘Leadership skills’ and ‘analytical skills’ are not relevant. Other skills, like ‘Adaptability to change’, ‘interpersonal skills’ and ‘time management’ could be considered as Medium/high important since their ratings are below 4.

On the other hand, standard deviation results reaffirm what has just been mentioned. Results near 1 are the least important (‘Leadership skills’; 0.93 and ‘adaptability to change’; 0.88) while lower results are considered as essential (‘Cope with pressure’; 0.71 and ‘Teamworking skills’; 0.75).

b) Master and Chief Engineers.

In the analysis of the results of Master and Chief Engineers ‘Cope with Pressure’ (118) is once again the winner in HI&E results, followed by ‘Problem Solving’ (114) and ‘Leadership (111)’. Analytical skills (110) and Teamwork (107) completed the top5.
The average values show some different results. In this case, ‘Leadership skills’ is valued as the most important with an average of 4.65 out of 5, making the skill ‘Essential’ for Engineers. ‘Cope with pressure’ and ‘problem solving skills’ completed the podium with averages of ~4.5. ‘Analytical skills’ and ‘teamworking skills’ were also considered as very important since they got an average of ~4.3.

As in Officers of the watch results, Standard Deviation values reaffirm average results. Results near 1 are the least important while lower results are considered as essential.

4.1 RADAR CHART: RESULTS COMPARISON OF BOTH PROFESSIONS

The following figure displays the average results of ‘Officers of the Watch’ (orange), the average of Master and Chief Engineers (blue) and the average of both (average). The chart provided us a great help to decide which skills would be selected.
Figure 6. Skills considered as ‘HI&E’ for M&C Engineers.

The average values show some different results. In this case, ‘Leadership skills’ is evaluated as the most important with an average of 4.65 out of 5, making the skill ‘Essential’ for Engineers. ‘Cope with pressure’ and ‘problem solving skills’ completed the podium with averages of ~4.5. ‘Analytical skills’ and ‘teamworking skills’ were also considered as very important since they got an average of ~4.3.

Figure 7. TOP 5 Skills for M&C Engineers (Average).

As in Officers of the watch results, Standard Deviation values reaffirm average results. Results near 1 are the least important while lower results are considered as essential.

4.1 RADAR CHART: RESULTS COMPARISON OF BOTH PROFESSIONS

The following figure displays the average results of ‘Officers of the Watch’ (orange), the average of Master and Chief Engineers (blue) and the average of both (average). The chart provided us a great help to decide which skills would be selected.

4.10 4.20 4.30 4.40 4.50 4.60 4.70
Cope with pressure/ Work under Pressure
Problem Solving skills
Leadership skills
Analytical skills
Teamworking skills
Willingness to learn
Time management (being organised)
Apply quality standards/ Follow procedures
Adaptability to change

Figure 8. Radar chart.

5. CONCLUSIONS

- Transversal skills are higher valued for Master and chief Engineers than for officers of the sea. As displayed on figure 7, there is no skill that was better rated for officers of the watch.
- It is clear that ‘Cope with Pressure’, ‘Teamworking skills’ and ‘Apply quality standards’ must be assessed in the ‘Informal skills scanner’. They are both high valued in the two professions.
- ‘Problem Solving skills’ is considered as very important for Engineers but not for Officers of the watch, nevertheless it should also be assessed since it occupies #4 in the average and standard deviation ranking.
- ‘Analytical Skills’, ‘Time Management’ and ‘Willingness to learn’ got exactly the same average result; 4.07. Hence, they should also be considered in the ‘Informal skills scanner’.
- ‘Leadership skills’ was top rated for Master and chief engineers, and even though it was considered as the least important for Officers of the watch, it should be added to the list in order to not lose the most important transversal skill of Engineers.
- Finally, it was agreed by all partners that Language Skills and ITC skills would be added to the skill scanner, since nowadays, both skills are the most demanded by companies.
6. DISCUSSION

Developing a methodology to analyse and identify transferable hard and job-specific skills that are held by seafarers and later identifying onshore jobs and careers that utilise these transferable skills, is an effective solution to provide guidance for mid- to long-term career planning for MET students and seafarers.

The obtained results up to this point from the research phase show significant analogies between the offshore and onshore professions. The combination of IMO, ECVET and ESCO list of knowledge, skills, and competences plus the expertise of projects partners will provide a verified, solid, and useful tool that will deliver a solution that other studies haven’t been able to solve yet.

On the other hand, the results of the survey conducted to identity the most relevant soft skills for Seafarers, proves the importance of these personal abilities to perform their day to day activities. 122 maritime experts throughout Europe evaluated the majority of these skills as “Highly Important” for the workplace, with an average above 4 out 5 in all cases. For this reason, identifying and assessing soft skills, will provide seafarers an added value to their skills portfolios and support their career opportunities.

The next steps of the Skills Beyond the Seas Project will involve the participation of 50 onshore experts who will evaluate the offshore skills and select those in accordance with their professions. This together with the expertise of maritime project partners and the input of EU and IMO resource will continue adding value to projects results. Furthermore, the 300 assessment tests of the Informal Skills Scanner will be evaluated by experienced psychologists and Human Resource Managers to ensure an effective testing of the 10 selected soft skills.

7. APPENDIX:

Survey description

<table>
<thead>
<tr>
<th>The challenge</th>
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<tbody>
<tr>
<td>There is still an urgent need for young people to enter into the professions of seafarers and although overall numbers are significant, their future employment and career perspectives are very uncertain and unclear. This uncertainty especially affects young seamen and maritime trainees and makes it a difficult decision for youth to enter this sector. It thereby hinders them to enter into highly valuable VET training which offers them learning outcomes that can be used far beyond sea-going professions.</td>
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<table>
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<tr>
<th>The objective</th>
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<tbody>
<tr>
<td>For active seafarers and students in Maritime Education and Training (MET) across the EU, who all need a perspective for their future, the project Skills Beyond the Seas offers the much-needed information and guidance for mid- to long-term career planning. The tools that will be developed by the project will provide seafarers with a detailed list of their formal and</td>
</tr>
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</table>
informal skills, highlight their transferable skills sets and suggest career pathways to other occupations where these skills are needed.

### Your contribution

The aim of this questionnaire is to verify through your professional experience, which transversal skills are required and commonly present in different seafarer ranks so that we can later assess them for the correct skill sets. For that reason, in the following questionnaire we will ask you to specify the organisation you are working for and to rate by priority some transversal skills for different ranks. Informal transversal skills are those skills that have been learned often unintentionally and in a daily informal setting (family, leisure, work) and are transferable to a wide range of occupations and sectors. If you are unsure about the meaning of any of the listed skills, then please check the definitions at the end of the survey.

<table>
<thead>
<tr>
<th>1. Could you specify in which country are you working?</th>
<th>Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Other (please specify).</th>
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<tbody>
<tr>
<td>2. What type of company/ institution/ organisation are you currently working for?</td>
<td>Maritime University, Maritime Highschool/ VET, Shipping company, Seafarer Recruitment agency, Seafarer Union, Research institution, Maritime association, Nautical qualification body, EU Maritime agency, International Maritime agency</td>
</tr>
<tr>
<td>3. Any other company/ institution/ organisation</td>
<td>Your answer</td>
</tr>
<tr>
<td>4. By number of employees, what’s the size of company/ institution/ organisation you are currently working for?</td>
<td>Micro (less than 10 employees), Small (10-50 employees), Medium-sized (50-250 employees), Medium-Large (250-1000 employees), Large (more than 1000 employees)</td>
</tr>
<tr>
<td>5. Which transversal skills do think are most required and commonly present in Officers of the Watch? Please rate these by priority.</td>
<td>Adaptability to change, Analytical skills, Apply quality standards/ Follow procedures, Cope with pressure/ Work under Pressure, Interpersonal skills, Leadership skills, Problem Solving skills, Teamworking skills</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Not a priority</th>
<th>Low priority</th>
<th>Medium priority</th>
<th>High priority</th>
<th>Essential</th>
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<tbody>
<tr>
<td>Problem Solving skills</td>
<td>Cope with pressure/ Work under Pressure</td>
<td>Interpersonal skills</td>
<td>Leadership skills</td>
<td>Teamworking skills</td>
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</tbody>
</table>
6. Any other informal transversal skills? (please suggest)

<table>
<thead>
<tr>
<th>Time management (being organised)</th>
<th>Willingness to learn</th>
</tr>
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</table>

Your answer

7. Which transversal skills do think are most required and commonly present in Masters and Chief Engineers? Please rate these by priority.

<table>
<thead>
<tr>
<th>Not a priority</th>
<th>Low priority</th>
<th>Medium priority</th>
<th>High priority</th>
<th>Essential</th>
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</thead>
<tbody>
<tr>
<td>Adapability to change</td>
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<td>Analytical skills</td>
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<tr>
<td>Apply quality standards/ Follow procedures</td>
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<tr>
<td>Cope with pressure/ Work under Pressure</td>
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<td>Interpersonal skills</td>
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<td>Problem Solving skills</td>
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<td>Teamworking skills</td>
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<tr>
<td>Time management (being organised)</td>
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<tr>
<td>Willingness to learn</td>
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</tbody>
</table>

8. Any other informal transversal skills? (please suggest)

Your Answer

#### TRANSVERSAL SKILLS DEFINITIONS

**Adapability to change**

Adaptability as a skill refers to the ability of a person to change his actions, course or approach to doing things in order to suit a new situation. Ability to prioritize, effectively adapt to the changing professional environment but also to the emotional states generated through the daily interactions with professionals possessing different levels of authority. Supporting change implemented via new approaches, initiatives, methods, and technologies. Being able to manage priorities and changes, and to adapt his/her own plans, behaviours, strategies or approaches to the situational changes.

**Work under Pressure**

- The ability to work under pressure relates to how the employees respond when put under pressure. In a work context, pressure can be defined as the stress and urgency of matters requiring attention, the burden of physical or mental distress and the constraint of circumstances. Employees who are able to work under pressure will be able to deal with constrains which are often outside of their
<table>
<thead>
<tr>
<th>Transversal Skills</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Time management (being organised)</td>
<td>The ability to interact and co-operate with a group of people to achieve a goal. It involves hands-on working together, as well as processes of organisational planning, decision-making and development. Effective team working requires team members to co-operate, listen to each other, communicate clearly, share knowledge and information, show commitment to the team and task and be supportive of other members.</td>
</tr>
<tr>
<td>Leadership skills</td>
<td>The ability to influence and motivate others to achieve a common purpose or goal. An effective leader is a person who does the following: creates an inspiring vision of the future, motivates and inspires people to engage with that vision, manages delivery of the vision and coaches and builds a team, so that it is more effective at achieving the vision.</td>
</tr>
<tr>
<td>Interpersonal skills</td>
<td>The ability to relate to and get along with others, build trust, empathise and see things from different perspectives.</td>
</tr>
<tr>
<td>Willingness to learn</td>
<td>Employees who are willing to learn have desire and passion for improving their professional skills through formal, non-formal and informal situations. This skill includes awareness of one's learning process and needs, identifying available opportunities, and the ability to overcome obstacles in order to learn successfully.</td>
</tr>
<tr>
<td>Analytical skills</td>
<td>The ability to examine information or a situation in detail in order to identify key or important elements, their strengths and weaknesses and use these to compile a persuasive argument, make recommendations or solve a problem.</td>
</tr>
<tr>
<td>Problem solving skill</td>
<td>Problem solving is an individual’s capacity to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations to break them down into their key components; consider various ways of approaching and resolving them and to decide which is the most appropriate.</td>
</tr>
<tr>
<td><strong>Time Management</strong></td>
<td>Time management is the process of organizing and planning how much time you spend on specific activities.</td>
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<td>--------------------------------------------------------------------------------------------------</td>
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<tr>
<td><strong>Apply quality standards/ Follow procedures</strong></td>
<td>Applying quality standards or following procedures refers to the skill of being able to stick with a fixed standard or procedure effectively, either individually or when working in a group. The person who has this skill can follow a procedure which has been prepared either by himself or externally.</td>
</tr>
</tbody>
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**References:**


Time management is the process of organizing and planning how much time you spend on specific activities. Applying quality standards or following procedures refers to the skill of being able to stick with a fixed standard or procedure effectively, either individually or when working in a group. The person who has this skill can follow a procedure which has been prepared either by himself or externally.

References:


A NEW APPROACH TO MAKE INDOOR AIR QUALITY IN THE ACCOMMODATION OF SHIPS UNDERSTANDABLE AND ACTIONABLE FOR SEAFARING STAFF

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Abstract:

Today’s society is increasingly aware of the impact of air quality on human life. Air quality in and around ships is a challenging subfield because pollution is aggravated by cargo vapours, exhaust emission and even cooking on board. The assessment of the air quality requires substantial chemical analyses at several locations over prolonged periods. In addition, the huge amounts of collected data and the complexity of the underlying relationships are important barriers for persons not trained in data science. The situation is aggravated by the plethora of guidelines, standards, recommendations, and legislations from several countries and organizations specifying permitted exposure limits. These criteria often result in contradicting information, confusing seafarers.

The purpose of this study is to develop a mathematical method to translate all this complex data and opinions into actionable information, easy to understand for non-specialists. We developed a mathematical algorithm where all these opinions were brought together in a statistical model, resulting in a more nuanced interpretation. The concentration values of the pollutants is associated with an estimated risk-index. The levels of risk are presented in a simplified way using colour-maps. The method developed was applied on a dataset obtained from a measuring campaign performed on a research vessel, sailing close to the Belgian coast. Multiple parameters such as NO₂, NO, CO₂, CO, SO₂, O₃ and H₂S concentrations were analysed during the time of the measuring campaign. In this contribution, we will present the risk assessment we derived during the measuring campaign and the actionable interpretations we derived from them.

Keywords:

air quality assessment, intuitively readable data.
Abstract:

The present work aims to perform a risk analysis of ambient air on human health. For this, a method is proposed that can converts large data streams about several environmental parameters into an overall risk-index that can easily be understood by seafarers who have limited expertise in environmental and data science. That method will accommodate of ships understandable and make air quality transparent for an analytic.

1. INTRODUCTION

Ships generate air contaminants from different activities such as maintenance labours (e.g. welding process, metal grinding, painting, etc), bunkering, exhaust gases, or even human activities like smoking or cooking [1-6]. The total emissions from this sector alone represent around 13% of the overall EU greenhouse emissions from the transport sector and around 2.5% of the global greenhouse emissions [7]. Moreover, ships spend a substantial amount of time in harbours where industrial activities generate elevated levels of pollution [8]. This means that the crew on board might be exposed to higher concentrations of pollutant gases for longer periods when compared to persons living ashore. In this context, it is more important to crewmembers to have a better understanding of the air quality and the levels of pollution they are exposed.

There is a wide range of emission compounds in and around marine and inland vessels [add more than one reference]. These emissions can contain particulate matter of different compositions and sizes, gases such as CO2, NOX, SO2, CO, and even a wide-range of organic substances [9]. In addition, several physical parameters such as temperature (T), relative humidity (RH) or wind speed influence air quality as well. All these parameters are affected by the activities on the ship, resulting in a fluctuation of the measured parameters. This means that real-time monitoring of multiple parameter is needed to have a better understanding of air quality [10]. The traditional methods of data processing focus on the visualization of trends of all the measured parameters. Unfortunately, the relation between air quality and the measured parameters is complex and that air quality is often not shown in a direct way. Instead, trends of several parameters are usually presented. This situation can lead to information overload [11]. As a result, such measurements are not used properly to improve the air quality in and around ships. According to Miller et al, people have finite limits to the information they can assimilate and process. Under overload conditions, people become confused and likely to make poorer decisions [12]. Other authors argued that cognitive overstimulation interferes with our abilities and it is likely that a reduction in decision quality will occur [13]. Hence, it is necessary to find a method of processing all this information and make air quality transparent for an analytic.

The present work aims to perform a risk analysis of ambient air on human health. For this, a method is proposed that can converts large data streams about several environmental parameters into an overall risk-index that can easily be understood by seafarers who have limited expertise in environmental and data science. That method will
allow them to infer the information quickly and if needed enabling them to take action effectively. The proposed method responsible for the conversion is based on expert elicitation where threshold values from the legislation and guidelines about occupational limit values of different countries are considered as different expert opinions.

To have an idea about the real-time trends of the air quality in the accommodation of a ship, a measuring campaign has been performed in a sleeping quarter of the Research Vessel Belgica during a journey on the North Sea without any cargo on board. The measuring campaign took place in a sleeping quarter. The selection of the measuring location was based on two conditions. The first is a safety reason because it is a place where the monitoring station is not going to hinder seafarers operations; and second, because sleep quarters is one of the places where seafarers spend much time and hence an important place to know the levels of pollution. In addition, the selected sleeping quarter was the one closest to the engine room.

2. EXPERIMENTAL

2.1. MEASURING LOCATION

A measuring campaign was performed in a sleeping quarter of the Research Vessel Belgica from January 19, 2020, up to January 24, 2020 (Fig. 1). The first 2 days, the sleeping quarter was empty with intermittent presence of people until January 21 when the ship left the harbour. From that day on, the location was occupied by one researcher until the end of the measuring campaign. The sleeping quarter had a ventilation inlet that was running during the time it was occupied by that person.

The ship departed from the port of Zeebrugge on January 21 for a journey of 3 days on the North Sea. The campaign ended on January 24 and there was no cargo on-board. Within that period there were no remarkable events concerning weather conditions, except for mist on the day of departure. During the measuring campaign, a logbook with information regarding all the actions or events that might influence the air quality and the moments when the occurred was registered. The most striking actions were identified as, switching on and off the ventilation, a fire drill, ship bunkering, engine running or stopping, and personnel presence close to the measuring devices.

Fig.1: Research Vessel Belgica and sleeping quarter where measurements were performed.
2.2. DATA ACQUISITION

An in-house developed multi-sensor tool measured a large number of environmental parameters [14]. The monitoring tool consisted of a multi-purpose data logger (DataTaker DT85, Thermo Fischer Scientific, Scoresby Vic, Australia) to which a wide range of off-the-shelf sensors were coupled. The measuring system analyses several environmental parameters from the same location. Temperature, relative humidity and CO₂ were collected with a GMW90 (Vaisala, Helsinki, Finland) [15-17]. The pressure is measured with a PTB110 (Vaisala, Helsinki, Finland) [18-20]. Particulate matter is recorded with the Shinyei sensors PPD-60 (i.e., it detects all particles larger than 0.5 µm) and PPD-20 (i.e., it detects all particles larger than 1 µm) respectively [21]. Concentrations of CO (CO-B4), NO₂ (NO2-B43F), O₃ (OX-B431), H₂S (H2S-B4), SO₂ (SO2-B4) and NO (NO-B4) were collected using the B4-sensors of Alphasense with a 32 mm diameter package (Alphasense, Essex, UK) [22]. The concentration of total volatile organic compounds (TVOC) was estimated with the B4-sensors of Alphasense with a 32 mm diameter package [23]. Although motion in front of the measuring device is not an environmental parameter, human activity can explain features in the times series such as spike-signals, step functions, etc. Therefore, the AMN24112 motion sensor of Panasonic was coupled to the data logger as well. This sensor has a detection distance of 10 m and a detection area between 93° and 110° [24, 25]. The data logger counts the number of pulses generated by the sensor in a time window of 5 minutes. All sensors were read out in phase with a frequency of 1 minute, while 5 minutes averages were saved by the data logger. The sampling rate is sufficiently high to consider the discrete time series as a continuous signal.

2.3. DATA PRE-PROCESSING

The output of the multipurpose data logger is a data matrix. The matrix consists of rows that groups the measurements of all the sensors measured at the same moment. The parameters measured are organized as columns. Each data point (i.e., matrix row) is labelled with a timestamp. The raw data contained a limited number of measuring errors: (1) one data point is missing and (2) 4 subsequent measurements of the PPD-20 sensor were over ranged. The raw signal of the sensors contained some noise that hampers the readability of the information. The median is a robust measure of central tendency, less sensitive to outliers. Therefore, to remove measuring errors and to suppress noise in some extent, a central moving median filter has been applied [26]. To minimize the deformation of spike-signals, step-functions in the signal with edgy borders or peaks, the smallest possible window has been applied to remove the measuring errors: a total window size of 5 points.

The cleaned signals are converted to their quantities by means of calibration functions [27]. The calibration of the Vaisala sensors has been certified by the company, meaning that temperature, relative humidity, CO₂ and pressure can be considered as quantitative measurements. Alphasense delivers calibration constants with their sensors. The advantage of these sensors is that they give an insight into gaseous pollutants for an affordable price. However, the limitation of such mid-price sensors is their cross-sensitivity. As a result, a single gas can affect the signal of several sensors [28]. In addition, the calibration of the sensors close to their detection limit is not very accurate. This means that for some gas sensors, the calculated concentrations can be below zero. This has been compensated by shifting the concentration so that the lowest value is equal to zero. The signal of ozone consisted of a horizontal background and large negative
spikes. In that case, the background was shifted to zero. The sensors for particulate matter and the PID-sensor do not have any calibration information from the suppliers. In addition, the signal of the PID-sensor is highly dependent on the mixture of organic substances in the air.

2.4. Data visualization

Figs. 2a and 2b show different time series with the real time behaviour of the parameters obtained during the measuring campaign in the period between 19th and 24th of January of 2020. The shaded areas represent the most important external actions affecting the environmental parameters Fig. 2a shows some auxiliary parameters that give an enhanced insight in the environmental conditions close to the measuring location. During the measuring campaign, two significant actions occurred due to different contamination factors overlapping during the same period. The first one corresponds to 20th of January between 7:20 and 16:25. During that period, several activities affecting the environmental parameters took place such as the presence of personnel working in the sleeping quarter, displacement of the ship from one berth to another in the port and bunkering of the ship. Peaks in the concentration of several gases (NO, NO2, CO, H2S) were noticed. The other relevant moment corresponds to the period between 7:50 and 16:50 on January 23. During that time, a fire drill was performed in the facilities of the ship and intermittently, a pump close to the inlet of the ventilation system of the engine room was turned on while the ventilation in that location was off. Figure 2 shows peaks of all the gases except for O3. These important moments in Fig. 2 are shown as shaded areas.

Fig. 2a shows some auxiliary parameters that give an enhanced insight in the environmental conditions at the measuring location. Fig. 2b shows the environmental parameters that are used to perform the risk analysis. Some parameters show progressive changes (steady increase of T after Jan-20, decrease in RH, drop in atmospheric pressure). Other parameters show step functions (CO2, O3). At other occasions spike-shaped signal occurred. Many of these changes can be attributed to actions or events noted in the logbook. This suggest that several sources of pollution have an effect on the air quality in the sleeping quarter. The Fig 2 is a typical example of a conventional visualization. Based on this information, it is impossible, for non-trained people to arrive to fast and accurate decisions.
Fig. 2: Trends of several parameters as measured by the monitoring system. The tick labels of the vertical axes are written in the following way: minimum|maximum. a) Overview of several physical and chemical parameters not used to evaluate air quality; b) Overview of the inorganic gaseous pollutants used in the calculation of the overall level of risk.

3. LEVEL OF RISK ASSESSMENT METHOD

In this investigation, the sleeping quarter is considered as the working place of the researcher. For that reason, “occupational exposure limits” (OEL) are used as threshold to perform air quality assessment. OELs represent the maximum airborne concentration of a toxic substance to which a worker can be exposed over a period without suffering any harmful consequences [29]. They are an important regulatory instrument to protect workers from chemical exposures. Different organizations have set their own OELs and
may use different terminology. For example, the American Conference of Governmental Industrial Hygienists (ACGIH) term for OEL is "Threshold Limit Value" (TLV) while the NIOSH term is "recommended exposure limits" (REL) [30]. According to the ACGIH, 3 categories of occupational threshold limit values can be distinguished:

- **Threshold Limit Value - Time-Weighted Average (TLV-TWA):** The concentration of a hazardous substance in the air averaged over an 8-hour workday and a 40-hour workweek to which it is believed that workers may be repeatedly exposed, day after day, for a working lifetime without adverse effects.

- **Threshold Limit Value - Short-term exposure (TLV-STEL):** A 15-minute time weighted average exposure that should not be exceeded at any time during a workday, even if the overall 8-hour exposure is below the TLV-TWA. Workers should not be exposed more than 4 times per day to concentrations between TLV-TWA and TLV-STEL. There should be at least a 60-minute interval between exposures. The short-term exposure threshold has been adopted to account for the acute effects of substances that have primarily chronic affects.

- **Threshold Limit Value - Ceiling (TLV-C):** This concentration should not be exceeded during any part of the working hours.

The values of these TLVs can vary substantially from one organization to the other. For example, it is known that, in average, the US OSHA exposure limits are nearly 40% higher than those of Poland [31]. This difference evidence the lack of consensus between organizations, hampering risk management decisions. To get an overview of this inconsistency, the TLV-TWA and TLV-STEL from more than 45 country legislations and organizations were compiled for each of the substances under study [32]. In Table 1 some of the most important properties of the TLVs collected are shown, i.e. pollutants studied, number of TLVs collected for each pollutant, average, standard deviation, minimum and maximum values of the set of TLVs.

**Table 1: Properties of the TLVs collected.**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Number of data points</th>
<th>Average (ppm)</th>
<th>Standard Deviation (ppm)</th>
<th>Min (ppm)</th>
<th>Max (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃-8h</td>
<td>18</td>
<td>0.091</td>
<td>0.033</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>O₃-st</td>
<td>19</td>
<td>0.163</td>
<td>0.067</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>SO₂-8h</td>
<td>23</td>
<td>1.28</td>
<td>1.04</td>
<td>0.5</td>
<td>5.0</td>
</tr>
<tr>
<td>SO₂-st</td>
<td>22</td>
<td>2.48</td>
<td>1.92</td>
<td>0.5</td>
<td>5.0</td>
</tr>
<tr>
<td>NO₂-8h</td>
<td>20</td>
<td>1.8</td>
<td>1.2</td>
<td>0.5</td>
<td>3.0</td>
</tr>
<tr>
<td>NO₂-st</td>
<td>21</td>
<td>2.8</td>
<td>1.9</td>
<td>0.5</td>
<td>5.0</td>
</tr>
<tr>
<td>H₂S-8h</td>
<td>24</td>
<td>6.3</td>
<td>2.5</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>H₂S-st</td>
<td>24</td>
<td>11.5</td>
<td>3.67</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>NO-8h</td>
<td>26</td>
<td>15.2</td>
<td>11.4</td>
<td>0.5</td>
<td>25.0</td>
</tr>
<tr>
<td>NO-st</td>
<td>4</td>
<td>22.5</td>
<td>20.7</td>
<td>1.0</td>
<td>50</td>
</tr>
</tbody>
</table>
By considering all these values as opinions, we can use expert elicitation to combine all this knowledge into a single model that is able to convert pollutant concentrations into a level of risk [33, 34]. Expert elicitation is based on the synthesis of opinions of authorities on a subject where there is uncertainty due to insufficient knowledge, when data is unattainable because of physical constraints or lack of resources [35]. Where the TLV of each pollutant studied is defined as unknown value, while the compilation of all the TLVs collected from different organizations are considered as experts opinions. It is assumed that the opinions about a specific pollutant are distributed around a central tendency according to a Gaussian distribution (Fig. 6). That distribution is defined by the average and standard deviation calculated from the set of TLVs. Concentrations need to be converted into a level of risk, which is a sliding scale between 0 and 1. The level of risk is evaluated by applying the cumulative distribution function (CDF) of the standard normal distribution using equation 1. In that sense, risk can be interpreted as the probability of the concentration measured to be higher than the occupational exposure limit according to the information provided by experts.

\[
R(C) = \frac{1}{2} \left[ 1 + \text{erf} \left( \frac{C - \overline{TLV}}{S_{TLV} \sqrt{2}} \right) \right]
\]  

(1)

In equation 1, \(R(C)\) represents the level of risk, \(C\) is the measured concentration, \(TLVs\) are the thresholds compiled for one specific parameter, \(\overline{TLV}\) and \(S_{TLV}\) are the average value and standard deviation of the \(TLVs\) set. If the obtained level of risk is closer to 1, it is probable that the concentration is higher than the occupational exposure limit and hence, air quality conditions are worse. If the level of risk is closer to 0 then it is less probable that the threshold is exceeded and hence air quality is better. The relation between concentration and level of risk is shown in Fig. 3.

<table>
<thead>
<tr>
<th>CO-8h</th>
<th>25</th>
<th>26.9</th>
<th>8.5</th>
<th>17</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO-st</td>
<td>21</td>
<td>126.9</td>
<td>80</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>CO₂-8h</td>
<td>27</td>
<td>5278</td>
<td>1416</td>
<td>5000</td>
<td>12500</td>
</tr>
<tr>
<td>CO₂-st</td>
<td>17</td>
<td>21471</td>
<td>9198</td>
<td>10000</td>
<td>30000</td>
</tr>
</tbody>
</table>

### Table 1: Properties of the TLVs collected.
The risk values of each individual parameter under study were calculated by evaluating the average on the measured data stream in a moving window of the previous 8 hours or 15 minutes. Therefore, it is possible to obtain time-weighted averages of every moment in time. The time-weighted averages are compared with the set of TLV-TWA and TLV-STEL values.

Once the risks are calculated for each parameter for 15-minutes and 8 hours exposure, an overall risk can be determined expressed as a single index. The overall risk-index summarizes the environmental measurements in each data point as a single index. Three methods have been used:

- **Averaged level of risk**: From each data point, the average level of risk is calculated from the last 8 hours and short time exposure of NO, NO₂, CO, CO₂, SO₂, O₃ and H₂S.

- **Euclidean norm**: If the level of risk of each gaseous pollutant for 8 hours and short-term exposure is considered as an independent variable in an n-dimensional orthogonal space, the distance related to the coordinates can be calculated using the Euclidean norm (i.e., the square root of the sum of the squares).

- **Worst level of risk value**: The overall level of risk is governed by the environmental parameter (8 hours and short-term exposure) causing the highest level of risk.

An intuitive visualization of the risk-index is provided using a graphical representation based on colour codes. A colour map comprises a range of 100 different colours, individually assigned to discrete values of the risk-index with a resolution of 0.01. The reversed jet colour-map is used to convert the sliding scale of the levels of risk between 0 and 1 to a specific colour (i.e., 3 colour coordinates). That conversion is illustrated in
Fig. 3: Proposed method based on the probability distribution describing the likelihood of the position of the threshold value and the cumulative distribution describing the relation between concentration of a pollutant and the corresponding level of risk.

The risk values of each individual parameter under study were calculated by evaluating the average on the measured data stream in a moving window of the previous 8 hours or 15 minutes. Therefore, it is possible to obtain time-weighted averages of every moment in time.

The time-weighted averages are compared with the set of TLV-TWA and TLV-STE values.

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Fig. 4: Relation between the overall level of risk R and colour as defined by the colour map Reverse Jet. The corresponding colour transition for the risk values from 0 up to 1 to colour coordinates is determined by the conversion functions for blue green and red.

An in-house developed software written in Python 3 is applied to convert all data points of the matrix into an indoor air quality assessment [36]. In this work, the analysis of the indoor air quality index was calculated using the data obtained of NO, NO₂, CO, CO₂, SO₂, O₃, and H₂S.

4. RESULTS

From the real-time information shown in Fig. 2, the average concentrations for short time and 8-hour exposure were calculated. In addition, the level of risk of each parameter is visualized using colours. Fig. 5a shows individual risks calculated for all parameters in the previous 8 hours of exposure and Fig. 5b for 15 minutes exposures. Fig. 5 shows substantial differences in behaviour between the risk associated to 8-hour exposure and the short-term exposure.

The 8 hours exposure risk shows a smoother behaviour over time, this is, lower and wider peaks. In addition, the peaks of 8-hour exposure risk are shifted to the right compared to the short-term exposure. These differences can be explained by the time-window applied in the moving average. The moving average is achieved by averaging a given numbers of equidistant concentration values over time and replacing them with the average value. The window size selected affects data point peaks reducing height and increasing width. In the case of 8-hours exposure, the window size is bigger than for short-term exposure (15 minutes) causing a bigger reduction and widening of this peaks, and in some cases causing the removal of them, giving place to other features such as in the case of NO₂ and
Furthermore, the moving window position can also affect peaks, shifting them if it is not a central window. A one-sided moving-window was applied. Therefore, the moving average is placed at the end of values being averaged. This shifting effect is more pronounced depending on the window size. In Fig. 5 is possible to see bigger peaks shift to the right in the 8-hour exposure risk.

Fig. 5: The level of risk of individual environmental parameters over time (a) level of risk for an 8-hour moving exposure and (b) level of risk for a short-term exposure abbreviated as st (15 min.) exposure.

The differences between every single time-averaged risk calculated for each parameter is determined by equation 1. For a given TLV data set, the level of risk will be directly proportional to the concentration value. Therefore, in such conditions, as closer the concentration value to the TLV higher the level of risk is going to be. In Fig. 5, it is shown that moments with higher time-averaged concentrations correspond to higher levels of risk. However, in practice, this relation is not that simple, due to the set of expert opinion differs from one substance and time-weighted average to the other. In the case of Fig. 5, the level of risk was very low for all parameters. This occurs because the maximum
concentration values obtained during the measuring campaign were several orders of magnitude lower compared to their corresponding TLVs. The values of $S_{TLV}$ also affects the results shown in Fig. 5. The $S_{TLV}$ value indicates the level of disagreement between experts opinion.

Even though the graphs in Fig. 5 are easier to read because of the superimposed information about the level of risk, it is still a substantial amount of information to be processed. This can be improved by compressing all this information in one single overall risk. Fig. 6 shows the three methods applied to compress the information. From Fig 6 we can extract information in a simple way. The colour associated to the level of risk is always in the range blue, meaning that the level of risk is very low and with small variations during the period studied. This can be explained by the concentrations that are much lower than the estimated exposure limits. Although the changes are small is still possible to see dynamic changes on the overall risk. These changes (i.e. peaks) are in correspondence with the different actions that occurred in the ship during the measuring campaign. Although, in general, the different overall risks show a similar pattern, they have particular characteristics:

- **Averaged level of risk:** The overall level of risk determine as the average of all exposures, is dominated by NO-st concentration profile. This can be explained because the concentration are closest to the average threshold value or because there was less consensus between the expert opinions (i.e., higher standard deviation and thus a wider Gaussian distribution).

- **Euclidean norm:** The main features such as peaks and sudden jumps in Fig. 6b also occurs in the average level of risk (Fig. 6a). However, the peaks are accentuated while the background is somewhat reduced. The uniform colour is somewhat more cyan, suggesting a somewhat higher level of risk.

- **Worst level of risk value:** The trend in Fig. 6c is different from the trends in Fig. 6a and b, but also shows higher concentration peaks during the important moments.
5. THREATS TO VALIDITY

The analysis suggests that the working conditions on board of the Research Vessel Belgica are well below the thresholds, suggesting safe environmental conditions.
However, several error sources may influence these conclusions. The most important sources are:

- **Imperfect sensors:** Although the sensors are able to generate a signal at the measured concentrations (although for H₂S the signal is extremely close to the detection limit), such measuring devices are only a cheap alternative for reference instruments. They are sensitive to cross-sensitivity. This might introduce errors in the real-time measurements;

- **Imperfect calibration of the sensors:** The Vaisala sensors are well calibrated by the supplier. However, the provided calibration constants of the Alphasense sensors result in negative concentration at low concentrations. This has been corrected by applying a second calibration. However, that calibration can contain errors. This might affect all concentrations of a single parameter.

- **Work place vs. Living place:** The indoor air quality has been evaluated by comparing the concentration with occupational exposure limits. These thresholds are used to evaluate work places. However, sailing personnel not only work on a ship but also live on a ship. This means that the personnel are exposed much longer to these pollutants than the traditional 8-hour exposure.

6. CONCLUSIONS

A mathematical method was used as back office that is able to generate graphs that are easy to read by sailing personnel with limited expertise in environmental and data science. The exposure thresholds were considered as opinions and brought together using a statistical approach, giving a more nuanced interpretation. The method used was able to combine the concentration values from different pollutants (NO₂, NO, CO₂, CO SO₂, O₃ and H₂S) in a single overall risk value. The levels of risk were presented in a simplified way using colours. We were able to translate complex data and opinions into actionable information. The method developed was applied on a dataset obtained from a measuring campaign performed on the Research Vessel Belgica, sailing close to the coast of Belgium. The air in the sleeping quarter as a working place was safe at all moments.

References:


HEAT STRESS ON BOARD: RISK AND PREVENTION

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Abstract:

The heat stress is the load of heat that a worker receives and accumulates in his body and that result of the interaction between the environmental conditions of the place where he works, the physical activity he does and the clothes he wears. The direct action of heat on the body causes a defense against this elevation of temperature inside our organism with the aim of keeping the internal temperature within limit parameters. As Directive 89/654/EEC concerning the minimum safety and health requirements for the workplace indicates the thermal and hygrometrical conditions that can cause thermal stress on the workers health have to be studied.

On board ships, specifically in the engine room, seafarers are subjected to very high temperatures during long time periods and to considerable variation in temperature. The objective of this paper is to analyse the impact of thermal stress on engine room workers on board ships, to study the consequences of such thermal stress to the organism and to review the current labour legislation with regard to risks due to thermal stress by heat. At the same time a relationship between heat stress and fatigue on board is established. It is concluded that the current thermal regulation measures as well as the applicable legislation are clearly insufficient. Moreover, heat stroke and dehydration are the most serious risks of exposure to heat in the engine room.

Keywords:

heat stress, fatigue, health.

INTRODUCTION

Thermal heat stress is the heat load that workers receive and accumulate in their body and that results from the interaction between the environmental conditions of the workplace, the physical activity they perform and the clothes they wear (1).

The direct action of heat on the body triggers within our body a defense against that temperature rise to try to maintain the internal temperature within parameters.

The most common effect of heat is discomfort at work, but if the conditions are extreme the discomfort can be transformed into danger. The spectrum of heat illnesses include relatively minor heat rashes, cramping, heat syncope and dehydration, to more serious heat exhaustion,
which, if untreated, can lead to heat stroke with central nervous system involvement progressing to multi-organ dysfunction syndrome affecting major organs, including the brain, kidneys, and heart, and can be fatal (2,3).

Following Zander et al. (4) negative impacts of hot weather include, higher work accident frequency because of concentration lapses, higher levels of fatigue and poor decision making because time perceptions change, and increased stress hormone levels which also affect cognitive performance and decision quality. Furthermore, according to American Bureau Shipping (5) “sustained high temperatures leading to heat stress conditions can lower work performance and morale and impair mental alertness, increasing the risk of workplace accidents, and ultimately compromising the readiness of the ship”.

Thermal heat stress is not a pathological effect that heat can cause in workers, but the cause of the various pathological effects that occur when excessive heat accumulates in the body. When working in conditions of thermal stress, the individual's body is disturbed. It suffers a physiological overload, because, by increasing its temperature, the physiological mechanisms of heat loss (mainly sweating and peripheral vasodilation) try to lose the excess thereof. If, in spite of this, the central temperature of the body exceeds 38 ºC, different damages to health may occur, whose severity will be in line with the amount of heat accumulated in the body.

According to Directive 89/654 / EEC, which establishes the minimum health and safety regulations in the workplace (6), the environmental conditions existing in the workplace (air temperature, thermal radiation, humidity and air speed) together with other parameters that influence the thermal equilibrium of the body (heat generated by the physical activity performed, thermal insulation of clothing) can cause situations of risk to the health of workers, either by heat or cold. That is why the thermo hygrometric conditions that can cause thermal stress on the health of workers should be studied.

Seafaring is associated with special mental, psychosocial and physical stressors and cannot be compared with jobs ashore.

Some ships compartments are undoubtedly considered severe hot environments due to high temperature values, such as the engine room and, depending on external conditions, cargo holds and storage areas (7). Such peculiarity further increases already high stress levels related to awkward work postures, lack of space and appropriate lifting tools, noise, vibrations, and poor air quality. Technical spaces such as engine rooms are also affected by the external climate resulting in air temperature values from 10ºC to 20ºC higher than the external temperature. The work in the engine room control has over recent years undergone major changes, mainly due to the introduction of computers on board. This has implied obvious changes in the ECR with regards to both working conditions and equipment (8).

In these machinery spaces, seafarers are subject to very high temperatures for long periods of time while doing their job. It is not only the degree of heat or cold that a marine engineer is exposed, but also the duration of exposure and the relative change between environments (9). The organism of these workers is subject to considerable temperature differences between the different work spaces (for example if the engine room control is closed it will have a temperature lower than the area of engines or boilers), giving rise to the need for intermittent body acclimatization.
Also, the study carried out by Rengamani and Murugan (10) reveals that heat in work places joined to the long working days, separation from their family, time pressure /hectic activities, insufficient qualifications of subordinate crew members, noise, ship movement, sea sickness, hard physical work, lifting, carrying, lack of exercise and climatic changes during the voyage are considered as the most vital factors in influencing the seafarers stress when they are on-board.

Oldenburg et al. (11) indicate that stress level due to heat in workplaces was lower in seamen with a longer job duration at sea (and consequently of older age) than in those with a shorter job duration. This may be due to the adaptation to job demands or the healthy worker effect.

Additionally, several studies (4, 12, 13) indicate that heat stress not only has an effect on the health of workers but also there is a direct relationship between heat stress, productivity and economy. Productivity losses reported were extended work hours due to fatigue / exhaustion, sickness / hospitalization and wages lost.

It is for these reasons that the study of the impact of thermal stress on engine room workers requires special attention.

1. RISK AND DAMAGE FACTORS

Heat stress causes an increase in heart rate (HR) and internal body temperature. The maximum HR and / or internal temperature of about 40°C establish the absolute physiological limit of the physical capacity to work in a hot environment (14)

When assessing thermal stress, it is important to take into account various factors that could be triggers of risks and damage to the health of the individual subjected to them. Such factors are the duration and thermal environment.

- Duration of heat exposure: Even if the temperature is not very high, being exposed for many hours would cause the accumulation of heat in dangerous quantities.

An excessive thermal aggression can have serious consequences for the human organism. Therefore, it is necessary to limit the time of exposure (t EX) in places with such characteristics. It will be the time necessary to increase the internal body temperature by 1°C, considering a specific heat Ce = 0.82 cal / (g °C).

When we want to assess the risk of thermal stress, we use the “Required Sweating Index” that provides, among other data, the maximum recommended time to stay in a given situation, also called “Exposure Limit Duration” (ELD), for each one of the risks and according to alarm and danger levels.

At the alarm level, no worker will have health problems if the exposure time for such level is not exceeded. If it is exceeded, a worker could have a health problem. In the case of danger level, most of the workers would have health problems if the ELD is exceeded.

- Particular individual factors: They also intervene aggravating the situation, personal factors such as overweight, physical fitness, health status, lack of acclimatization, etc.

Below is a list of possible individual factors that can reduce heat tolerance:
2. THERMAL ENVIRONMENT. HEAT ACCLIMATIZATION

There are various methods to assess the thermal environment in its different degrees of aggressiveness.

In the case of moderate thermal environments, it is useful to know the predicted mean vote index (PMV) index, whose calculation allows to assess the level of comfort or discomfort in a work situation.

The Wet Bulb Globe Temperature index (WBGT) (15) is used, due to its simplicity, to quickly discriminate whether or not the thermal stress risk situation is admissible. Also, its calculation allows decision-making with regard to the possible preventive measures to be applied.

The lack of heat acclimatization is one of the most important personal factors. It can be defined as the decrease in physiological cost that a given exposure implies, when it is repeated several successive days (16).

The study carried out by Arbury et al. (17) over 20 cases of heat illness or death showed that in 13 cases a worker died from heat exposure, and in seven cases two or more employees experienced symptoms of heat illness. Nine of the deaths occurred in the first 3 days of working on the job, four of them occurring on the worker’s first day.

During exposure to heat, the non-acclimatized person has a high rectal temperature, high heart rate and low sweat loss.
Non-acclimatized workers may suffer damage under heat stress conditions that are not harmful to their peers who have been working in those conditions for some time.

Acclimatization is a complex process involving the circulatory system (increasing cardiac output, increasing volume / heartbeat, since maximum heart rate is reduced), the endocrine system (increases aldosterone to increase blood volume and circulating plasma) and sweat glands that secrete more sweat and less sodium. This helps dissipate heat through cutaneous vasodilation and sweating. Since the cooling effect occurs when that sweat evaporates, this happens as long as the relative humidity of the air is able to accommodate that water vapour, otherwise, i.e. tropical environments with high humidity rates, the sweat does not evaporate and the body does not refrigerate. Therefore, ventilation and good equipment maintenance are essential to avoid excessive humidity in the engine room.

This progressive physiological adjustment, increasing the duration of exposure to heat, makes it possible for a person to work effectively under conditions that would be unbearable prior to acclimatization.

Heat acclimatization makes the body able to better tolerate the effects of heat, as it favors physiological thermoregulation mechanisms: it increases sweat production and decreases its salt content, increases peripheral vasodilation without increasing heart rate. In this way the central body temperature does not rise so much.

But this is not an immediate process and can last between 7 and 14 days depending on the worker. During this time, the body adapts to perform a certain physical activity in hot environmental conditions progressively.

In the holiday or leave periods of the worker, he suffers an acclimatization that will require a new period of adaptation at the time of his return to work. Unfortunately, in most cases this intermediate period of labor production is not allowed, as in the case of the engine room personnel of a merchant ship, subjected to thermal shock from the outset when joining the crew and entering watch from the first day, the engine rooms being at high temperatures and generally poorly conditioned.

A study by Orosa and Oliveira (18) found temperature differences between the engine room and the engine room control of more than 12 ° and differences in the average relative humidity of more than 15% between these spaces. These differences are so pronounced that they can cause thermal shock among workers.

With the aim of reducing this workplace risk, Orosa and Alvarez (9) propose to change the limit values of the thermal comfort conditions in the control engine room and, therefore, a new thermal comfort control system must be designed. This new control system must take into consideration the difference between the thermal environments in the control engine room and the own engine room in the working conditions at all latitudes.

Of course, the ship as a work and living place is a very particular case and its temperature or thermal environment conditions are sometimes difficult to improve due to various factors (changes in the route and therefore variations in seawater temperature, ambient temperature and ultimately weather conditions, design of the ship and its compartments in the absence of legislation in this regard at the time of its construction) as noted Montero et al. (19) sometimes it is impossible for different reasons to establish comfort situations in a position. Under such
conditions, ergonomics must find solutions that at least place the work in permissible conditions or, otherwise, establish work and rest regimes applying different techniques. That is, to achieve an environment that imposes a load as small as possible for the body thermoregulatory system, taking into account the productive efficiency of the system.

Another parameter that may have an impact on the acclimatization process is the physical size of the person. It is advisable not to expose people under 50 kg to extreme conditions neither to people with obvious obesity who usually have cardiovascular problems. Age is also a factor to take into account. The ideal age of acclimatization is between eighteen and forty, due to high cardiovascular responses (200 beats per minute) and oxygen consumption (5 l/m), factors that are significantly reduced with age. Heat tolerance is reduced in the elderly as they take longer to sweat than young people, reacting with greater peripheral blood flow during exposure to heat.

It has also been proven that women tolerate moisture better than men; although in its menstrual stage they can retain up to 1-2 kg of water.

In the case of people with lower aerobic capacity, they will register a greater increase in heart rate and body temperature, which means that their ability to withstand additional external heat stress will be lower than for people with higher VO2 max (maximum absorption of oxygen).

The American Conference of Governmental Industrial Hygienists of the United States, summarizes in a table the threshold limit values (TLVs), according to different categories of workloads (20).

These limits, specify the maximum combination of environmental heat and metabolic heat to which workers should be exposed. Exposure limits are lower for workers who are unacclimatized to heat, who wear work clothing that inhibits heat dissipations, and who have predisposing personal risk factors (3).

Likewise, ISO 7243:2017 (15) Ergonomics of the thermal environment -- Assessment of heat stress using the WBGT (wet bulb globe temperature) index presents a screening method for evaluating the heat stress to which a person is exposed and for establishing the presence or absence of heat stress. This method applies to the evaluation of the effect of heat on a person during his or her total exposure over the working day (up to 8 h) and to the assessment of indoor and outdoor occupational environments as well as to other types of environment, and to male and female adults who are fit for work.

In this method adjustment to the WBGT value to account for the effects of clothing that has different thermal properties from that of standard work clothing is made.

3. EFFECT OF HEAT STRESS ON HEALTH

About 60% of the total weight of an adult person is made up of water; one third is located in the extracellular fluid and the remaining two thirds at the intracellular level. The water balance is of the utmost importance for workers who perform their tasks in high temperature environments.

Human body’s response to ambient temperature depends primarily on a very complex balance between the level of heat production and the level of heat loss.
Heat is lost by radiation, convection and evaporation, so that in normal resting conditions the body temperature is maintained between 36.1ºC and 37.2ºC.

When workers are exposed to high levels of radiant or directed heat, they can suffer damage to their health in several ways. Thus, for example, the high temperature on the skin (above 45 ºC) can burn the tissue.

The key effects of an elevated temperature occur if the deep body temperature is increased to more than 42 ºC, that is, it is increased by 5 ºC.

An inadequate thermal environment causes reductions in physical and mental performance, irritability, increased aggressiveness, distractions, errors, discomfort from sweating or shivering, increased or decreased heart rate and even death.

Different repercussions on the person are derived according to an internal temperature scale:
- 42º- 44 º C Heat stroke. Hot and dry skin; t> 40 º C, convulsion, coma (15-25% mortality)
- 40 ºC Possible brain injuries
- 38 ºC NORMAL
- 36 ºC NORMAL
- 34 ºC Feeling cold, shivering
- 33 ºC, 32 ºC, 30 ºC Hypothermia: bradycardia, hypotension, drowsiness, apathy, stiff muscles.
- 28 ºC Relaxed muscles, respiratory function failure

The risk of thermal stress for a person exposed to a hot environment depends on the heat production of his/her body as a result of his/her physical activity and the characteristics of the surrounding environment, which determines the heat exchange between the environment and the body. When the heat generated by the organism cannot be emitted to the environment, it accumulates inside the body and its temperature tends to increase, and irreversible damage can occur.

The fundamental risks of excessive exposure to heat are dehydration and heat stroke. Sometimes these risks can occur very quickly, suddenly, and have rapid and irreversible outcomes. Most of the time the causes of thermal stress are easily recognizable and the possibility of damage is equally easily predictable. In other circumstances, in which the environmental conditions are not extreme, thermal heat stress can go unnoticed and cause damage to workers.

Excess of body heat can cause:
- an increase in the likelihood of accidents at work,
- previous illnesses (cardiovascular, respiratory, renal, skin, diabetes, etc.) are aggravated.
- health damage occurs.
To try to eliminate heat excess the thermoregulation mechanisms of the body itself (physiological thermoregulation) are started: workers begin to sweat (when the sweat of the skin evaporates, it cools) and, the flow of blood to the skin increases (peripheral vasodilation) to bring heat from the inside of the body to its surface and from there it can be expelled to the outside. This causes the heart rate to increase.

In workers who have a chronic disease, it can be aggravated. If these heat conditions continue and the workers continue to work and accumulate heat, there will come a time when they will produce various damages, including in so-called heat-related illnesses, the severity of which is proportional to the amount of heat accumulated. The most serious one is the heat stroke (it appears when the central temperature, regardless of the degree of ambient temperature, exceeds 42 ° C) that often causes death. On the other hand, even if the work under high thermal stress conditions ceases and there is no excessive accumulation of heat in the body, workers will also suffer damage if they do not replace the water and electrolytes (salts) lost in sweating. Severe dehydration can cause heat exhaustion and circulatory collapse, the person is unable to maintain blood pressure and loses consciousness.

4. HEAT RELATED DISORDERS

**Skin disorders**: Uneven red rash on the skin caused by excessive sweating or humidity. The obstruction of the sweat ducts prevents sweat from reaching the skin surface and steaming. It is the most common skin disorder associated with heat exposure.

**Thermal cramps**: They are involuntary and painful muscular contractions, which appear due to an excessive loss of salts when sweating in a lot. The individual replenishes a lot of water but not the sodium lost by sweat. These low levels of sodium raise the concentration of calcium in muscle fibers causing muscle contraction. They can appear during work or later.

**Heat syncope**: It is a temporary loss of consciousness as a result of reduced cerebral irrigation. Cutaneous vasodilation and hypovolemia due to profuse sweating can reduce preload to the heart to cause orthostatic hypotension. The cutaneous vessels are influenced by vasodilation to favor thermolysis and vasoconstriction to maintain blood pressure, in which case vasodilation dominates. The worker will present a picture of weakness, thirst, nausea, vomiting, cold and wet skin sweating, hypotension and tachycardia.

It can be suffered mainly by workers not acclimatized to heat at the beginning of the exposure.

It is not serious, but in many cases its onset is not different from a heat stroke. It is therefore necessary to assess in all cases:

- The central temperature.
- Heart rate and blood pressure.
- Heat stroke symptoms such as confusion or / and disorientation.
- Monitor the worker on subsequent days and assess the possibility of a temporary change of job. (This measure is hardly applicable in members of the engine room department of a ship).
**Heat exhaustion:** It occurs as a result of severe dehydration after losing a large amount of sweat. It is a systemic reaction secondary to the depletion of water and salts by profuse sweating when it is not adequately replenished. Water loss causes intense thirst and weakness (tiredness), volume depletion (hypotension, tachycardia) and hyperventilation. The loss of salt causes muscle cramps, nausea, vomiting, weakness and also hypotension and tachycardia. It can lead to heat stroke.

**Heat stroke:** It is a complex clinical picture characterized by uncontrolled hyperthermia that causes significant tissue damage. There is a failure of the cooling system, accumulating heat in the body, raising the core temperature above 42 °, damaging the cells. When the capacity of thermolysis is exceeded, proteins are denatured and lesions arise that can lead to cytolysis or cell death. The increase in temperature increases the metabolism with which a vicious circle is established, increasing from 10 to 15% for each degree the temperature rises.

Heat stroke is a clinical entity not too frequent, but of high mortality (15 to 25% of cases despite correct treatment). It is more frequent in:

- Children or the elderly who are suddenly exposed in a heat wave or on a trip to a warm country. In the elderly, more care must be taken because they lose their sense or sensation of thirst, and do not hydrate.
- Young people who exercise intensely in a warm environment (eg, military training)
- Workers who perform moderate to heavy physical work in warm and humid environments with significant radiant heat or waterproof work clothes.

The first symptoms may resemble the aforementioned clinical entities, then the three clear symptoms of heat stroke are manifested:

- Warm and dry skin, without sweating
- Very high internal temperature: greater than 40ºC
- Neurological symptoms: confusion, incoherent language, coma, convulsions.

Generally, the complete triad is difficult to observe. Other important symptoms found are:

- Tachycardia greater than 130 beats per minute, low blood pressure
- Hyperventilation
- Liver injury: increased transaminase levels, which can be maintained for several weeks
- Muscle injury: CPK elevation
- Renal injury: elevation of serum creatinine
- Disruption of blood coagulation tests

These symptoms can occur in the workplace itself or after a few hours of ceasing exposure.
The first treatment should be carried out immediately by removing the patient from the heat source and undressing, watering or bathing in water, ventilating and if possible by passing ice through the neck, armpit and groin. Later she/he will be transferred to a hospital.

If this cooling has an effect, in the majority of cases the evolution will be favorable; but the evolution towards acute renal failure or disseminated intravascular coagulation is always a possibility to consider.

Symptoms and signs derived from heat thermal stress could be summarized in the following list:

- Hyperthermia
- Vasodilation
- Activation of sweat glands
- Increase in peripheral circulation
- Sweat electrolyte change: loss of NaCl
- Psychic disorders

**5. RELATIONSHIP BETWEEN HEAT STRESS AND FATIGUE. EFFECTS AND CAUSES.**

Fatigue is generally described as a state of tiredness, exhaustion or drowsiness caused by prolonged physical or mental work, long periods of anxiety, exposure to a hostile environment or lack of sleep. Fatigue implies a decrease in performance and alertness (21).

As Willmore and Costill (22) describe, in a hot environment there is a large amount of blood that goes to the skin instead of the muscles, increasing oxygen consumption, an increasing muscle lactate, heart rate, a large production of sweat, a greater use of muscle glycogen; and ultimately a greater energy production.

It is believed that this fatigue and these changes in the body may be due to the direct effects of hyperthermia on the central nervous system, and are a defense mechanism of the body that acts as a "fuse" that prevents the worker from continuing to produce heat and exceed an internal limit temperature that causes heat injury, heat stroke, and even death (23).

If thermal stress is important, or not being so, and workers continue to work for a long time without taking breaks, there comes a time when they are so hot that they cannot work well. They are very uncomfortable, with apathy, diminished capacity for perception and attention and memory, etc. In this state, the probability of accidents at work increases greatly.

Excess of body heat can cause a series of diseases or conditions directly related to heat (skin rash, dehydration, cramps, exhaustion), it can aggravate previous ailments (respiratory, cardiovascular, diabetes) and of course, it boost the work accidents occurrence.

Fatigue as a result of a heat stress situation is present in several occupational accidents on ships. In 1986, the IMO Subcommittee on Standards of Training, Certification and Watchkeeping
conducted a study on the effects of fatigue in safety, where it is concluded that, in the face of fatigue, the crew is impaired its ability to react and act in various situations.

6. LABOR LEGISLATION REGARDING RISKS CAUSED BY HEAT THERMAL STRESS: INTERNATIONAL, EUROPEAN AND SPANISH CASES

Although the occurrence of fatigue in the crew is recognized as a risk factor for both the integrity of the ship and its crew, the existing legislation generally focuses on fatigue due to exhaustion, that derived from an insufficient rest period, an excess of working hours or situations of greater psychological stress, leaving the issue of heat stress fatigue abandoned. As for this type of pathology, there is a legal gap in the maritime field, leaving without timely legislation for example the temperature limits of compartments such as the Engine Room in which the temperatures far exceed the permissive values for health.

Several studies show the presence in engine rooms of environmental conditions outside the appropriate values to preserve the health of workers. In a study by Orosa et al. (24) in which data on temperature and relative humidity measurements are provided in various compartments of a ship, it is clearly seen how the actual values are far from the indications of the ISO 7730: 2006 (25), according to which the reference values for indoor conditions in summer would be above 23°C of temperature and between 30-65% of relative humidity. In the aforementioned study, the average values of temperature and relative humidity recorded in the engine room are 32.5°C with peaks up to 38.5°C (excessive) for the first parameter and 25% for the second (value clearly lower than recommended).

In addition, another problem added to the performance of tasks in these conditions, is that the crew does not usually carry out periods of thermal recovery in an appropriate environment, to release the accumulated heat, which implies a greater exhaustion and risk of occurrence of important damages in its Health.

The MSC Circular / Circ. 1014 Guidance On Fatigue Mitigation And Management (21) describes the possible causes and effects of fatigue on the different crew members, but an error is made when encompassing bridge and engine officers in the same group. It is clear that the temperature conditions in the main engine room is much higher than in the cargo control office where the first deck officer is located, possibly with a built-in air conditioning unit and doing a job, usually more sedentary. But it is also true that throughout the circular, only the harmful effect on the health of an excess of temperature is mentioned in its first paragraph, this factor being forgotten in the whole document when deepening the issue of fatigue. Excessive heat and cold are also a problem among deck staff (officers and seafarers) in deck jobs.

The directive of the Council of the European Communities concerning the minimum health and safety provisions in the workplace stipulates in its annexes I and II (6, 26) that the temperature of the workplaces must be adequate for the human body during working time, taking into account the work methods applied and the physical risks imposed on workers.

In Spanish legislation, specifically in RD 486/97 concerning minimum safety and health provisions in the workplace (27) sets the environmental conditions of the workplaces and in one of its sections establishing that the environmental conditions of the workplaces must not constitute a source of discomfort or inconvenience for the workers.
For this purpose, extreme temperatures and humidity, sudden temperature changes, annoying air currents, unpleasant odors, excessive irradiation and, in particular, solar radiation through glazed windows, lights or partitions must be avoided.

In this regulation, the National Institute for Occupational Safety and Health (INSHT) was obliged to elaborate the “Technical guide for the evaluation and prevention of risks related to the use of workplaces” (28). In this guide the conditions to be met in the enclosed workplaces are established:

a. The temperature of working places where sedentary works of offices or similar are carried out will be between 17 and 27º C. The temperature of working places where light works are carried out will be between 14 and 25º.

b. The relative humidity will be between 30 and 70%, except in places where there are risks of static electricity where the lower limit will be 50%.

But both the RD 486/97 and the Technical Guide leave doubts about the risk diagnosis method, comfort or discomfort and especially about its prevention.

Furthermore, Directive 93/103 / EC, of November 23, establishes the minimum safety and health at work provisions on board fishing vessels (29), but merchant ships remain in the limbo of the General Ordinance of Safety and Hygiene at Work (OGSHT), of 1971, specifically, of its Title II, “General conditions of workplaces and protection mechanisms and measures” (30).

It is also important to mention the absence of recommendations and regulations related to the thermal shock that workers suffer when they suddenly pass and without a period of acclimatization of a room at a high temperature to another of much lower temperature, with their corresponding negative response in the health of these individuals. A clear example are greasers, officers and other engine room personnel of a ship, who continually have to leave the engine control room and enter other compartments subject to high temperatures and poor ventilation in many cases.

7. CONCLUSIONS

- The two most serious risks of heat exposure are dehydration and heat stroke.

- The pathology produced by thermal heat stress, is characterized by its acute onset; and can cause death. The first step to be taken will be from prevention; eliminating or at least reducing the risk.

- Sea professionals, on numerous occasions are exposed to inadequate work environments with high temperatures and humidity indices. This poses a serious health risk as well as an obstacle to their productivity. But cost plays an important role, and in the absence of legislation and / or management that regulates the need to improve thermohygrometric conditions (ambient temperature, radiant temperature, humidity, air renewal, ventilation) in enclosures such as the engine rooms of ships, shipowners and shipping companies cut costs and limit themselves to conditioning these spaces with jets of air directed to the interior of the room that take their drive, in many cases, from garages or warehouses located in upper holds and decks, but that are stale environments with fumes and gases and high temperatures.
Due to the particularity of the ship as a work and living place and the complexity of its design and structure, in terms of regulations and legislation on minimum conditions that must be met by workplaces and maximum permissible values of various variables, this is generally excluded from compliance with those laws. This is the case, for example, in Spain, where Royal Decree 486/97, on the minimum provisions for Safety and Health in Workplaces, in its section a) of Article 1.2 excludes workplaces located within the means of transport (ships), and in section e), to fishing vessels. Subsequently, Royal Decree 1216/1997, dated July 18, established the minimum health and safety regulations at work on board fishing vessels, but merchant ships remain in the limbo of the General Ordinance of Occupational Health and Safety (OGSHT), of 1971, specifically, of its Title II, "General conditions of workplaces and protection mechanisms and measures".

References:


DEVELOPMENT OF A STANDARDIZED TOOL TO CALCULATE CARBON FOOTPRINT IN PORTS

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Abstract:

Ports are essential contributors of a country’s economy. One of the significant environmental threats in ports is Climate Change due to carbon dioxide emissions generated by different activities in these areas.

In the recent years many ports have started to calculate their Carbon Footprint and report it. However, generally each Authority or Operator uses its own method which makes the comparison of results very difficult. There is no single or unified method to calculate Carbon Footprint in ports.

Therefore, the aim of this paper is to present the development of a practicable, user-friendly and free available tool with a standardized method for the calculation of Carbon Footprint in ports. This has been demanded by the port sector in different occasions (e.g. Greenport, 2018).

The tool provides options to select the scopes that are more suitable and applicable to each port. In addition, the tool allows normalizing (standardize to a common ground) the total annual emissions in terms of total tons of cargo handled or annual TEUs. This is basically done to allow a comparison of the results of different ports on the same ground.

The completion of this excel based tool is expected to be around 20 minutes (if data are available) and it is divided into three steps:

- **Step1**: General data such as the port’s name, the country and the port total cargo are required.
- **Step 2**: The port should select the different scopes to be included in the calculation and the required data should be filled in order to get the final result.
- **Step 3**: By pressing the result button, a report is produced with the total CO2 equivalent emissions and also with emissions by capacity (Carbon Footprint) and by scope. This document can be saved as a pdf file.

Keywords:

Ports, Climate Change, Carbon Footprint, CO2 calculation tool.
INTRODUCTION

Growing emissions of Greenhouse Gases (GHG) have been proved to be the cause of global Climate Change in port operations [1] and it is one of the main environmental concerns in recent years. In a survey conducted by the European Sea Port Organization (ESPO) in 2019, Climate Change occupied the 3rd position in the ranking of top 10 environmental priorities in ports [2]. This shows the fact that the topic of Climate Change in the maritime industry is getting more importance every day.

For ports it is increasingly acknowledged that the consequences of Climate Change, such as changes in sea level rise, changes in weather or in the storm frequency, will affect both existing and new seaport, and inland waterway infrastructures [3]. Therefore, ports require special treatment because of their economic importance as essential links in supply chains, their location in the heart of sensitive estuarine environments, their reliance on waterfront locations, and the significant existing infrastructure that links them to inland transportation networks [3].

In order to calculate, control and reduce CO₂ emissions in ports, an indicator has been developed: Carbon Footprint. The Carbon Footprint is the total amount of Greenhouse Gases emissions that are emitted directly and indirectly by an activity.

As mentioned before, in recent years some ports have calculated their carbon footprint and reported it. The problem is that there is no single or unified method to calculate Carbon Footprint in ports. Therefore, the development of a practicable, user-friendly and free available tool with a standardized method for the calculation of Carbon Footprint in ports is needed and it has been demanded by the port sector [4]. In this regard, the main aim of this research is to develop this standardized tool. In the next section the concepts of Climate Change and Carbon Footprint are explained in more detail.

1. CLIMATE CHANGE AND CARBON FOOTPRINT

Climate Change is an inherent global issue which has become a major focus of attention because of its potential hazards and impacts on the environment [5]. Due to the increase of the industrialization of human society, the already variable climate of the Earth has been influenced significantly by such human actions [6].

Generally, Climate Change refers to the gradual change in the Earth's climate and physical geography that accompanies an increase in the Earth's temperature [7]. The human contribution to this effect can be measured by the carbon footprint.

Wiedmann & Minx [8] propose the following definition of the term Carbon Footprint: "The Carbon Footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

Concerns about Climate Change were expressed for the first time in 1979, when the first World Climate Conference was held in Geneva and sponsored by World Meteorological Organization (WMO) [9].
In 1988 the Intergovernmental Panel on Climate Change (IPCC) was set up by both the United Nations Environmental Program (UNEP) and WMO, to provide policymakers with regular scientific assessments on the current state of knowledge about Climate Change [10]. This was followed in 1992 by the development of the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro to stabilize GHG concentrations in the atmosphere [11]. The IPCC Guidelines for National Greenhouse Gas Inventories were accepted in 1994 and published in 1995. The revised version of the IPCC Guidelines for National Greenhouse Gas Inventories were issued in 2006 and updated in 2019 [12] and [13]. These guidelines have been used as a reference to developed the new tool.

In addition, in 1998 the World Resources Institute (WRI) and World Business Council for Sustainable Development [14] together with companies, governments and environmental groups from around the world developed the GHG protocol. The GHG Protocol developed standards, tools and online training that helped countries and cities to track progress towards their climate goals [14]. These GHG protocol related documents have been also used to developed the new tool.

Since then several attempts by different organizations have been done to control the effects of Climate Change. The most recent and important one in 2015, the Paris Agreement, recognized Climate Change as an urgent threat and set the mitigation goal of limiting the global temperature increase up to 2 °C and ideally up to 1.5°C within the framework of the United Nations Framework Convention on Climate Change [15].

As mentioned before, one of the human activities which have an effect on Climate Change is activities in ports and maritime sector. International attempts to control Climate Change in ports are introduced below.

In April 2008, the World Ports Climate Initiative (WPCI) was established by the International Association of Ports and Harbours [1]. As a part of the WPCI’s mission to provide a platform for the exchange of information, a guideline was developed to serve as an introduction to “carbon footprinting” and as a resource guide for ports wanting to develop or improve their GHG emissions inventories [16]. This guideline is another reference that has been used to develop the new tool.

Beside these initiatives, in recent years several attempts have also been done in this regard. For example, IMO’s recent decisions, such as the adoption of a strategy to reduce GHG emissions from shipping by 50% until 2050 (compared to 2008), created a need for finding ways to comply with this goal [17].

As it can be seen, some initiatives have been carried out to foster the reduction of GHG’s in the maritime sector. In addition, diverse methods have been developed to calculate the carbon footprint in ports. In a study by Azarkamand et al. [18], more than 21 different methodologies to calculate Carbon Footprint in ports, port terminals and ships were studied and analysed. Ships studies were also included since their emissions are contributing to the total port area carbon footprint. This study presented the Strengths and Opportunities for further development of these methods. The main weaknesses were:

- Each procedure was different and there was not any standard method to calculate CO2 emissions in this sector.
- In most of the cases, all the emission sources mentioned in the standard guidelines (direct or indirect) were not calculated. In order to have a comprehensive and realistic figure of GHG emissions and Carbon footprint in ports, all emission sources should be taken into account.

- In the majority of the methods emissions from waste operations, which can take place in a port such as incinerators or waste water treatment plants, were not included in the calculation.

- In most of the studies, scopes were not defined based on the standard methods.

- In around 70% of the cases, emissions from employees’ commuting were not included. These are a significant source of emissions in scope 3 (i.e. emissions from tenants, vessels and employees’ commuting).

- In around 65% of the cases, some of the recognized scopes or parts of them were excluded. For example, the calculation of the scope 3 emissions was not taken into account in some ports.

- In around 60% of the studies, the whole set of scope 3 emissions were not calculated.

Therefore, the total amount of CO2 emissions would not present a real figure of the Carbon footprint in that particular port.

- In about 60% of the studies where a tool was developed (five cases), the access to this tool was not possible.

As a consequence of this analysis, the need of a tool that overcome all these weaknesses and includes most of the strengths was required. This development of this new tool is introduced in the next sections.

2. METHODOLOGY

Taking all the strengths and weaknesses into account a new standardized tool has been developed. The creation of this tool has been done by the use of Excel software and Visual Basic. In addition, the tool has been based on the IPCC [12 and 13], GHG protocol [14] and WPCI guideline [16].

In the new tool, all scopes and all the direct and indirect emission sources are taken into account. The new tool also includes emissions from waste treatment plants present in the port area such as incinerators, waste water treatment plants and others. They should be taken into account, where there exist, since they are sources of CO2 emissions as well that should be counted in the total carbon footprint of a port. In addition, emissions from ships are added to this tool.

Moreover, the three main GHG (carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O)) are included in the new tool and the total amount is presented as a CO2eq, as it includes all three GHGs emissions.
Finally, the calculation of carbon footprint is presented as a total value as well as a ratio between the total amount of CO$_2$eq and the total cargo of the port, following the example of a successful experience of Climeport project [19]. This would allow more realistic comparisons between ports if they want to share their figures. In addition, this is basically done to allow a comparison of the results of different ports on the same ground.

The tool provides options to select the scopes and boundaries that are more suitable and applicable to each port.

In order to choose the sources and scopes, WPCI guidelines are used. Based on this guideline scopes in ports are divided in three main groups (Figure 1) [16]:

**Scope 1**: Port Direct Sources. These sources are directly under the control and operation of the port administration entity and include port-owned fleet vehicles, port administration owned or leased vehicles, buildings (e.g., boilers, furnaces, etc.), port-owned and operated cargo handling equipment, and any other emissions sources that are owned and operated by the port administrative authority.

**Scope 2**: Port Indirect Sources. These sources include port purchased electricity for port administration owned buildings and operations. Tenant power and energy purchases are not included in this Scope.

**Scope 3**: Other Indirect Sources. These sources are typically associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbour craft, tenant buildings, tenant purchased electricity, and port and tenant employee commuting (train, personal car, public transportation, etc.).

In addition, in the new tool emission sources are categorized based on WPCI [16] guidelines and GHG protocol [14]. In WPCI, emission sources in ports are divided into two main groups, mobile sources and stationary sources [16]:

- **Mobile sources**
Greenhouse gas emissions are produced by mobile sources as fuels are burned. The mobile sources in a port are divided in three main groups: on-road vehicles, waterborne vehicles and construction equipment.

- **Stationary sources**

  Stationary sources are the second group of sources emitting GHG found at ports. They typically account for significantly less Greenhouse gas emissions than the mobile sources. Stationary source emissions come from fixed, particular, identifiable, localized sources or facilities that use combustion processes. The main stationary sources in ports are power plants, boilers, emergency generators and purchased electricity.

  As employee commuting is one of the main sources of GHG emissions in scope 3, this source has also been included in the new tool, based on the GHG protocol [14].

  In order to choose the calculation method, IPCC (2006, 2019) and GHG protocol guidelines have been used. UNFCCC COP3 which was held in 1997 in Kyoto reaffirmed that the IPCC Guidelines for National Greenhouse Gas Inventories should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" [20].

3. DEVELOPMENT OF THE TOOL

The new tool is specifically designed for port authorities to calculate their Carbon Footprint and report it accordingly. This tool is user-friendly, voluntary and free-available.

Options are provided in the tool so that each port authority can calculate the scope and boundaries that are more suitable and applicable to its circumstances.

The tool, the guidelines and the video can be downloaded from http://eports.cat/carboonfootprint. Once the user downloads the three files, he/she should save them all together in a folder. Then, the user could run the tool by enabling it. Figure 2 shows the screenshot of the website and the link of the tool.

**Figure 2. The screenshot of the website of the tool.**
The completion of this excel based tool is expected to be around 20 minutes (if data are available) and it is divided into three steps:

- **Step 1**: General data such as the port name, the country and the port total cargo are required (Figure 3).

**Figure 3. General data of the port.**
Step 2: The port should select the different scopes to be included in the calculation and the required data should be filled in order to get the final result (Figure 4). Figure 5 shows a sample page of scope 1 to calculate emissions.

Figure 4. Scopes’ selection.

As mentioned before emission sources are divided into two main groups; mobile sources and stationary sources. For the calculation of all sources of scope 1, the related cells should be filled with appropriate data. Two pages of scope 1 belong to mobile sources and two pages belong to stationary sources.
In scope 2, emissions from purchased electricity for port administration owned buildings and operations are calculated. The needed data are consumption amount and intensity. This latter value is different in each country and you can select from a list your country and the value appears directly (Figure 6).

**Figure 6. The calculation page of scope 2.**

In scope 3, emissions from tenant are calculated. The emission sources of the tenants are divided into four main groups which are mobile sources, stationary sources, purchased electricity and employee commuting. The required data of these three sources should be filled in eight sheets of the tool. Figure 7 shows the sample calculation page of the scope 3.

**Figure 7. The sample calculation page of scope 3.**
In scope 2, emissions from purchased electricity for port administration owned buildings and operations are calculated. The needed data are consumption amount and intensity. This latter value is different in each country and you can select from a list your country and the value appears directly (Figure 6).

Figure 6. The calculation page of scope 2.

In scope 3, emissions from tenant are calculated. The emission sources of the tenants are divided into four main groups which are mobile sources, stationary sources, purchased electricity and employee commuting. The required data of these three sources should be filled in eight sheets of the tool. Figure 7 shows the sample calculation page of the scope 3.

Figure 7. The sample calculation page of scope 3.

Step 3: By pressing the result bottom (Figure 8), a report is produced with the CO\textsubscript{2} equivalent emissions by scope, the total ones and the carbon footprint which can be saved as a pdf file. Figure 9 shows the sample of pdf result of the tool.

Figure 9. The sample of the results of the tool as a pdf file
4. CONCLUSIONS

In recent years, international organizations and ports are implementing measures to fight against Climate Change effects and to reduce CO₂ emissions. The review of different studies shows that in recent years many ports calculate their Carbon Footprint and report it. However, each port uses each own method and the emissions from some sources such as wastes, commuting employees and vessels are excluded from calculation in many cases. Therefore, there is not any unified and complete method to calculate Carbon Footprint that allows comparing results among different ports. This proves the need for such a methodology for ports. This is supported by most of the participants in the Greenport Congress in Valencia that consider that a common port-sector Carbon Footprint scheme would benefit individual port authorities and the port-
In recent years, international organizations and ports are implementing measures to fight against Climate Change effects and to reduce CO\textsubscript{2} emissions. The review of different studies shows that in recent years many ports calculate their Carbon Footprint and report it. However, each port uses each own method and the emissions from some sources such as wastes, commuting employees and vessels are excluded from calculation in many cases. Therefore, there is not any unified and complete method to calculate Carbon Footprint that allows comparing results among different ports. This proves the need for such a methodology for ports. This is supported by most of the participants in the Greenport Congress in Valencia that consider that a common port-sector Carbon Footprint scheme would benefit individual port authorities and the port sector as a whole. Therefore, the development of a practical tool with a standardized method for the calculation of Carbon Footprint in ports could be very helpful.

The creation of the tool has been done by the use of Excel software and Visual Basic, based on the WPCI, IPCC and GHG protocol guidelines. This tool is specifically designed for port authorities to calculate their Carbon Footprint and report it accordingly.

It should be mentioned that the development of the tool is just the first step. This tool has been improved and modified based on the feedback obtained from diverse world-wide reviewers. In order to complete and improve this tool, it will be tested with data gathered from different case studies. The results obtained from the tool will be compared with the results of the ports which calculate their Carbon Footprint with their different calculation methods. This will help to have a better understanding of the benefits of this method and it will show the areas which may need to be improved. Then, the required modifications and improvements will be implemented to finalize the tool. In the next step, the tool will be to distribute to all interested ports in Europe and outside Europe for free.

References:


ECONOMIC PROFITABILITY AND ENVIRONMENTAL IMPACT FOR THE INSTALLATION OF A COGENERATION SYSTEM IN AN AFRAMAX OIL TANKER

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Abstract:

Nowadays, maritime transport has many challenges. Fuel consumption is necessary to make work the main and auxiliary systems, electrical and electronic equipment. However, during the process of consumption part of the thermal energy is not used, contributing to environmental impacts. In this context, ships share the concern, and to illustrate this, it is performed an “Economic Profitability and Environmental Impact for the Installation of a Cogeneration System in an Aframax Oil Tanker”. From the exhaust gases and implementing thermodynamic techniques it is possible to know the amount of recoverable energy using a gas turbine, steam or combined cycles. The feasibility of its application is based on the fuel saved by not using the auxiliary engines totally or partially, and evaluating in a period of 15 years through financial indexes. Finally, knowing the fuel savings, it is demonstrated how many of air pollutants (CO₂, NOₓ, SOₓ and PM) would be avoided for installing the cogeneration system.

Keywords:
Cogeneration, WHRS, PTG, STG, economic profitability, air pollutants.

NOMENCLATURE

Letter symbols

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<td>T</td>
<td>Temperature, K or °C</td>
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<tr>
<td>ηₜ</td>
<td>Isentropic efficiency</td>
</tr>
<tr>
<td>ηₜ</td>
<td>Boiler efficiency</td>
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Abstract: Nowadays, maritime transport has many challenges. Fuel consumption is necessary to make work the main and auxiliary systems, electrical and electronic equipment. However, during the process of consumption part of the thermal energy is not used, contributing to environmental impacts. In this context, ships share the concern, and to illustrate this, it is performed an "Economic Profitability and Environmental Impact for the Installation of a Cogeneration System in an Aframax Oil Tanker". From the exhaust gases and implementing thermodynamic techniques it is possible to know the amount of recoverable energy using a gas turbine, steam or combined cycles. The feasibility of its application is based on the fuel saved by not using the auxiliary engines totally or partially, and evaluating in a period of 15 years through financial indexes. Finally, knowing the fuel savings, it is demonstrated how many of air pollutants (CO₂, NOₓ, SOₓ and PM) would be avoided for installing the cogeneration system.

Keywords: Cogeneration, WHRS, PTG, STG, economic profitability, air pollutants.

NOMENCLATURE
Letter symbols
\( \dot{m}_{bypass} \) Mass flow of gas through bypass, kg/s
\( T_{bypass} \) Gas temperature after combustion, K
\( \dot{m}_g \) Mass flow of gas after turbo, kg/s
\( T_{turbo} \) Gas temperature after turbo, K
\( \dot{m}_{g,total} \) Total mass flow of gas after combustion, kg/s
\( P \) Pressure (bar)
\( V \) Volume (m³)
\( \dot{P}_{gt} \) Gas turbine output, kW
\( c_p \) Heat capacity at constant pressure, kJ/kg.K
\( h \) Specific enthalpy, kJ/kg
\( \dot{P}_{st} \) Steam turbine (HP and LP) output, kW
\( \dot{m}_{VH} \) HP steam mass flow, kg/s
\( \dot{m}_{VL} \) LP steam mass flow, kg/s
\( \dot{m}_{g,bal.} \) Total mass flow before HRB, k/s
\( T_{bal.} \) Gas temperature before HRB, K
\( T_{go,H} \) Gas temperature after HP economizer, K
\( \dot{m}_{V,H} \) Mass flow of HP steam, kg/s
\( h_{vs,H} \) HP steam enthalpy in superheater, kg/s
\( h_{wp,H} \) HP water enthalpy in preheater, kg/s
\( T_{gi,L} \) Gas temperature after LP superheater, K
\( T_{go,L} \) Gas temperature after LP economizer, K
\( h_{vs,L} \) LP steam enthalpy in superheater, kg/s
\( h_{wp,L} \) LP water enthalpy in preheater, kg/s
\( N_i \) Indicated power output, kW
\( D \) Displacement, ton
\( V \) Speed, knots
\( C_a \) Admiralty coefficient
\( I_i \) Cash inflow, $
\( O_i \) Cash outflow, $
\( I_0 \) Initial investment, $

Acronyms:
NPV Net present value
DR Discount rate
IRR Internal rate of return
CO₂ Carbon dioxide
NOₓ Nitrogen oxides
SOₓ Sulphur oxides
PM Particulate matter
WHB Waste heat boiler
WHRS Waste heat recovery system
SMCR Specified maximum continuous rating
PTG        Power turbine generator
STG        Steam turbine generator
ICE        Internal compression engine
GHG        Greenhouse gases
SED        Specified emission data

Greek letters:

σ          Pressure ratio
γ          Heat capacity ratio

1. INTRODUCTION

1.1 BACKGROUND

The potential use of waste heat or energy contained in exhaust gases produced by the combustion in an ICE has been investigated for decades through cogeneration systems. Low fuel prices and high production costs have caused that WHRS are economically unattractive, despite the fact of contributing to the reduction of environmental impact. In addition, the lack of confidence of shipowners and the volatility of the maritime transport market have influenced in the development of this technology. On the other hand, the environmental standards by the use of cleaner fuels may cause the surge of WHRS.

Two-stroke low-speed marine engines are the most used propulsion machines in maritime transport. Most of waste energy of fuel used is contained in exhaust gases; its temperature is relatively low and with considerable mass flow, but, powerful enough to produce additional work through a cogeneration cycle.
Figure 1. Heat balance for a MAN 12S90ME-C9 engine.

Energy optimization seeks all possible alternatives to improve efficiency, reduce costs and environmental impact. Nowadays, to recover the unused energy from the fuel, three aspects can be attacked:

- Cooling jackets and lube oil cooling
- Air cooling
- Exhaust gases

In a study undertaken by (MAN, 2014), the available energy in the fuel after combustion is disaggregated using a Sankey diagram, figure 1. It was shown that 25.5% of the total energy is wasted through the exhaust gases, 16.5% by air cooling, 5.2% for cooling jacket and 2.9% for the oil cooling. Citing the MAN 12K98MEC / MC 69,640 kW engine as an example, when it operates at 85% SMCR, supplies about 58,344 kW. Over a period of 280 days a year and 24 hours a day, there are losses of 31,726 tons of fuel through exhaust gases, jacket waters, air intake and lube oil.

Energy optimization seeks all possible alternatives to improve efficiency, reduce costs and environmental impact. Nowadays, in order to recover the unused energy from the fuel, three aspects can be attacked:
1.2 PREVIOUS WORKS

Related to ship efficiency in ships in applying new technologies such as WHRS, there are a moderate amount of researches develop. (Baldi and Gabrielli, 2015) propose a method to calculate the amount of useful power that can be recovered. The results give a reduction of fuel consumption from 4% to 16% for a Panamax chemical/product tanker with two four-stroke Diesel engines rated 3840 kW each; (Liu et al., 2020) propose a new type of WHRS based on the single steam Rankine cycle (SRC) and organic Rankine cycle (ORC) to utilize the heat of the exhaust gases and jacket cooling of a two-stroke marine engine. the results show that the ORC recovers more waste heat of the exhaust gases than the SRC; These results are consistent with a similar research for a container vessel which have a continuous rating (MCR) of 10,126 kW done by (Nielsen, Haglind and Larsen, 2014). Utilizing a ORC after the conventional waste heat recovery system is able to increase the combined cycle thermal efficiency by 2.6%; (Senary et al., 2016) choose to study the application of WHRS in a Liquefied Nature Gas Carrier with 3 dual fuel engines. In addition to demonstrate that thermal efficiency increases, they concluded that Nitrogen Oxide and Carbon dioxide emissions reduce in 36.28% and 16.88% respectively; (Lampe et al., 2018) proposes a novel method that can be used to predict the operational savings and costs of a WHRS; (Kyriakidis et al., 2017) presents a model of a waste heat recovery system for a two-stroke marine diesel engine, but they include in the research, an integrated exhaust gas recirculation system in order to reduce NOx emissions; (Shu et al., 2017) present a thermal-economic analysis based on the ship’s operational profile of a passenger cruise ship. They concluded that not all organics fluid can satisfy the payback limit; (Ballasso et al., 2020) presents a novel and energy-efficient way to supply zero-emission power during harbor stays of marine vessels through the use of a thermal energy storage (TES) and a waste heat recovery system based on the organic Rankine cycle technology. The results prove that TES gives a lower cost of electricity than the battery systems; (Mohammed et al., 2020) study a bulk carrier with an engine power (MCR) of 10,100 kW. The results showed that using ORC would decrease fuel consumption by 2.1 ton/day; (Mondejar et al., 2017) present the quasi-steady state simulation of a regenerative organic Rankine cycle (ORC) integrated in a passenger vessel. They proved that approximately 22% of the total power demand on board is supplied by the WHRS; (Ma, Yang and Guo, 2012) perform a Thermodynamic and economic analyses of a WHRS Combined Turbine. Thermodynamic results indicate that it is possible to recover 5066 kW. On the other hands (Lümmen et al., 2018) use the ORC in a 900 kW fast passenger ferry Diesel. They concluded that the transit is too short for recovering enough waste energy from the exhaust gases and its limitations in the use of WHRS.

2. COGENERATION IN SHIPS

According to (Fukugaki, 1994), new technologies were developed with the purpose of recovering the highest possible energy from the exhaust gases, using the recovered heat efficiently and reducing the consumption of electricity and steam. In chronological order, the cogeneration systems developed through the years are described as follows:

• 1978: Dual pressure system
2.1. NEED FOR COGENERATION IN SHIPS

The maritime transport is the foundation of the world economy; it is well known that cargo carried on sea is made by 70,000 merchant ships that cover the carriage of around 90% of world trade. In addition, maritime transport is the most environmentally-friendly, from the perspective of GHG, something similar to the concept of economy of scale, merchant ships have the lowest emissions ratio of CO₂ per ton of cargo transported.

Furthermore to CO₂, air pollution generated in maritime transport comes primarily from SOₓ, NOₓ, and PM. According to (Neef and Box, 2009), shipping accounts for 15% of global NOₓ emissions (more than all cars, buses and trucks combined), between 2 and 3% of CO₂ and between 3 and 7% of SOₓ of Global production. According to (Cormack, 2018), Global shipping emissions are predicted to increase by between 50 and 250% by 2050, depending on future economic and energy developments.

These results prove the alarming of situation and the need for crucial measures to be adopted on the way of new technologies. For that reason, studies have been carried out for the fuels used and continuous improvement in the energy efficiency, with mandatory standards, based on national and international legislation. Technical solutions can be applied, such as scrubbers to reduce environmental impact, or reduce fuel consumption through the Ship Energy Efficiency Managements Plan (SEEMP) and besides the application of new technologies such as the use of WHRS.

2.2. TYPES OF WASTE HEAT RECOVERY SYSTEMS

PTG is gas drive turbine, installed in the exhaust gas bypass. The construction of the power turbine is based on turbocharger design, with some modifications in the support bearings and axis.

- 1982: Dual pressure system with mixed pressure turbine
- 1984: Steam and hot water system with flash steam turbine
- 1986: Combined steam and gas turbine generator

PREVIOUS WORKS

COGENERATION

On the other hands (Fukugaki, 1994) proved that approximately 22% of the total power demand on board is supplied by the exhaust gases and jacket cooling of a two stroke Diesel engine. TES present a novel and energy economic analysis for a two cycle thermal efficiency by 2.6%; they conclude that the transit is too short for recovering enough waste energy from the exhaust gases, using the recovered heat of marine vessel through the use of a thermal energy storage system based on the organic Rankine cycle technology. The results prove that TES give a reduction of fuel consumption by 2.1 ton/day with an engine power (MCR) of 10 kW done by et al. (Kyriakidis et al., 2017). The results show that the PTG would decrease the single steam Rankine cycle (SRC) and organic Rankine cycle (ORC) to utilize the heat of exhaust gases and Carbon dioxide emissions reduce in 36.28% and 16.88% respectively. In addition to demonstrate that not all organics fluid can satisfy the payback limit; they present a model of a waste heat recovery system that could recover 5066 kW of useful power during harbor stays. These results are consistent with a similar research for a container vessel which have a continuous rating (MCR) of 10,126 kW, new technologies were developed with the purpose of reduce environmental impact, or reduce fuel consumption through the Ship Energy Efficiency Managements Plan (SEEMP) and besides the application of new technologies such as the use of WHRS.
In most cases the exhaust gas pipe system of the main engine is equipped with a boiler system. With this boiler, some of the energy in the exhaust gas is utilized to produce steam for use on board. Thus, with STG (figure 3) is possible to produce more steam and recover 5 to 8% of waste energy. The steam turbine can either be a single or dual pressure, depending on the size of the system.

In the case that the demand for electricity on board a ship is high, such as a container ship, the power turbine and steam turbine can be built together. The power turbine and the steam turbine is built onto a common bedplate and, via reduction gearboxes, connected to a common generator. A combined cycle, gas and steam scheme is shown in Figure 4, in which 8 to 11% SMCR power is recovered.
2.3. MARITIME LAW

The IMO, a specialized agency of the United Nations, is the global authority for the regularization of pollutant emissions from maritime transport. The agreement that regulates the prevention of pollution from ships is MARPOL 73/78, and related to this research is involved the Annex VI about to the prevention of air pollution.

As a result of three years examination, MEPC 58 (October 2008) adopted the revised MARPOL Annex VI, which entered into force on 1 July 2010, limits the main air pollutants contained exhaust gases, including CO$_2$, SO$_X$ and NO$_X$. Then, in short, the most relevant aspects of the regulatory control of emissions are:

**CO$_2$.** Due to uncontrolled increase in CO$_2$ emissions caused by world's fleet of ships, the IMO decided to adopt two energy efficiency measures: the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Managements Plan (SEEMP).

**NO$_X$.** Marine engines are required for testing, recognition and certification, in order to comply with NO$_X$ emission limits. Under MARPOL Annex VI, this applies to marine diesel engine of over 130 kW, ships constructed after 1 January 2000 and like those that have undergone a major conversion.

**SO$_X$.** MARPOL convention, as described its articles, there are Sulfur Emission Control Areas (SECAs). However, as regards the maximum SO$_X$ allowed, this has been progressively reduced. The IMO has decided to regulate sulphur limit fuels at 0.50 % mass by mass from 2020, as against the current 3.5%.
3. CASE STUDY

An Aframax oil tanker with keel laying 2010 is selected for this study. Figure 5 specifies the dimensions and specifications. The aim of the research is to know the economic feasibility and pollutant emission reduction by the implementation of the cogeneration system. This is divided into three parts. First, using thermodynamic techniques for gas turbine, steam or combined cycle with different load operation, from 50 to 100 % SMCR, it is possible to know the usable energy contains in the exhaust gases. Second, based on the operational profile and marine navigation at different speeds, it is possible to know the actual remaining capacity. Finally, translated into economic terms the recovered kWe, an economic analysis is carried out in the remaining 15 years of operation.

![Figure 5. Technical specifications of the Aframax oil tanker.](image)

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Data</th>
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<tbody>
<tr>
<td>Length (m)</td>
<td>244</td>
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<tr>
<td>Beam(m)</td>
<td>42</td>
</tr>
<tr>
<td>Draft (m)</td>
<td>15</td>
</tr>
<tr>
<td>Dead weight (t)</td>
<td>105,310</td>
</tr>
<tr>
<td>Gross tonnage (GT)</td>
<td>62,400</td>
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<tr>
<td>Net tonnage (NT)</td>
<td>32,926</td>
</tr>
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<td>15</td>
</tr>
<tr>
<td>Output (HP)</td>
<td>16,360</td>
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</tbody>
</table>

The main engine has an output of 11,900 kW and uses fuel with a heating value of 42,700 kJ/kg. In addition, the exhaust gas production reaches a flow of 31 kg/s and temperature of 518 K. However, as shown in the figure 6, the study is carried out in 6 different power states: 50, 60, 70, 80, 90 and 100% SMCR.
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Figure 6. Variation of the exhaust gas flow (blue line) and temperature (red line) of a MAN B&W S60MC-C8 engine

3.1. THERMODYNAMIC MODEL OF THE GAS CYCLE
The main engine produces exhaust gases with a certain mass flow and temperature, however, not all gas goes directly to the power turbine, the most is necessary to drive the turbochargers. Then, from a starting point of a diesel and gas turbine cycle, the fluid behaves as it is shown in Figure 7.

Figure 7. Thermodynamic configuration of a diesel and Turbine expansion.

The thermodynamic transformations of diesel cycle and turbine expansion are specified as follows:

1-2: Isentropic compression of air (ICE);
2-3: Constant pressure heat transfer to air (ICE);
3-4: Isentropic expansion (ICE);
4-5: Expansion of gas before reaching the turbine;
5-6: Isentropic expansion in the gas turbine,
6-7: Heat transfer to a WHB;
7-1: Heat rejection to atmosphere.

As shown in Figure 7, from point 5 to 6 there is irreversibility. Then, equation 1 defines the real enthalpy $T_6$ in relation to the gas efficiency turbine.

$$T_6 = T_5 - \eta t \times (T_5 - T_{6s}); K$$ (1)

*Equation 2* is applied to calculate the mass flow that drives the power turbine:

$$m_{bypass} = m_{gstat} \times \%bypass; \frac{kg}{s}$$ (2)

The power supplied by the turbine is calculated using *equation 3*, product of the net work produced and the mass flow:

$$P_{gt} = m_{bypass} \times cp \times (T_5 - T_6); kW$$ (3)

The temperature of the exhaust gas shown in the engine specifications is after the turbochargers. Then, the temperature of the exhaust gas before reaching the power turbine is calculated using *equation 4*,

$$T_5 = T_{6s} \times (\sigma)^{\frac{y-1}{y}}$$ (4)

3.2. THERMODYNAMIC MODEL OF THE STEAM CYCLE

The equations are obtained from a Rankine cycle with dual pressure. To understand the STG system shown in figure 8 and for a better comprehension, the cycle is broken down into two bodies and each one with different stages as are shown in figure 8.

*Figure 8. Schematic diagram of combined system with dual pressure.*
Then, starting from 1 to 2, water is pressurized, \textit{equation 5} describes this part.

\[
h_2 = h_1 + pv; \quad kj kg^{-1}
\]  

\text{(5)}

A steam cycle with this configuration, high and low pressure turbine, the power based on the net work done is calculated by \textit{equation 6}.

\[
P_{st} = \dot{m}_H \times (h_6 - h_7) + \\
(\dot{m}_H + \dot{m}_L)(h_9 - h_{10}); \quad kW
\]

\text{(6)}

\text{Figure 9. TS diagram of the STG system with dual pressure.}

\text{Using figures 8 and 9, it is possible to discern an energy-heat transmission diagram with dual pressure, figure 10.}

\text{Figure 10. Temperature-heat transmission diagram with dual pressure for a MAN B&W S60MC-C8 engine.}

88\% of the total exhaust gases go to the turbochargers and the rest 12\%, to steam generator. The gases coming from the turbochargers and the gases coming from the bypass are mixed, in order to obtain the thermal balance. \textit{Equation 7} describes this phenomenon.
\[ m g_{\text{bypass}} \times T_{\text{bypass}} + m g_{\text{turbo}} \times T_{\text{turbo}} = m g_{\text{bat}} \times \frac{k g}{s} \] (7)

The power produced depends on the generation of steam in the high and low pressure sections. According to Figure 9, the exhaust gases release thermal energy to WHB, starting with the high pressure superheater (A) to the low pressure evaporator (E). Considering the divisions, a thermal balance can be done to calculate the mass flows of water and steam for the low and high pressure levels. First, from inlet gases to the exit of the high pressure economizer, heat is exchanged with the water or steam. Equation 8 describes this segment.

\[ \eta_b \times m g_{\text{bat}} \times [cp \times (T_{\text{bat}} - T_{\text{g}_{o,H}})] = \dot{m} v_H \times (h v_{s,H} - h w_{p,H}); \frac{k g}{s} \] (8)

The energy balance equation for the LP section is:

\[ \eta_b \times m g_{\text{bat}} \times [(cp \times (T_{\text{g}_{i,L}} - T_{\text{g}_{o,L}}))] = \dot{m} v_L \times (h v_{s,L} - h w_{p,L}); \frac{k g}{s} \] (9)

Finally, an energy balance is considered in the high turbine stage and in the mixing process that occurs with the LP steam, one coming from the low pressure (8) of the boiler and another coming from the HP turbine (7), until to get the balance (9) (see equation 10).

\[ m_8 h_8 + m_7 h_7 = m_9 h_9; \frac{k J}{s} \] (10)

3.3. OPERATIONAL PROFILE

WHRS operate as long as the ship is sailing, so there are three references when the ship is at sea: ship in port, ship in ballast and ship with cargo.

According to (6) the operation of an Aframax oil tanker varies among the references shown above. In addition, just as figure 10 a ship of these characteristics spends the most time sailing, either in ballast or with cargo. The proportion between 2005 and 2011, delivers an average in load, ballast and port of 31, 27 and 42 % respectively, this means that within 365 days of the year an Aframax oil tanker sales 209 days, equivalent to 4,906 hours.
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$$\eta_b \times m_b \times \left[ c_c \times (T_{b, b} - T_{m, t}) \right] = m_v \times h_{v, b} \times (h_{v, b} - h_{w, b}) $$

Equation 9

The energy balance equation for the LP section is:

$$\eta_b \times m_b \times \left[ c_c \times (T_{m, i} - T_{m, t}) \right] = m_v \times h_{v, l} \times (h_{v, l} - h_{w, l})$$

Equation 9

Finally, an energy balance is considered in the high turbine stage and in the mixing process that occurs with the LP steam, one coming from the low pressure (8) of the boiler and another coming from the HP turbine (7), until to get the balance (9) (see equation 10).

$$m_8 \times h_8 + m_7 \times h_7 = m_9 \times h_9$$

Equation 10

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Figure 5. Operation profile of Aframax tankers in navigation and port during the period 2005 and 2011.

Source: (Banks et al., 2013).

Additional information is taken from (6) to have a more precise relationship, figure 12 shows speed as percentage during sailing.

Figure 12. Sailing in ballast and cargo condition of Aframax oil tankers in relation to speed during 2011.

Source: (Banks et al., 2013)

To obtain the output in relation to speed, the admiralty formula is used.

$$N_i = \frac{D^{2/3} \times V^3}{C_\alpha} \times 0.7457 \; kW$$

Equation 11

3.4. FINANCIAL INDEXES

Economists evaluate the profitability of investment projects using the Net Present Value (NPV). This is a method applied to determine the current value of all future cash flows through a Discount Rate (DR), as it is understood in the equation 12.
\[ NPV = \sum_{i=1}^{n} \frac{l_i - O_i}{(1 + DR)^i} - I_0; \ $ \quad (12) \]

Another method of profitability is to use the Internal Rate of Return (IRR). It is an interest rate that sets the NPV equal to zero. If the IRR is higher than the DR, it follows that the project is profitable.

3.5. POLLUTION REDUCTION

The emissions are the product of fuel consumption and the energy efficiency. To know the reduction of CO₂, SOₓ, NOₓ y PM the equation 13 have to be applied.

\[ ER = SED \times WHRS_{output} \times N_{time}; \ tons \quad (13) \]

4. RESULTS AND DISCUSSIONS

The results will mainly depend on which WHRS is used, either through a gas, steam or combined system. The analysis is based on a separate study of its two main components: steam and gas turbine.

4.1. COMPARISON OF SYSTEMS

The PTG, STG and combined systems, with an operational profile of 80 % SMCR, provide energy in 2.24, 5.39 and 7.54 % respectively.

**Figure 6. WHRS recovery output data for an Aframax oil tanker with a MAN B&W S60MC-C8 engine.**

**Figure 13** shows the heat recovery capacity of the three systems studied between the ranges of 50 to 100 % SMCR. In the case of 100 % SMCR, the difference from one system and the other
is around 400 kW. To get a clearer idea, this represents the power that 40 high-consumption homes need.

4.2. HEAT EFFICIENCY

The efficiency of two-stroke diesel engines has increased considerably in recent years, up to 50%. For the MAN B&W S60MC-C8 engine, the efficiency at different operational loads with and without WHRS is shown in Figure 14.

**Figure 7. MAN B&W S60MC-C8 engine efficiency with and without WHRS.**

4.3. CONSTRUCTION COSTS

The components needed for the WHRS system take up some space in the engine room, which have to be considered in the overall machinery arrangement. The rearrangement increases space requirements in engine room and optimization of the existing rooms (Nielsen, Mech and Sc, 2009)

In addition to above, there is a penalty of weight, including rebuilding of casing, decks in engine rooms, cables, pipes and structural elements. Even a combined cycle system has a length, width and height of 11, 4, and 5 meters respectively, with a weigh of 115 tons. This unit has to be installed within 50 meters in length that has an engine room of an Aframax oil tanker. The WHRS unit for the Aframax oil tanker is composed of the components shown in figure 15.
Figure 15. Construction, operation and maintenance costs of WHRS for an Aframax Oil tanker.

Source: (Nielsen, Mech and Sc, 2009; Polo, Carlier and Seco, 2016).

The shipyard together with the manufacturer would work to install the different components. Figure 15 shows the work that the shipyard must attend, such as dismantling, welding, materials handling and services. On the other hand, the ship owner together with the surveyor must redesign the structural and distribution plans for their approval by the maritime authority, as well as supervise the work in the shipyard. The cost for the shipyard fees has been assumed is reference to the annual maintenance cost of an Aframax oil tanker. Then, the costs reach for the PTG, STG and combined systems are 0.15, 0.20 and 0.30 M$ respectively.
According to (Nielsen, Mech and Sc, 2009), the installation of a combined WHRS costs 1,137 $/kW. This information is approximated with the facilities of cogeneration plants on land. Then, for a PTG, STG and combined system the cost would reach 0.5, 1.00 and 1.34 M$ respectively.

Finally, the initial investment to install the WHRS is shown in table 2. In an Aframax oil tanker would be invested for the PTG, STG and combined system 0.65, 1.20 and 1.64 M$ respectively.

4.4. FINANCIAL STUDY

As a starting point, revenues depend exclusively on the amount of fuel that is not used due to implementing cogeneration.

**Figure 16. Fuel saving for using cogeneration - WHRS in an Aframax Oil Tanker.**

<table>
<thead>
<tr>
<th>Speed (knots)</th>
<th>SMCR (%)</th>
<th>PTG (kW)</th>
<th>STG (kW)</th>
<th>Combined (kW)</th>
<th>AFDC (g/kWh)</th>
<th>Sailing Hours</th>
<th>Fuel saving PTG ($)</th>
<th>Fuel saving STG ($)</th>
<th>Fuel saving C ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5</td>
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<td>N/A</td>
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Assuming that the price of fuel oil is 500 $/ton, the annual financial savings calculated for each system in the last three columns of **Figure 16** would be 0.11 M$ (PTG), 0.25 M$ (STG) and 0.32 M$ (combined)

The cash flow shows the costs that correspond to the money needed for the operation and maintenance the WHRS. In general, these would be labor, spare parts, lubricants, training, and administrative costs.

Using the Payback, the recovery time of the investment is known through cash flow. Due to this, a graph (**figure 17**) in cash values over the operational years of the Aframax oil tanker is obtained. Then, the recovery time of the investment for the PTG, STG and combined system is 8, 6 and 5 years respectively.
With cash flow for the 15 years of the Aframax oil tanker operation and a DR of 12 %, a positive NPV index is obtained for the three cogeneration systems. The second index, IRR, for the PTG, STG and combined system is 12.4, 18.6 and 17.0 % respectively. It means that both results are satisfactory.

4.5. ENVIRONMENTAL IMPACT

Using the SED, the output power of the WHRS and the navigation time, it is possible to know the reduction of polluting emissions (CO₂, SOₓ, NOₓ and PM). These results are shown in figure 18.

Currently, many industry projects lead to environmental impact, shipping industry is no exception. The Marine Environment Protection Committee (MEPC) under IMO's remit is constantly working to improve the energy efficiency of ships and one of its main aims is to reduce the environmental impact. Even, if the cogeneration project is not profitable enough for shipping companies, the environmental benefits are significant, as shown in figure 18. Only the implementation of the PTG system can reduce CO₂ emissions by 615 tons per year.
4.6. COMPARABILITY OF RESULTS

The researches on these systems have increased in the last 10 years. Many authors develop model based on standard conditions for a specific engine or ship. But, they don’t consider a real operational profile. To obtain the thermodynamic and economics results for the WHRS, a voyage plan is necessary. So, from this argument, a similar research was done by (Suárez de la Fuente, Roberge and Greig, 2017). The preselected design parameters and results obtained are compared in the figure 19.

It can be seen that the results are different. For example, the fuel saving per year is higher than the related research. This is because the initial data are different such as: the pinch point, WHRS type (they use a single pressure system), exhaust gas temperature outlet and the heat from jacket, lube oil and air is not use.

5. CONCLUSIONS

Three types of cogeneration systems were evaluated in the Aframax oil tanker, using thermodynamic equations, design parameters such as Pinch and Approach Point, flow and temperature of the exhaust gases and output of the main engine between the ranges of 50 and 100 % SMCR. For an average output of 80 % SMCR, it is possible to increase the efficiency in the STG, PTG and combined system for about 2, 5 and 8 % respectively.

The electrical balance and operational profile of the Aframax oil tanker was obtained. The service hours of the main engine influence in the amount of fuel that can be saved in a year of operation. During the 365 days of the year, the Aframax oil tanker navigates a period of 4,906 hours. Then, it is affirmed that if the ship did not navigate enough hours to produce economic benefits, its installation would be exclusively to improve the environmental impact.

The economic balance was made for a period of 15 years, the data needed are: the initial investment that consist in the structural configuration and WHRS installation, which cost...
1,137 $/kW; the revenue, considered as incomes that help save 219 (PTG), 492 (STG) and 635 (Combined) tons of bunker; the production costs to maintain the productively, such as spare parts. Then, Based on expected cash flows, the payback for installing the PTG, STG and combined system would be in 8, 6 and 5 years respectively. In addition, introducing the investment risk, the financial profitability indexes NPV and IRR are acceptable during the remaining 15 years of the Aframax oil tanker.

Finally, using the waste energy from the exhaust gases the reduction of bunker would improve the environmental impact. Therefore, following this line CO₂, NOₓ, SOₓ and PM: for the PTG system, 615, 19, 12 and 2 tons per year are reduced; for the STG system, 1383, 43, 25 and 5 tons per year are reduced; and for the combined system 1,784, 55, 34 and 7 tons per year are reduced.

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NEW STRATEGIES FOR ENVIRONMENTAL MANAGEMENT IN HARBOURS: THE CASE OF THE TARRAGONA PORT MONOBOUY

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Abstract:

Ports are a potential focus of sea pollution and therefore port authorities and operators have a key role on the sustainability and environmental protection of the coastal waters. In the last decades, monitoring techniques of the marine environment have been implemented in ports, and accurate meteo-oceanographic prediction systems have been developed. New available systems may be used to obtain real-time data in order to improve risk assessment and the management of pollution events (e.g. video surveillance systems, Unmanned Aerial Vehicles (UAV), remote sensing products, etc.). The availability of meteo-oceanographic operational services (for instance, the SAMOA initiative from the Spanish Port Agency) allows to implement statistical techniques, such as Monte Carlo simulations, to perform probabilistic studies of potential pollution events. This contribution aims to develop new strategies, focusing on two aspects of the marine management: 1) The incorporation of the statistical methods and the available data of the physical environment; and 2) The design of environmental risk management strategies adapted to the present regulations. These tools may enhance efficiency in the environmental management of port waters and nearby coastal areas reducing the negative impact of pollutant discharges.

Keywords:

Environmental risk assessment; oil spills; SAMOA project; Medslik model; Monte Carlo method.

Acknowledgments:

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INTRODUCTION

The environmental pollution caused by port operational accidents has received an increasing attention in the last decades associated to the increased environmental sensibility and blue growth. In particular, pollution by hydrocarbons is relevant because of its frequency (they are present in approximately 57% of accidents involving chemical substances [1]) and their toxicity. The oil pollution of marine habitats is an issue not only for researchers and environmentalists, but is also a main social and political concern, due to the serious impact of oil spills on marine life and on human activity, tourism and the exploitation of the sea’s resources.

Both public port administration and the private operators of ports and terminals have therefore to consider the potential effects of their activities on the marine environment in their planning and management. So, port managers need tools in which the interactions of logistic and environmental factors can be considered to define their policies. Thus, environmental risk assessment tools are meant to become a generalized tool for environmental management and decision-making for port authorities [2]. This management relies on the three-step process of hazard identification, risk assessment and risk management. Environmental risk assessment requires a description of hazards, the determination of the probability of impact, the vulnerability of the environment and thus derives the consequences from a hazard. This contribution focuses on the determination of the probability of impact.

Oil spill hazard can be considered under the source-pathway-receptor-consequence (S-P-R-C) methodology [3]. A critical point in this methodology is the analysis of the potential pathway between source and receptor. The hydrodynamic information of the receptor domain is necessary to analyse the pathway [4]. In recent years, several types of risk management instruments have been postulated in order to mitigate the potential environmental hazard in port operation. Two main classifications of such instruments can be considered [5]. First classification, according to their analytical approach, results into nine groups: even tree analysis, failure mode and effects analysis, fault tree analysis, risk maps, scenario analysis, bayesian belief networks, decision tree, bow-tie analysis and cause-consequence analysis. Also, the instruments can be classified according to the support method into four groups: analytical hierarchy process, fuzzy theory, evidential reasoning and simulation methods. Our work is directed to the risk map approach supported by simulation methods. Several examples of such instruments can be found [6, 7, 8, 9, 10, 11 & 12].

In this paper, we investigate the spatial distribution of probability of impact of an oil spill in the dock or the monobuoy of the port of Tarragona using a Monte Carlo method. We take advantage of the operational information available to use real wind and water current conditions for the oil spill simulations. Our goal is to verify the validity of the new method and the reliability of the results obtained.

The study case is the port of Tarragona, located on the Mediterranean coast of Spain (approximate coordinates are 1°14′E 41°05′N), which accommodates a hub of petrochemical industry. Wind and water current data in the port area are obtained from the SAMOA system (Sistema de Apoyo Meteorológico y Oceanográfico de la Autoridad Portuaria). SAMOA is an initiative of the Spanish Public State Port Agency to provide Port Authorities with user-customised operational met-ocean information for harbour safety, environmental management and operational decisions [13].
The paper is organized as follows. Section 2 describes the site and introduces the risk management instrument as well as the operational data and the model used. Section 3 presents the results of the simulations and a discussion on the design criteria for the risk management instrument.

1. MATERIAL & METHODS

The port of Tarragona is the main petrochemical port in the Mediterranean coast of Spain, connected to one of the largest Spanish oil refineries, and also an important industrial and commercial harbour. Repsol Petróleo, SA, owner of the oil refinery, operates a liquid bulk terminal within the port with mooring capacity for five vessels and an offshore station (i.e. monobuoy) for the mooring and unloading of very large vessels.

This port is very suitable for the implementation of new strategies for two reasons: the availability of detailed meteo-oceanographic operational data, and the existence of previous studies on oil spill environmental risk for comparison [6, 7, 8, 14 & 15]. In this sense, we define different environmental risk management tools which can be described using a conceptual layout (see Figure 1) with a set of inputs and outputs focused on environmental management.

This work is particularized for a tool with a specific layout (see Figure 1) whose purpose is to create probability maps associated to accidental spills in the oil transfer facilities of the harbour. The layout centres on the application of the simulation tool and the operational meteo-oceanographic models and the interpretation criteria for the results obtained from the simulation.

Figure 1. Layout of the environmental management tool for accidental spills in the oil transfer facilities of the port of Tarragona.

This tool is based on a set of Monte Carlo iterations using oil spill simulations obtained from an upgraded version of MEDSLIK-II, a Lagrangian model that simulates the evolution of a discharge of hydrocarbon products in the sea considering the effects of transport, dispersion and weathering, as well as the eventual oil fixation at the coast [16 & 17].

The model has been used to provide the position of oil particles at different time steps during a set of different simulated scenarios. By directly combining the results of all the simulations, the probability of oil presence has been obtained in terms of the superposition of the particles’ positions.

The premises considered in the Maritime Interior Plan of the Repsol installation of the port of Tarragona (written in 2009) have been used to parametrize the oil spill. A discharge of 5.4 T of crude oil has been considered in the simulations. An instantaneous spill has been defined since
the duration suggested by the plan (i.e. 5 minutes) is negligible in comparison to the simulation period. This hypothesis does not significantly alter the probability maps obtained.

The model was forced by wind and hydrodynamic fields obtained from the SAMOA project. Specifically, data corresponding to the period between October 2017 and September 2018 have been used, providing one year of data and allowing to perform simulations evenly distributed along all months. These have been designed using a Monte Carlo algorithm to define a random release time for the simulated oil spills. Thus, combinations of different releases, with the associated meteo-oceanographic conditions given by SAMOA, are generated randomly. The evolution of the oil slick has been obtained using MEDSLIK-II.

Numerical experiments have been carried out with oil spills from the monobuoy and from the dock. The simulation length is 8 hours, with a 6-minute timestep, and model results were recorded for each time step. The number of tracer particles used per simulation was 10. The value adopted for horizontal diffusivity for both spill cases (10 m²/s) has been chosen after a sensitivity analysis within the limits suggested in the literature [18].

The results obtained in the experiments have been used to generate first impact probability maps based on particle counting within predefined cells. Each probability map has been obtained by normalizing the corresponding particle count map, i.e. dividing the value in each integration cell by the maximum value, which corresponds to the cell where the spill originates.

2. RESULTS AND DISCUSSION

Probability maps obtained are presented in Figure 2 for oil spills occurred in the dock and in Figure 3 for oil spills from the monobuoy. These maps take into consideration the probability of presence of tracer particles at a given point at any time during the 8-hour simulation period. Probability is computed only in the area where convergence of the Monte Carlo series has been achieved. For visualization purposes a logarithmic probability scale has been chosen.

**Figure 2. Probability map for spills from the dock.**
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The comparison of these probability maps (i.e. Figure 2 and 3) suggests that a spill from the monobuoy can potentially affect a larger area than an oil spill occurred at the dock. These probability of impact results are consistent with the results of previous studies which highlight the protection provided by Cape Salou [14 & 14] (shown in figure 4). Furthermore, they are also compatible with the studies suggesting three main directions of oil dispersion (approximately E, ESE & WSW) for the monobuoy spill [6, 7 & 8] (shown in figure 5) as a result of the typical meteo-oceanographic patterns.

Figure 4. Effect of Cape Salou: (a) dock spill, (b) monobuoy spill. Yellow arrows show the main direction of dispersion of a potential oil spill based on probability maps.
Figure 5. Main directions for oil spills from the monobuoy. Yellow arrows show the main direction of dispersion of a potential oil spill based on probability maps.

The impact probability maps obtained, presenting the three main directions shown in figure 5, are consistent with the meteo-oceanographic characteristics of the region [19, 20, 21, 22 & 23] that are: a) south-westwards averaged water circulation and b) NW energetic wind events.

3. CONCLUSIONS

The probabilistic method presented, based on Monte Carlo simulations, allows us to obtain impact probability maps using information from meteo-oceanographic operational systems. The results shown for oil spill risk in Tarragona Port facilities, validated with previous studies for those facilities and consistent with the meteo-oceanographic characteristics of the region, suggest that this tool is appropriate for environmental management systems in other ports where meteo-oceanographic operational systems are available. Also, this method’s potential will grow with the development of meteo-oceanographic operational systems models in ports and coastal areas and the accumulation of data. In the implementation of this method, the scope and scale of the maps have to be considered taking into account the available meteo-oceanographic information and the model requirements. In areas with limited meteo-oceanographic information, expert judgment will be necessary if areas with low probability of impact have to be considered.

References:


The impact probability maps using information from meteorological operational systems models in ports and coastal areas are consistent with the meteorological characteristics and trends. The impact probability maps obtained, presenting the three main directions shown in figure 5, are consistent with the meteorological characteristics and trends. Also, the scope and scale of this method will grow with the accumulation of data and the development of meteorological operational systems models in ports and coastal areas. In areas with limited meteorological characteristics and trends, the monobuoy. Yellow line – NW energetic wind events.

CONCLUSIONS

Environmental Management

Gómez, A.G.; Lecue, M.

Figure 5. Arrows


