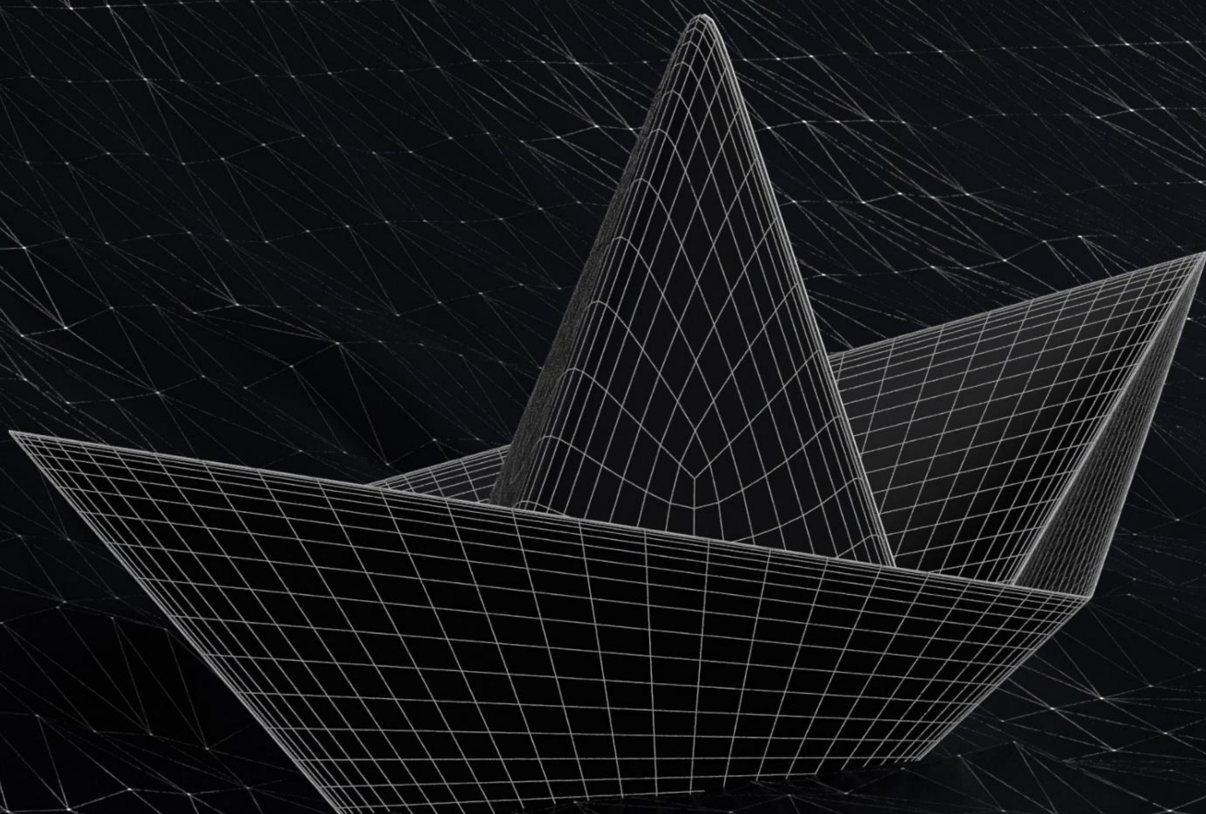
“The adoption of digitalization in shipping and the road to digital transformation”.

Technical University of Crete

Master in Technology & Innovation Management



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I dedicate this work to all those who resist to change and to those who struggle with the vision of sustainable evolution.

Abstract

This thesis deals with the digital transformation of the shipping sector. It analyses the smart technologies in maritime, goes deeper in specific applications of them and presents the challenges and the drivers of adoption of digitalization. Using several sources (online and physical), examples and personal experience it tries to underline the human-driven approach of digital transformation in shipping and propose some considerable factors for the effectiveness and smoothness of this digital journey.

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1 Introduction

1.1 The Motivation

After the successful completion of my Master courses I started working as a service engineer in a Greek ship broker company (BPCO LTD) which is exclusive agent of Panasia; a global leader in smart and green technologies and state of the art in emission gas systems and ballast water management systems for vessels. The job description involved a wide range of activities and responsibilities in the field and outside of it that they will be analyzed in later chapter. The deeper I was going in the maritime ecosystem the more I was founding myself excited with technologies and innovations in this specific sector. Researching and trying to generate ideas related to digital technologies for BPCO was an integral part of the day. Furthermore, to expand my knowledge on smart technologies I decided to attend a three-month online course on smart shipping by Lloyds Maritime Academy. Having an overall view of the smart technologies in maritime and one year intercultural work experience with high-tech maritime systems, gave me a clearer view of the challenges and opportunities of the sector and how the adoption of digitalization can respond to them.

1.2 Problem Statement & Aim of the Thesis

This master thesis deals with locating and analyzing the digital technologies and their applications in shipping for safer, greener, optimized and more sustainable maritime activities. The overall scope is approaching the opportunities and difficulties around digital transformation in shipping. The main target of the thesis is to find the main challenges that rise from the adoption of digitalization in shipping and propose the necessities the maritime ecosystem have to give attention to, in order to accomplish a smooth digital transformation towards sustainable evolution. Of course, to achieve these targets, it is essential to find the drivers of digital transformation in shipping and analyze them.

1.3 Methodical approach

In these fast paced times, where digitalization is in the center of attention for industries, and perceived as possible way to overcome difficulties and take advantage of opportunities, staying updated and experiencing this situation from the inside is a top priority to acquire agility and minimize uncertainty. The same norm applies also to shipping industry. The data that are used for the synthesis of this thesis come from latest internet articles published, researches and books by reliable sources that are engaged directly or indirectly with maritime. Further research, analysis and personal aspects that arise from personal work experience in shipping occupy a big part of this thesis. Also, input from a state of the art high-tech company in shipping is used. After the combination of the above methods, conclusions are made to approach the aim of this research and reveal a possible road to an effective digital transformation of shipping.

1.4 Structure of the work

Starting with a brief explanation of the parts of the maritime ecosystem we continue with the basic definitions of digitization, digitalization, and digital transformation. This preface is essential to continue with deeper meanings and analysis in the specific sector of digitalization in shipping. The dissertation continues with a presentation of the current challenges in shipping followed by a short preview of the categories of digital trends in maritime. The main analysis and applications of these trends follows and an extended analysis of a specific innovation in shipping industry is conducted. Furthermore, the key challenges of digital transformation in shipping and the main drivers for the adoption of digitalization are presented. Thesis continues with proposal and analysis of remarkable subjects and actions that will have a strong positive input in the accomplishment of digital transformation. Finally, our work closes with the generation of a digital innovative idea based on current needs of the shipping industry.

2 The maritime ecosystem

This chapter presents an overall view of the maritime ecosystem, starting with the main systems of a vessel and the port ecosystem, continuing with a brief description of jobs' variety in the maritime sector and finishing with an explanation of my job description.

2.1 Types of ships

Prior to the main systems of a ship, the different types of ships are presented. A ship is a large watercraft that travels the world's oceans and other sufficiently deep waterways, carrying goods or passengers, or in support of specialized missions, such as defense, research, or fishing. (Wikipedia 2020). Ships are classified in the following types:

Tanker ships (Tankers): Tankers are vessels specialized in carrying large amounts of liquid cargo. Based on the cargo they carry they are divided in sub-categories such as Oil Tankers, Chemical Carriers, Liquefied Gas Carriers etc.

Container ships (Containers): A specialized vessel to hold huge amounts of cargo that are compacted inside various types of containers. There are different types of container ships. One of them is the refrigerated container ship that carries refrigerated cargo.

Bulk Carriers (Bulkers): Bulkers transport cargoes, and most of the times dry cargo. The cargo can be food grains, ores and even cement. Generally, the cargo that is transported with this kind of ships is loose cargo.

Roll-on Roll-Off ships (Ro-Ro): Ro-Ro ships are vessels that are mainly used to carry wheeled cargo. Their most common use is to transfer automobile vehicles.

Passenger ships: These ships are used for the transit of passengers. They are classified in Ferries and Cruise ships. The first are used for transiting passengers and vehicles on short distance routes, while the second are like sea hotels with high-end facilities and activities.

Offshore vessels: Their main use is for oil exploration and construction at sea. Offshore vessels divide in many subcategories such as Drill ships, Pipe Layers and Production Platforms.

Fishing ships: These vessels are used in commercial fishing.

Specialty ships: These are built and used for special purposes. Ice breaker ships and Research ships are some of their kind.

2.2 Main systems of a vessel

The main types of ships are demonstrated. The three main parts of a ship are the Hull, the Engine Room, and the Navigation Bridge. Some of the most important systems of a vessel are the following:

Communication system: A ship uses the communication system for ship-to-ship or ship-to-shore communication. There are used different communication systems depending on the needs of the ship i.e. VHF, Digital Selective Calling (DSC), satellites and internet access.

Navigation system: One of the most important systems of the vessel. It consists of navigational tools such as radars, gyro compass, automatics identification systems (AIS), GPS receivers etc. It is used to implement voyage practices to control and monitor the movement of the ship from one place to another.

Steering system: It is used for the steering of the ship. This system consists of a steering gear, a rudder, a rudder carrier, a rudder horn, and a steering gear. Any malfunction of this system may be critical as it is used when the ship is underway. (Wartsila, 2020)

Propulsion system: This system provides impetus to propel the ship. It consists of propulsion machinery and the auxiliary systems for their operation, the equipment for the transmission of propulsion power into thrust and the necessary control and monitoring systems. Engine temperature, fuel consumption and combustion temperature are some of the things that are monitored by propulsion control system. (Wartsila, 2020)

Power management system: Controls the electrical system of the ship. It is used to make sure that the electrical system is efficient and secure. If power consumption overpasses power production capacity, load shedding takes place to avoid a possible blackout. Also, as the load varies the power management systems can be used to control the diesel generators or other machines such as the thrusters. (Radan, Damir, 2008)

Auxiliary machinery management system: This system can control several auxiliary parts of the ship. Some of them are pumps, blowers for air in the main engine, purifiers, portable and freshwater control.

Ballast water management system: Ballast water is pumped in ballast tanks to maintain secure operating conditions as the ship is underway. This way the stress on the hull is reduced, ship has transverse stability, improved propulsion, and maneuverability and safe on and off loading of cargo due to the compensation of weight changes. (International Maritime Organization, 2020)

Cargo control system: This system usually consists of a loading computer, tank radar and temperatures probes, bunker ballast, fresh-water and draught gauging and an independent alarm system.

Having mentioned several ship-systems it is essential to set the definition of Information Technology (IT) and Operational Technologies (OT) for shipping as stated in Lloyd's Maritime Academy course "Smart Shipping":

Information Technology (IT): All interconnected and/or dependent systems supporting shored-based and shipboard operating environments, and the operational technologies that they support/operate. (Lloyds Maritime Academy, 2020)

Operational Technology (OT): The technology commonly found in cyber-physical systems that is used to manage physical processes and actuation through the direct sensing, monitoring and control of physical devices like pumps, valves, and motors. In a vessel these systems include plant and machinery, RF communications, on and off board sensors and navigation systems. (Lloyds Maritime Academy, 2020)

2.3 The port ecosystem

Ports are a main element in the global maritime supply chain. They are the entrance of passengers, products, and merchandise to the country and they are the exit door for all the exports of a country to the global market. Their infrastructure and services diverse from one port to another and between different countries. They are a meeting point of coastal and inland transportation systems and the necessity to adapt over the years it is an integral part of their lifecycle. The local geographic specifications, the activities that are related to the location of the port and the different challenges that the port faces demand adaptability in port's infrastructure and services. As a result, to cope with these factors, the port has specific functions and provides some main services. (Georgia Tech Panama Logistics Innovation and Research Center, 2020)

- Vessel loading/unloading services
- Vessel berthing services
- Temporary storage and staying services
- Ensuring of safety of seagoing vessels entering the port, operating in, and leaving the port
- Providing access to hinterland and intermodal transportations

The infrastructure of a port consists of marine infrastructure (locks, jetties, mooring piers, breakwaters etc.), distribution infrastructure (railways, roads, passages etc.) and terminals and buildings that are managed by Port Authority. Port Authority usually sets in charge private terminal operators for the managing of superstructure (control facilities, silos, cranes) to carry out the facility functions. There are also other side authorities that provide services, inspection, maintenances, and controls that are related to the overall port operations.

The port ecosystem is characterized by diversity and complexity. Different ports have different governance, operate under different economic and operational models, they have various stakeholders and shared responsibilities between them. For this reason, from one port to another there are tremendous differences in IT and OT systems and in the way these systems are managed by different stakeholders. This mix and implementation of IT and OT makes each port both complex and unique. (Lloyds Maritime Academy, 2020)

2.4 The different stakeholders in maritime and the various job descriptions.

The purpose of this chapter is to underline the variety of stakeholders and the large amount of different job descriptions in maritime. Of course, it is impossible to cover every occupation and each role and this is not the purpose here. Our aim is to understand that there are quite many people working in this sector and that each and one of them has a specific role. As it is discussed in later chapter, this role is interconnected with every other role in the maritime ecosystem and that is why it is essential to present some of them below.

The organizational chart of a shipping company owning ships could have the following departments: Management, Technical, Spares, Operation, Crew, Insurance, Health Quality Safety & Environment, Information & Communication Technology, Marine, In-House Travel, Receptions, Conference Rooms and more. In these departments many roles could be included such as managers, operators, charterers, lawyers, superintendent engineers, software engineers etc.

Except of the ship owners, another vital part of the maritime industry are the 3rd party vendors. Third party vendors can be ship engine makers, pump manufactures, environmental systems manufacturers, underwater service providers, shipyards, marine safety providers, afloat repairs, companies that provide SaaS and/or PaaS, IoT systems manufacturers, cybersecurity providers, fuel traders, ship brokers and many more. Depending on the business activity of each vendor and the corresponding departments inside the organizations, job descriptions may vary. Data engineers, software developers, service engineers, R&D engineers, marketing managers, innovation managers, sales executives, business developers, secretaries, after-sales support, installation engineers, cybersecurity specialists, ship security guards, shipyard workers, financial analysts, spare parts executives, brokers and operation executives are just a few of them. Finally, Authorities, Classifications and Flag State Control include also a wide range of human roles within their structures.

All these roles are connected within the same organization and the overall maritime ecosystem. Every change or transformation that takes place in shipping affects these roles and is affected by them.

2.5 My job description

Bellow there is a brief description of my role in maritime industry as an employee of BPCO and MTIM student doing his research for his master thesis.

BPCO LTD is a Greek ship broker company that collaborates with global maritime manufacturers and service providers. BPCO’s business portfolio includes agreements for maritime equipment and dry dockings, service repairs for various systems, commissioning, spare parts purchasing and after-sales support. BPCO is the exclusive agent of PANASIA in Greece. Panasia is a global leader in smart and green technology in maritime.

My training included theoretical and practical part and it was held by official Panasia service engineer.

Job description:

- Commissioning Emission Gas Cleaning Systems and Ballast Water Treatment Systems on shipyards around the world with commissioning team.

- Maintenance, service repairs and troubleshooting of EGCS, BWTS and Tank Level Gauge Systems on board vessels

- Remotely claim solving and technical support to ship owners through communication and collaboration with R&D and quality departments in South Korea (Panasia centrals) when needed.

- Training offshore and onshore ship owner's personnel (superintendents, fleet managers, vessel crew etc.) on EGCS and BWTS

- Assisting sales department with technical and natural presence in business meetings with ship owners and potential customers

- Seeking for technological and market opportunities for further business development.

Having worked in an intercultural environment and cooperated with many different people and departments during my employment, I took the opportunity to identify several challenges of the shipping industry. Giving special attention to the challenges that the adoption of digitalization can transform to opportunities, I got deeper in research and studies of smart shipping and started analyzing the notes and experiences that I had acquired. Combining this analysis with my master studies and further research on today's maritime challenges, helped me develop my interest for the digital transformation of shipping and motivated me for the chapters that follow.

3 Why digital transformation?

Firstly, his chapter presents the definitions of digitization, digitalization, and digital transformation. It continues with a sort presentation of the digital trends in shipping and finishes with the key challenges of the shipping industry.

3.1 "Digit-" definitions

Digitization, digitalization, and digital transformation as definitions are often used the wrong way in the business world. It is a fact that although digitization has a clear definition, digitalization and digital transformation have not.

According to Gartner glossary "**Digitization** is the process of changing from analog to digital form. Digitization takes an analog process and changes it to a digital form without any different-in-kind changes to the process itself (work automation, paper minimization)." (Gartner, 2020)

Regarding digitalization J. Scott Brennen, Doctoral Candidate in Communication, and Daniel Kreiss, Associate Professor, both at the University of North Carolina School of Media and Journalism have a social approach (J. Scott Brennen & Daniel Kreiss, 2016). On the other hand, Gartner has a business approach regarding the same term. (Jason Bloomberg, 2018) It is essential to combine both scopes because especially nowadays business and social life interact with each other. As a result, we end up with the following definition of digitalization:

Digitalization is process of employing digital technologies to change a business or/and social models to provide value-producing opportunities. (i-SCOOP, 2020)

Regarding digital transformation, many definitions and meanings can be found on this topic with the most referring to customer-driven strategic and business transformation with the implementation of digital technologies as well as overall organizational changes. (Collen Chapco Wade, 2018)

Concluding we ended up with the following definition:

Digital transformation is a human-driven strategic, business, and social transformation under the prism of the adoption of digitalization, management of change and digital culture development, in the form of a long-term investment aiming at sustainable evolution.

These three bolded definitions will accompany us is the rest of the thesis as we refer to digitization, digitalization, and digital transformation in shipping sector.

3.2 Digital trends in shipping

Digitalization offers several opportunities to shipping stakeholders beyond traditional shipping services. From enhancing customer relationships to the persuasion of new revenue streams and costs reduction (including vessel operation, fuel, customer services etc.). Of course, the level of adoption of the digital trends in shipping varies from one organization to another and the successful adoption depends on several factors that will be later discussed. It is important though to understand the value that these trends have to offer in the maritime industry. Below there is a brief presentation of the 7 digital trends in shipping that Boston Consulting Group (2018 survey) believes they will transform the container shipping sector. As these digital technologies are still trending in 2020 in the overall maritime industry, most of them and their applications will be analyzed in the next chapter. (Safety4Sea, 2020)

- E-Platforms: These platforms can find use in online booking systems, online cargo management, information sharing, customer personalization and more.
- Advanced Data analytics: Software of this kind can be used to achieve network optimization, dynamic pricing, empty container repositioning and lead generation.
- IoT sensors: These sensors and related software applications can be used for condition monitoring, either for vessel machinery, crew, or reefer container.
- Artificial Intelligence (AI): AI finds several uses in shipping industry and it is a catalyst for the implementation of smart systems in shipping industry today and in the long future. AI can be applied to e-service centers, predictive maintenance systems, route optimization and the list can go long.
- Blockchain: An established and promising technology used for bills of lading, cargo insurance and payment automation.

- Cybersecurity: This is an essential digital technology, the adoption of which, contributes towards the security assurance of the customer and employee data. The security assurance of automated operation is also depended on cyber-resilience measures, policies, and procedures.
- Autonomous vessels and robotics: This technology uses essentially most of the above-mentioned digital trends and it is still under research. The development of this technology aims at automated vessel navigation and automated port calls.

3.3 Key challenges in shipping

The list of challenges that shipping industry faces nowadays is long. In this chapter we are going to mention the most important of them according to some accurate surveys and statements. There will be also mentioned some key challenges that were identified during personal professional experience in shipping. Adoption of digitalization can make a good start facing many of these challenges and digital transformation is able to deal effectively with the most of them. Many key challenges in shipping are also key drivers for the adoption of digitalization in the industry, so it is important to set them and further analyze them as drivers.

- **Environmental regulations, decarbonization**: Although shipping is considered to be the cleanest mode of transport, especially in terms of CO_2 emissions, the pollution that comes from maritime activities has a significant imprint in air and water biodiversity. Combining the above with the increased environmental awareness of last decades due to climate change and air and water pollution, European and International maritime policies have increased the environmental regulations to pursue the protection of the environment and the sustainability of maritime activities. Two regulations could be mentioned as the most referenced and they are set by the IMO (International Maritime Organization). Sulphur 2020 and Decarbonization 2050. Sulphur 2020 obligates shipping companies to comply with a global Sulphur limit of 0.50% (previous was 3.50%) and still 0.10% in ECA zones. With Decarbonization 2050 a GHD reduction strategy was adopted with a plan to fully decarbonize the shipping industry within this century. The first aim is to reduce the average carbon intensity (CO_2 per tonne-mile) by 40%

till 2030 and 70% by 2050 compared with 2008. (IMO,2020) (Lloyd's Register, 2018) Considering the above shipping stakeholders and especially ship owners and environmental systems and fuels manufactures probably face the biggest challenges ever in shipping. Non-compliance with regulations even for a few hours of vessel's operation brings huge fines to ship owners. Also, Emission Gas Control Systems have a big cost of installation and are not complied with every type of vessel, as well as compliant fuels are expensive. Fuel manufacturers and environmental systems manufacturers must stay up to date, perfect and always further develop their fuels/systems and after sales support to ship owners in order to avoid illegal vessel operations and harm of the environment. Generally, with the rise and strictness of regulations, the velocity and effectiveness of communication within and between the stakeholders is essential for compliance and continuity of shipping operations.

- **International regulations keeping pace with technological developments:** With the radius development and implementation of new technologies in shipping many questions arise regarding the corresponding regulations that must be applied. According to a survey from Reedsmith (2018), with respondents from many areas of the shipping market and across many regions, a big concern is whether IMO has to adapt existing regulations to advanced technologies or must introduce new conventions and regulations. (Hellenic Shipping News, 2019) Another question further of this research is if IMO is the appropriate policy to created and introduce regulations regarding the new technologies applied in shipping industry.

- **Possible limited funding due to rise in regulations**: Capital markets may hesitate to finance the large investments that are required for shipping companies to meet new regulations. It is possible that new funding models may be essential to be explored in order to meet the appropriate changes in shipping regarding new ways of ship design and building, new technologies and further research and development.

- **Increased piracy**: Piracy will be always a confrontation for shipping industry. And in periods of economic crisis piracy incidents will increase. Referring to possible post COVID-19 social and economic global circumstances this challenge has to be faced seriously by shipping industry. International Maritime's Bureau Piracy Reporting Center (PRC) recently recorded 98 incidents of piracy and armed robbery in the first half of 2020. (IMB's Piracy Reporting Centre, 2020) On the meantime in its Q1 2020 report, the RECAAP ISC reported an increase of the incidents that happened during the period January-March 2020, comparing with the same month of last year. (ReCAAP, 2020)

Figure 1. Piracy and armed robbery against ships
Source: ICC-ReCAAP

- **Rise of Cyber-attacks**: One of the biggest challenges in today's shipping is dealing with cyberattacks by enhancing cybersecurity. According to Chronis Kapalidis, former Greek Navy Officer and senior researcher and experienced consultant with technical and policy-related knowledge of cybersecurity, the last 3 years there is a rise in cyber attacks in maritime (Lloyd's Maritime Academy, 2020) and according to Naval Dome, CEO of Itai Sela, there is a 400% rise in cyber attacks since February 2020. This last phenomenon occurs due to Covid-19 travel restrictions. The difficulty of service engineers to update and service critical OT of vessels, leaving them open to cyber threats and the remote working situation gave cyber attackers the opportunity to act easier. (Security Magazine, 2020)

- **Industry consolidation drives freight rates down**: A rise in mergers and acquisitions between big ship owners has resulted in domination of shipping industry by large companies. This phenomenon boosted economies of scale and enabled big players of the industry to operate with reduced costs and lower freight and charter rates. As a result, smaller companies will not be able to handle the competition, thus must develop ways to respond. (Hellenic Shipping News, 2019)
- **Workforce and skill shortages:** As the challenges increase with fast pace in the maritime sector, we can observe the lack of the appropriate workforce and skills in the industry. (Survey of Global Maritime Issues Monitor, 2019) To deal with the key challenges and adapt to new standards in shipping i.e. automation of jobs and tasks, stakeholders should include in their agenda employees and trainings that rise beyond the traditional maritime job descriptions.

- **Difficulties in adoption of digitalization:** Combining workforce and skill shortages with traditional management systems and unwilling to change we end up with difficulties in adoption of digitalization. Of course, this is a top challenge that is discussed in this dissertation and the main challenges that rise from the adoption of digitalization will be set and analyzed in Chapter 6.
- **Social demands for sustainability:** Giving mostly weight to the workforce of the shipping industry and their working conditions and efforts, it is mentionable that the monetary gains and amenities that they receive from their employers, are not the ones they expect. With the last trends of increasing value of personal time, health, and identity these social demands and their treatment is a key challenge for shipping companies and their managers. To maintain productivity and retain talent is a top priority for every organization.
- **Time zone correspondence:** The nature of shipping operations demands often availability in communication within an organization or between stakeholders 24/7. In simpler words ship owners and 3rd party vendors demand that their employees have to be 24/7 available as long as shipping operations take place non-stop. Of course, the immediate response for claims and problems that occur

in vessels and beyond is essential for sustainable shipping operations. Every ship owner collaborates with many 3rd party vendors for several spare parts and services. It is a fact that a 24/7 availability in communication with every stakeholder is far from taken for granted as long as there is nothing standardized that organizes this need. Shipping employees often avoid answering calls or e-mails that come outside of their official working hours and they get disappointed with their 24/7 stand-by situation. This creates problems in fast claim and problem solving and can bring huge costs for ship owners and the overall logistic chain.

- **Time sensitivity of onboard-data and connectivity lag:** Transmitting data in near or real time over satellite is costly, and with current connectivity methods between vessels and ashore, near 90% of data never leaves the ship. (Fururenautics & Vodafone Maritime, 2020) Although half of them are time sensitive, this is a challenge for todays and future shipping operations as long as data analysis can have a huge positive impact in vessels performance, maintenance, and risks and costs management.
- **Tacit knowledge stagnation:** Tacit knowledge is difficult to transfer verbally, written or visually from one person to another. (Magnier-Watanabe, Caroline Benton, Dai Senoo, 2011) It is the knowledge that is acquired through experiences, skills, observation, feelings, and senses. It is subjective and can offer great value if transferred effectively within organizations and between stakeholders. Especially in the intercultural environment of shipping that operates with traditional management tactics, tacit knowledge is often lost. Although the use of it can offer great competitive advantages to organizations, the importance of this specific knowledge is not given the appropriate attention. Tacit knowledge in shipping will be discussed more in Chapter 7.
- **Unexpected events:** Considering the most recent global pandemic and the consequences at the shipping sector, we could refer to “Unexpected events” as a huge challenge for the maritime industry. Especially human-centric unexpected events like Covid-19 set the bar high for every shipping stakeholder that wants to

maintain sustainability, recover, or further develop its operations. Digital transformation plays a key role dealing with these issues.

4 Analysis and applications of smart technologies in shipping

This chapter gives a closer look on smart technologies in shipping. The smart trends will be further analyzed and several applications of them in the maritime ecosystem will be set. It is important to understand the value that these technologies have to offer in shipping industry in order to adopt them. Overall knowledge on digital technologies is essential for this purpose. The list starts with hybrid connectivity, the hot topic of IoT and continues with E-platforms and Advanced data analytics, Blockchain, artificial intelligence and cyber-security.

4.1 Advanced Hybrid Connectivity

As mentioned in Key challenges chapter and verified by studies of Futurenautics and Vodafone, ship operators lose valuable analytics insight that can improve performance and efficiency of shipping operations. The classification of time sensitivity of data is a part of this problem and its near or real time transmission with satellites (LTE) is costly. Vessels spend 60% of their time in ports and half of the onboard data are time sensitive. This means that operators can choose to use mobile connection (4G) while near shore to transfer data from ship to shore. Despite this fact 90% of data never leaves the ship and according to the aforementioned survey only 38% of shipping companies use hybrid LTE/4G technology. Also, this segment of users only take advantage of the cost efficiency of LTE/4G and they use the technology of 4G only as a complementary of LTE, although it is an effective way to transmit data back to the shore. Of course, satellite solutions are the primary tool in shipping for emergency communications and open and deep-sea operations, but a hybrid connectivity solution (LTE/4G) coordinated appropriately can offer great value and benefits. Lower hardware investment, unlimited capacity, higher speed, and less latency than satellite are some of them. Mobile connections are not in contrast with satellites. As a matter of a fact advanced hybrid connectivity demands the planned coordination of both networks in order to serve the needs of communication in shipping and extend the maritime interconnectivity.

Going a bit deeper in advanced communication technologies mentioning the arrival of 5G is something exciting for shipping industry. This advanced communication technology will have a big input in the improvement of real time monitoring of ships, connectivity of IoT sensors, remote-controlled and autonomous ships, accidents prevention and pollution reduction. 5G has a special value for shipping, as its right adoption will further develop hybrid connectivity and will boost the value of every smart technology. The advantages of 5G are quite many and we only can present some of them on the following figure.

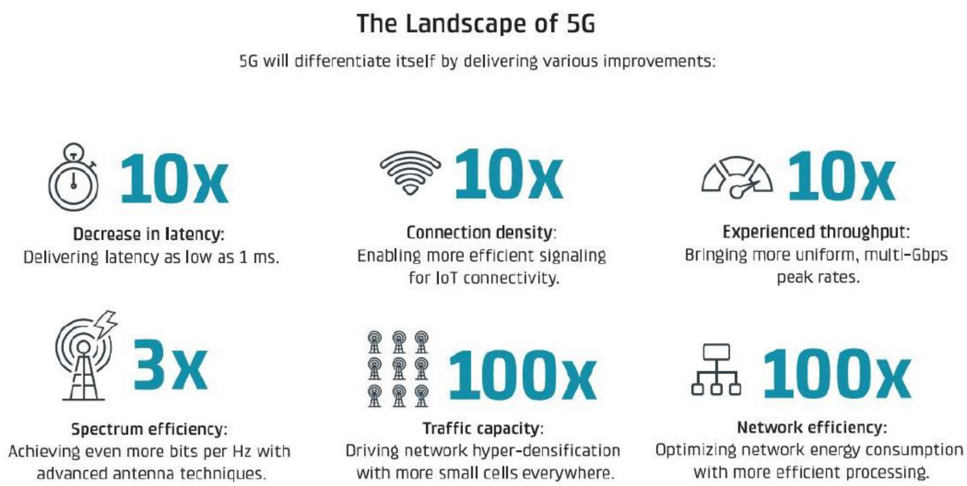


Figure 2. The advantages of 5G-
Source: Visual Capitalist www.visualcapitalist.com

4.2 Internet of Things

For the purpose of this dissertation the definition of Internet of Things, as suggested by Gartner, states as:

"IoT is a network of dedicated physical objects (things) that contain embedded technology to sense or interact with their internal state or their external environment."

Examples of IoT include smart wearable devices, smart home devices, smart vehicles and many more. General purpose devices like Smartphones, tablets and PCs are not included in IoT. They can be turned into IoT if they are connected with devices such as the ones we previously mentioned to control them and/or exchange data.

In shipping industry advanced ship-to-shore connectivity has boosted the IoT technology opening a wide spectrum of opportunities. Different elements such as machinery components, cargo containers, engines, fleet management and ports can be connected with each other with the use of onboard sensors and monitoring equipment.

Right below there is a typical wireless remote monitoring and performance analysis system as presented by LAROS.

Figure 3. Wireless remote monitoring and performance analysis system-
Source: LAROS

The value that IoT can offer is the way to understand the meaning of maritime IoT and familiarize individuals and organizations with their adoption and use. The adoption of IoT can generate enhanced business models, operational efficiency, and new customer experiences.

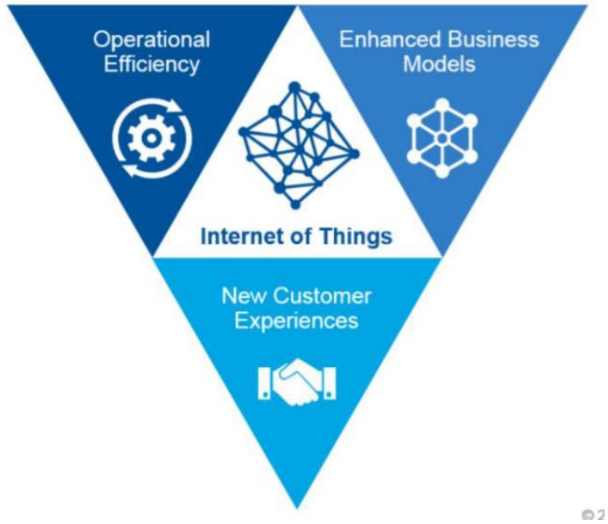


Figure 4. The business impact of IoT
Source: Gartner

The areas in shipping sector that can benefit from IoT are the following:

- Easier and more efficient operations: IoT technology offers many new tools making communication easier and faster. Navigation tracking, effective route optimization, cargo container management and scheduling are some of the benefits that IoT can offer. Except RFID sensors, GPS, and onboard monitoring equipment, IoT finds use in advanced applications such as driving behavior monitoring, weather APIs, traffic monitoring, vessel tracking etc.
- Better analytics: IoT has the ability to collect data from various sensors. These sensors have a main role for improving performance and diagnostics of equipment and processes. Shipping companies that adopt this technology are able to get useful insights on fuel consumption, ship speed and idling, ship behavior, regulations' compliance and more.
- Automated processes: In an IoT network architecture, devices are interconnected and can perform as a part of an integrated process. In fleet management this gives the opportunity to automate many processes. Maritime companies can automate daily logistic processes and trip scheduling. Logistics companies can move their day to day operations in the cloud and track fleets and their cargo from anywhere

they desire. Shipping companies can also automate rerouting, weather notifications, and even get automatically tickets in their offices if they have broken down ship systems. The scenarios that can be automated in shipping industry are several and they increase with fast pace in this digital era.

- Vendor management: Asset tracking with IoT technology can be beneficial also in vendor management. With efficient systems that track successfully ordered goods and packages that are transferred, vendors can be provided with useful real-time information. This helps retaining contact with them and enhance business relationships. As a result, customer experience and engagement are impacted positively.
- Efficient deliveries: IoT in shipping brings out tracking and monitoring solutions, allowing for more accurate delivery dates and order details. The connection between transport vehicles and the data acquisition can offer benefits to customers, and enable other related processes like traffic analysis or area related insights for location-based services.
- Maintenance: Dealing proactively with maintenance in shipping is now a reality with maritime IoT. By collecting data from shipboard equipment and machinery, ship owners can identify issues and prevent failures and malfunctions of systems onboard. The continuous and efficient operations of systems on vessel can reduce costly down time. Also, preventing malfunction and failure of the equipment and machinery enhances crew safety.
- Competitive advantage and increase revenue generation: The early adopters of IoT in shipping will benefit a technological advantage. Collecting, sharing real-time information, and making accurate decisions based on them will improve overall performance and reduce costs. Also, as customer relationships are strengthened due to on-time deliveries and quality control, the use of IoT can offer the opportunity to boost productivity in higher levels and increase revenue.

4.3 Cloud technology and Advanced data analytics

Cloud computing is the on-demand availability of a service or services by using an IT system architecture without direct management by the user. Cloud computing exists in several business models. The most common used are the following:

SaaS: Software as a Service offer the software that is centrally hosted, and accessed through a thin client to the customers.

PaaS: Platform as a Service is a service that offers a development environment. Software developers can use the hardware and software layers of the platform to develop their own software and application solutions.

IaaS: Through Infrastructure as a Service the service providers outsource their equipment and charge it for metered service. The equipment can support several operations such as hardware, storage, and networking components.

Cloud computing technology is already used by many shipping companies. The capacity and possibilities that it can offer, saves stakeholders from expensive investments in infrastructure, training, and software licensing. With the use of cloud technologies shipping companies can collect data from every asset and process in their organization and have access in them from anywhere. While having all fleet management data in one place through the cloud, companies can minimize to zero their investment capital for getting data to shore. The adoption, flexibility, and adaptability of shipping operations of stakeholders around the world could meet higher levels using cloud computing and help in digital transformation. We could refer to cloud technology as a main aspect of digital transformation.

Just as important as could technology are the advanced data analytics. With the huge amount of data that are produced during the functions of each organization, it is a fact that with the analysis of the collected data shipping stakeholders can get valuable insights. As Ibrahim Al Omar, CEO of Bahri said (Bunker Port News Worldwide, 2016),

“By embracing analytics and turning data into actionable insights, shipping and logistics players can have an opportunity to drive improved efficiency and quality. In the long run, this will help transform their organizations into smarter, more dynamic entities that have a more informed picture of market trends and demands and are better prepared to meet the challenges of tomorrow."

Like cloud computing, advance data analytics can stand alone as a technology or can be combined with other technologies that are mentioned in this dissertation and develop further its value. Below in Figure 5 there are presented briefly some current and future applications of advanced data analytics in shipping as taken from a research report in "Use of Big Data in shipping industry" by Trelleborg Marine Systems and Port Technology. (Trelleborg, n.d)

ROLE	FUNCTION	EXAMPLE OF BIG DATA APPLICATION
Ship Operator	Operator	Energy saving operation Safe operation Schedule management
	Fleet planning	Fleet allocation Service planning Chartering
Ship owner	Technical management	Safe operation Condition monitoring and maintenance Environmental regulation compliance Hull and propeller cleaning Retrofit and modification
	New building	Design optimization

Figure 5. Big Data applications-
Source: Trelleborg Marine Systems and Port Technology

The future of possibilities that arise from the adoption of cloud computing and advanced data analytics is bright. Already several stakeholders have come to partnerships to develop further technology capabilities. Also, the number of companies that offer maritime data analytics software has dramatically increased. Ship owners and operators try to use big data to reduce bunker costs and further offset the record of low freight rates in the market. (Ishaan Hemnani, 2018) Furthermore, many shipping companies have set up internal infrastructure, such as private clouds, for more secure and efficient data acquisition and analysis. The opportunities are endless and the input of these technologies in the digital transformation of shipping is critical. This justifies the fact that there have been numerous recent cases of funding in both cloud technology and advanced data analytics. (Shippingwatch, n.d)

4.4 Blockchain

Blockchain is a complete technology primarily introduced to the world as the distributed ledger technology (DLT) used to store transactional data of the famous Bitcoin peer-to-peer network. Bitcoin is perceived to be the first transactional system that offered global feasible transfers between parties, without the supervision and validation of any financial institution. A more detailed definition can be the following:

Blockchain is a distributed and secure ledger or database that is used to register transactions, contracts, records, and other information of assets or users in an automated way, without the need of a traditional financial institution or any third party. It is a sequence of blocks that grows with every new transaction. These transactions are linked together under cryptographic functions. These functions guarantee that these time-ordered transactions that take place in the blockchain can never be modified. This way it is ensured that parties share a common state of truth of what is happening in present and what happened in the past regarding transactions and continue to interact with each other in an efficient and transparent way. Below in Figure. 6 we can see how Blockchain works and in Table 1 the basic characteristics of Blockchain.

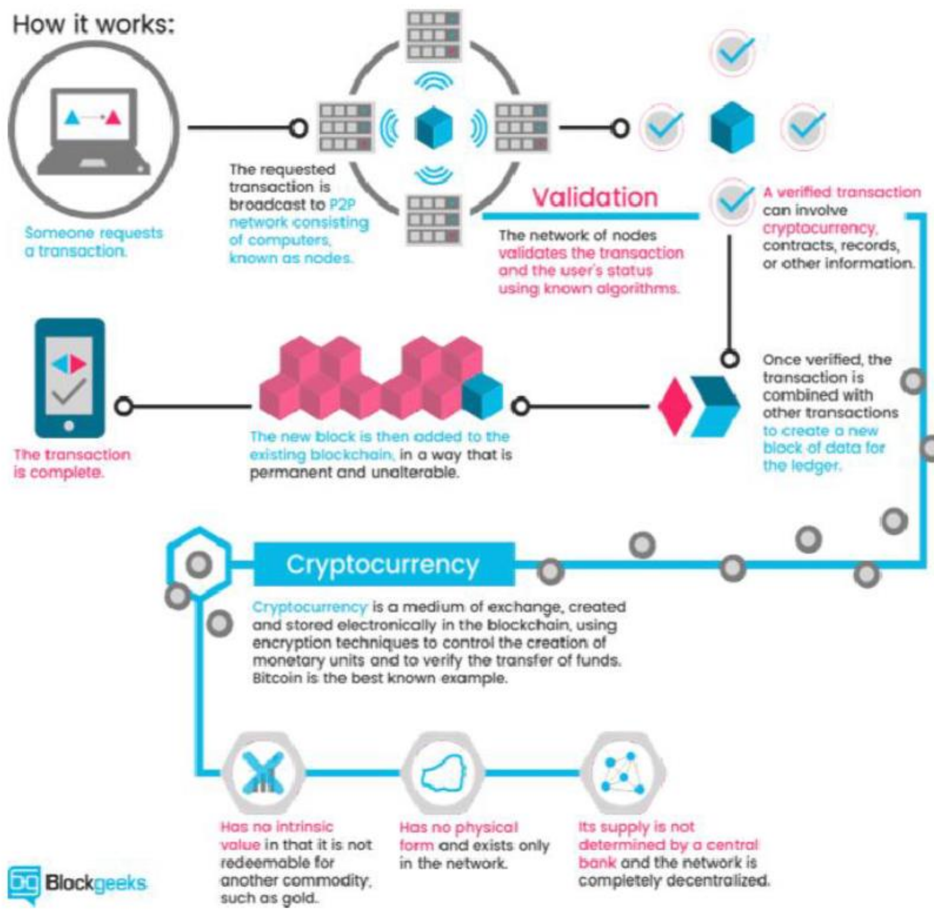


Figure 6. How Blockchain works-
Source: Blockgeeks

The unique combination of properties in Blockchain	
Decentralisation	No single point of trust and thus no single point of control
Auditability	Participants of the network can verify the veracity of records directly, without external querying.
Accountability	All actions can be related to the person who initiated them and are recorded on the ledger.
Construction of direct trust	Unknown (and untrusted) parties can operate without the need of third-party intermediation.
Elimination of Single Point of Failure	No Central Authority or intermediaries are needed to oversee the transactions. A copy of each ledger is stored and maintained by each node of the network
Security	Strong cryptographic primitives (hash functions, digital signatures) are deployed to secure the network and the ledger.
Transparency	The ledger can be public and maintained by all nodes of the network.
Immutability	It is computationally infeasible to change any records on the ledger due to cryptographic sealing taking place via irreversible hash functions.
Reliability	Resistance to outages and manipulation.
Automation via Smart Contracts	Terms and conditions that underpin contracts can be encoded on the Blockchain using scripting languages compatible with the selected framework.

Table 1. Characteristics of Blockchain-
Source: Lloyd's Maritime Academy

A technology with these characteristics can find mentionable applications in shipping industry and offer several benefits. Blockchain in shipping can be used for cross-border payments, traceability of orders and goods, paper-based operations such as Bills of Lading (BoL) and more. (Hariesh Manaadiar, 2019)

Some remarkable applications of Blockchain technology in shipping are presented below:

Shipowner.io: Shipowner will probably be the first Blockchain platform for financing assets in shipping industry. Shipowner is aiming at giving access to ownership of shipping assets to bigger groups of people, reversing this way the current consolidation that takes place in the industry. Through the platform investments in SHIP tokens can take place starting from few dollars. Also ship owners will be able to tokenize their ships in the platform through a sale or other agreement. (Shipowner, 2020)

CargoX: CargoX is the first to land a B/L platform aiming to be a Blockchain based independent supplier of Bills of Lading. A smart B/L is in electronic form. This Smart B/L is created, uploaded, or signed in the CargoX platform for document blockchain transfer. The ownership of the Smart B/L is transacted to the new owner with full transparency in a trustworthy way. Then the new owner can claim his ownership rights according to law. (CargoX, 2020)

Shipchain: As the service description states, Shipchain is "A fully integrated system across the entire supply chain, from the moment a shipment leaves the production facility, to the final delivery on the customer's doorstep" based on transparent blockchain contracts. Shipchain offers full traceability and visibility of the location of shipments in real time. Also, with the use of geofencing through low-cost hardware it can achieve reduction of detention costs, waiting cost of employees and chargebacks. (Shipchain, 2020)

Closing with Blockchain technology, seven main benefits of Blockchain in shipping are presented in the next figure to emphasize on the offered value:

Figure 7. Benefits of Blockchain in shipping-
Source: ProShip

4.5 Artificial Intelligence

Artificial intelligence, sometimes called machine intelligence, finds solutions in various sectors of shipping and it is believed that in near future it will revolutionize and shape the maritime industry. Benefits of AI in shipping include more efficient routes, increased security, compliance with environmental regulations, autonomous vessels and more. The large amount of data that is produced by shipping companies gives the push to AI techniques like deep learning, machine learning and natural language processing, for the development of more efficient and automated processes in shipping operations.

Referring to AI in shipping operations, the term DAI (Distributed Artificial Intelligence) usually comes to the front. Especially for the purpose of this dissertation, DAI is a subfield of AI, closely related to multi-agent systems, that uses decentralized and cooperative agents to develop distributed solutions for a specific task. DAI is a key tool for accomplishing effective navigation, terminal management and avoid accidents such as ship collisions and groundings.

Considering navigation, DAI systems can help to manage maritime traffic control very effectively. With onboard traffic multi-agent systems vessels are equipped with sensors, controllers, and actuators, using them to detect the external environment, analyze the collected data, procced to good decisions and act accordingly. The distributed characteristics of water traffic, the intelligence of the ship and the level of its autonomy, play an important role on traffic control and therefore, effective navigation.(Alexander Love, 2020) Regarding safety, this technology combined with image recognition systems such as cameras and graphic processes units (GPU) can be used to avoid ship collisions and groundings. Also, AI and DAI can help seafarers make more accurate decisions by analyzing data on port conditions, weather, and crime incidents records, allowing ship operators to take proactive actions to maintain seafarers' safety and avoid unexpected damages and incidents. (Allianz 2019)

Closing with navigation security, AI can be applied in the AIS (Automatic Identification System) of vessel. AIS provides data that are valuable input parameters in ship traffic simulation models for risk analysis and accident prevention. This data can be speed, position, vessel identity, interval times, destination, and course. The distribution of this data differs from each other. The use of collaborative and distributive multi-agents with DAI technology can process the data collected from AIS and further improve navigational efficiency and safety of the vessel. (Leonardo Vanneschi, Mauro Castelli, 2017)

Another application of DAI in shipping is in the port environment. With DAI multi-agent systems port operators can achieve automatic container allocation and optimize their container terminal management. Except automation, DAI and AI technology can optimize port operations with the use of real-time data. Optimal use of data improves the coordination of arrivals in ports and estimates the waiting time of ports equipment. As a result, the waste of fuel and the idle time of facilities is reduced, and the port operators' labor and quay space are utilized.

Furthermore, AI is also used in reconfiguration of power systems in a decentralized way. As a study in "Multi-agent Based Power and Energy Management System for Hybrid Ships" proposes (Daogui Tang, X. P. Yan, Yupeng Yuan, Kai Wang, 2015), multi-agent controllers can be used in ship power systems to balance load and generation in real time, while considering load priorities and satisfying the system's operational constrains (e.g. motor voltage constraints, frequency constrains).

Continuing with AI applications, two notables are virtual assistants and document processing. Already in 2019 Maersk introduced "Captain Peter", a virtual assistant that assist customers during the transit of their cargo. This avatar gives information on containers temperature, humidity, CO_2 levels and pushes notifications if any deviation is observed. (Maersk 2019) In shipping industry, virtual assistants can also assist seafarers and office employees. By learning personnel's preferences and how they communicate, they can retrieve the appropriate data and translate information to provide quick answers or guidance in different situations. Referring to document processing, it is a fact that AI techniques such as machine learning and NLP have the ability to learn unlimited different forms of documents, read, scan and extract terms. This way data entry per capita is reduced and inaccuracies rate drops significantly.

Closing with overall AI applications, mentioning the positive input that this high technology can have in environmental issues is essential. As it highlighted in previous paragraph AI improves efficiency in navigation. It takes into account several factors to suggest the optimal route, reducing this way fuel consumption and carbon emissions.

Finally, combining AI with other digital technologies, IT and OT of maritime ecosystem could shape the future of shipping industry and achieve the milestone of fully autonomous shipping. More about autonomous shipping and on-board smart technologies with be analyzed in the next chapter (Chapter 5).

4.6 Cybersecurity

Having set and analyzed the smart technologies in this chapter it is time to introduce a technology that its adoption and implementation is top priority for the safe use of the aforementioned trends and sustainable shipping operations: Cybersecurity.

As already mentioned in the "Key challenges of shipping" the last decade there is a rise in cyber-attacks. "Cyber-attack is an event that is launched via the internet against a target with the intent to deny, disrupt, destroy or exploit a computer-enabled operating environment". (Lloyds Maritime Academy, 2020) The approach that is used by organizations (including shipping organizations) to prevent and deal with cyber-attacks is called Cybersecurity. According to "UK DFT Code of Practice, Cybersecurity for ships": Cybersecurity is the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment of organization and user's asset. (DFT Code of Practice, "Cybersecurity for ships", 2017) Cyber environment is composed of both interconnected IT and OT systems and their subsystems, including the electronics, computer-based and wireless systems they use, and the information, services and social and business functions that exist only in cyberspace. Organization and user's asset include the personnel, the infrastructure, the telecommunication systems, the computing devices, the services and all the data that is utilized in the cyber environment. Especially for a ship, computer-based systems include the IT components (laptops, PCs, servers, routers etc.) and OT(for example radars, control systems, sensors and actuators) (UK government, 2017)

To experience the value and understand the importance of Cybersecurity it is indispensable to set the objectives of cyber-attacks in shipping, the impact of them and the vulnerabilities of the maritime cyber environment:

- Objectives of cyber-attacks according to BIMCO Guidelines on cybersecurity onboard ships (BIMCO, n.d.) :
  a) Destruction of data
  b) Publication of sensitive data
  c) Selling or ransoming of stolen data
  d) Media attention
  e) Denial of access to the service or systems targeted
  f) Ransoming system operability
  g) Arranging fraudulent transportation of cargo
  h) Gathering intelligence for more sophisticated crimes like exact cargo location, off-vessel transportation, and handling plan etc.
  i) Getting through cyber security defenses to achieve financial gain
  j) Gaining technical knowledge of companies’ operations and administration in order to disrupt economies and critical national infrastructure normal operations
- Possible impact of cyber-attacks upon:
  a) The health and safety of people impacted upon by the work activities being undertaken
  b) The ability of the ship to operate safely and to not endanger other ships, maritime structures, or the environment
  c) The speed and efficiency at which the ship can operate
  d) The financial transactions conducted by office stuff
  e) The company’s reputation
  f) The penalties tied to non-compliance of mandatory regulations such as IMO’s 2021 Cybersecurity, and other cyber policies than need to be obligated.

- Vulnerabilities of maritime cyber environment:
    1. **The ease of transfer from one asset to another**: Due to the interconnected digital network architectures inside and between organizations cyber-threats can easier transfer inside company's cyber environment. For example, a malicious file can be transferred from bridge control system of a vessel to the company's offices' IT systems and from there to business functions ran by office management systems.
    2. **Vessels are often lightly governed, and they are a moving asset**: Regarding this vulnerability, vessels may serve the purposes of cyber-threat actors as channels of cyber-incidents throughout the maritime ecosystem. Breached vessels systems can introduce cyber-threats to other elements that relate to them in a digitalized way. These elements include the shipping company itself, ports they visit, terminal operators, classification societies, 3rd party vendors and any other stakeholder of shipping industry that is engaged directly or indirectly will all the aforementioned. Of course, this domino phenomenon can take place vice versa, from an element that ship interacts with toward the ship IT and/or OT systems. To remark the possibility of cyber-threat connection between vessel and port IT, 2018 Crew Connectivity Survey Report from Futurenautics Maritime finds that the future service that is most wanted by seafarers is the "Free in port Wi-Fi service". (Futurenautics Maritime, 2018)
    3. **The wide range of 3rd party vendors and the large amount of digital transactions and services that take place**: In simple words, the more the parts of maritime ecosystem that a company is engaged with, the bigger the possibility of spread of a cyber incident within the company if a 3rd party vendor is cyber-attacked. Also, regarding digital transactions and services between people and organizations, their daily number is so large

and widespread that cyber threat criminals can proceed to frauds and direct payments to their accounts much easier.

4. **The missing of cybersecurity awareness in corporate employees**: The times that cyber criminals invaded inside corporate IT systems through an employee's digital reaction in an email or a link sent by a cyber threat actor are not few. Unfortunately, there is not given the appropriate weigh in cybersecurity awareness of shipping companies' employees.
5. **The inside threats**: Ship crew and officers, office personnel, former employees. These inside entities can sometimes consist cybersecurity risks to a shipping company. Financial gain reasons and work dissatisfaction can lead them to cyber-criminal actions.

According to DNVGL the OT systems' criticality relating impact of a cyber-attack is bigger than the one of the IT systems. Developing the Cybersecurity plan of a company is a demanding and necessary procedure including measurements of risks, costs, impacts, criticalities, careful prioritization, and detection of several dependencies. Frameworks such as the aforementioned DFT Code of practice and regulations like IMO's Cybersecurity 2021 try to drive and enable the adoption and implementation of cybersecurity in shipping industry. Also, there is an effort by the UK government and the National Security center to implement principles to IoT manufacturers to produce IoT devices "secure by design". This way, they want to minimize the burden of the consumer to secure the IoT device on her/his own. On the other hand, TMSA3 includes guidelines for essential cybersecurity training of ship's crew and ashore stuff to enforce the cyber resilience of shipping industry. (Jason Stefanatos, 2018) (Shipnet, 2019)

Giving attention to all the above and trusting the suggestions of several cybersecurity experts (including TMSA3) after online research, we can say that cybersecurity requires a holistic approach. Except the attention given to technology and processes by shipping organizations regarding cybersecurity, people are the third pillar of an effective cybersecurity plan. The cyber-threat will not necessary breach directly through OT systems but also through employees and ship's crew. On the other hand, a cyber-threat can be repelled by an employee with cyber-risk awareness or other well-trained stuff.

Cyber threats are made by people and they target people and systems. It is essential to take into account the human factor really seriously and develop the cybersecurity plan under the aspects of technology, processes and people. In Figure 8 by DNVGL, the three pillars of cybersecurity are presented according to the holistic approach. This holistic approach is directly connected with the human-driven approach of digital transformation.

Figure 8. The three pillars of cybersecurity-
Source: DNV GL

5 Specific applications of smart technologies in shipping

5.1 Vessel performance optimization and E-Navigation

Economical aspects, regulatory compliance and customer expectations are the key drivers for the adoption of onboard smart technologies such as Vessel Performance management systems and E-navigation. Maximizing revenue and minimizing operational costs is a continuous challenge for ship owners. As long as fuel costs are 20-50% of ship's operational costs, the improvement of fuel efficiency is a top priority in shipping operations. Also, IMO has introduced several regulations regarding the improvement of operational efficiency such as regulations for energy efficient ship design. Finally, concerns about global warming, climate change, and energy efficiency have encouraged ship owners to improve operational efficiency and their customers to demand environmentally friendly operations.

To improve vessel performance, management of fleets and find solutions for the complex problems arising around this subject, an analytical approach is required. To optimize performance, operators have to measure several elements. Trim optimization, speed and throttle optimization, weather routing and route optimization, condition-based maintenance (CBM) of hull and propeller, engine performance monitoring, efficiency of machinery and fleet management are some of them. Understanding the impact of any action on the economic model by analyzing the deviation between expected and actual efficiency is a way that is often used by today's ship operators. These Vessel Performance management systems can use statistical models that take advantage of the capabilities of big data analytics, cloud computing and hybrid connectivity to collect and transform data into valuable information to perform this analysis. Ship Performance Management systems may use a wide range of smart technologies already mentioned in this dissertation to achieve their purposes. They may differ between them in terms of needs and functions they cover and their complexity.

Continuing with E-Navigation let us firstly set the definition according to IMO:

"E-Navigation is the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment."

E-navigation is enhanced by data and enabled by communication. As presented in Figure 9, several data are collected, organized, and shared between systems, assets, facilities and teams ashore and on land. The purpose of this network architecture and its process is to improve decision making and optimize operations. The integration of smart technologies in E-Navigation can add positive input in efficiency, safety, security, and cost control.

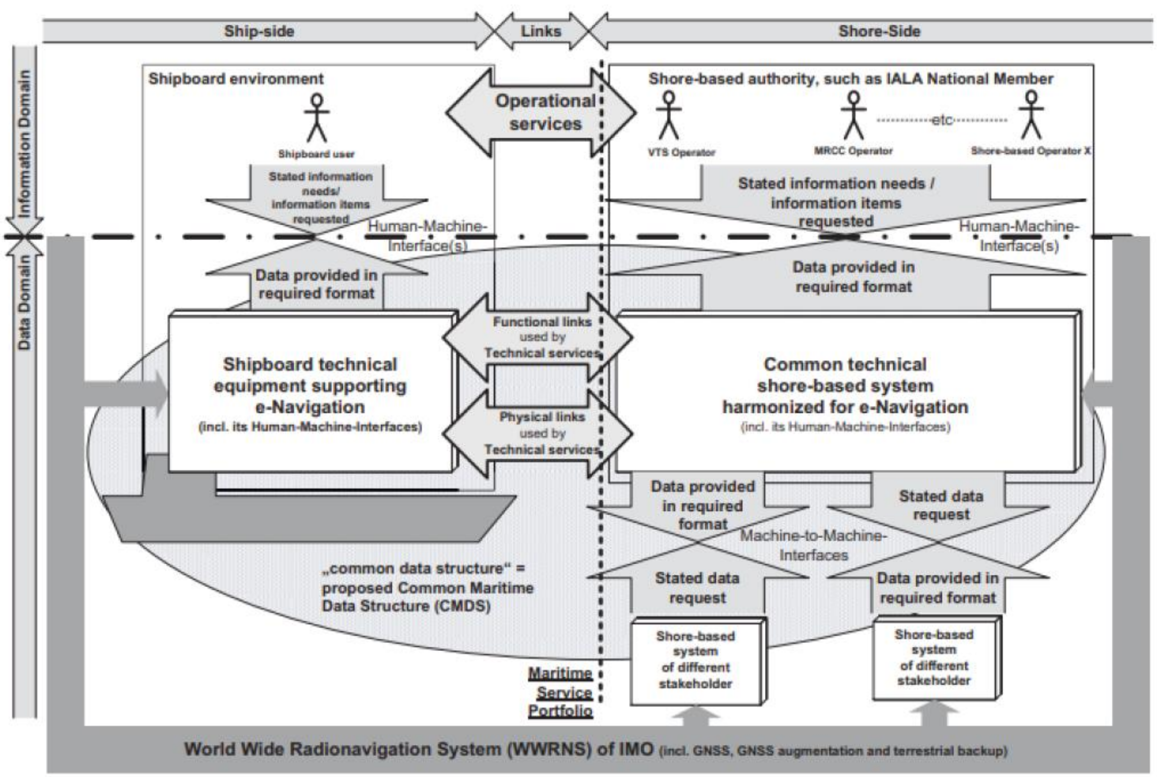


Figure 9. E-Navigation network architecture-
Source: IMO

With smart software tools several onboard administrative tasks can be automated. For example, passage planning that takes around 3.5 hours of time on the bridge can be turned down to 30 minutes. This way accuracy is ensured, human error-based risk is minimized and accessibility to information is enhanced. Also, digitally optimized routes that consider several factors such as real time tidal patterns and weather conditions can contribute to significant fuel saving. In addition, smart technologies applied in E-Navigation can offer the great benefit of transparent voyage monitoring and the exact time of arrival at port. Vessel fuel saving is again a valuable result through these applications and environmental benefits are of course huge. Ship owners that adopt smart technologies on their E-Navigation systems can have complete overview of real-time operational data, chart usage, ship's movement, and costs. Fleet management becomes easier and new ways of monitoring navigational operations are opened ahead for shore-based teams. Concluding with E-Navigation, the update of the Electronic Navigation Charts (ENC) becomes continuous, in a way that compliance with regulatory and authority inspections is ensured. This way the penalties and interruptions in shipping operations are minimized.

5.2 Emissions controlling and monitoring using smart technology.

Implication and compliance of environmental regulations is essential for sustainable evolution of businesses in shipping industry. It is also a huge challenge for shipping stakeholders. Especially considering the hot topic of ship emissions and decarbonization, ship owners must adopt ways to control their SO_2 and CO_2 emission of their vessels. On the other hand, authorities such as classification societies must find effective ways to monitor ships' emissions and further ship owners' compliance.

Starting with emissions controlling a large amount of ship owners are already using emission gas control systems (EGCS), also known as scrubbers. Scrubber is a smart system that operates as catalyst in the exhaust plume of the ship, using sea water to "clean" the ship's gas emissions inside an absorber, right before they are released in the atmosphere. Scrubber is composed of many subsystems and panels. Most EGCS include control panels (main and remote), water monitoring system (inlet and outlet), gas monitoring system, piping system, absorber, pre-absorber, variable frequency drivers (VFD) and more. They also include a big number of other machines and devices such as water pumps to suck the sea water, actuators and valves, sealing air fans, gas probes, pressure transmitters, temperature transmitters, level switches, flowmeters, PH and PAH sensors, turbidity sensors and more. Through control panel the operator can start/stop scrubber, check alarms and perform several checks and functions. During scrubber's operation the desirable ratio of SO_2/CO_2, according to IMO, that is measured in the outlet of the absorber with the help of a gas probe, has to be equal or lower than 4.3 if ship is inside ECA zone and 21.7 if it is outside of ECA. There are several parameters that EGCS considers in order to act smart and spray through nozzles in the absorber the desirable sea water that will clean the emissions. SO_2/CO_2 ratio and PH indication in the outlet water monitoring system are two of them. Of course, a complex system like this uses many sensors and transmitters to ensure its normal operation and overall safety. Several data and log files are saved in main control panel that can be used by the authorities for inspection or other purposes of ship owner such as claim solving and service from scrubber's supplier.

Scrubber is an innovative smart system that is developed to serve green shipping and help ship owners to comply with the strict environmental regulations. Although some scrubber suppliers manufacture an integrated system, its digital, complex, and innovative nature often creates claims and gives hard time to crews and legal and technical departments of shipping companies. The need of further support, recording of parameters, evaluation of performance and effects on other machinery is inevitable to secure the normal operation of scrubber, ship's machinery, and regulatory compliance. It is amazing how the adoption of more specialized smart technologies can help to satisfy this need and further enable the adoption and use of the EGCS. METIS CYBERSPACE TECHNOLOGY SA, a Greek company that develops products that apply the technologies of the 4th industrial revolution in maritime transport, has developed a "Scrubber Monitoring module" that gives intelligent solutions to this problem. (METIS CYBERTECHNOLOGY, 2019) We will analyze more about METIS example in the next chapter.

On the other hand, emissions monitoring is also a big challenge for the corresponding authorities. Several high-tech solutions have been developed to help authorities effectively monitor ships' and fleets' emissions and check the regulatory compliance of ship owners. Two of the most interesting are the remote monitoring through optical measurements of ship's exhaust plume and the drones with built-in sensors.

Regarding the passive optical measurement system, solar light is reflected on the ocean and it is reflecting up into telescopes that are placed on an aircraft. Then the ratio of SO_2/CO_2 is measured. This method is already in use in EU. The second remarkable method is the use of “sniffers”. Sniffers are sensors that come in contact with the exhaust itself. These sensors can be mounted on drones under bridges. In Denmark and Germany sniffers are already installed under bridges to help with emissions monitoring. Also, EU authorities and ports such as Hong Kong port have started flying drones with sensors into ships’ exhaust plumes. Although drones have limitations when it comes to payload capability, the benefits of using them are many. They are cheaper to operate than conventional aircraft and can be of course operated remotely, even 50 kilometers away from targeted vessel. As drone flies over the ship’s exhaust plume it draws air over an array of specialized sensors. These unmanned aerial vehicles are equipped with gas analyzer that can study air samples and monitor the SO_2, CO_2 and NO_2 levels. Data transfer back to the shore-based offices is easy and instant, giving also available live video feed from the vessels. Finally, although their payload is limited, these drones can carry different kinds of sophisticated equipment to monitor and acquire valuable data from the ship. Unfortunately, till now these high-tech monitoring solutions cannot be used as evidence in legal cases and courts. The evidence that arise from these smart systems can be used only as indicators for authorities in order to target vessels for onboard check when they reach the port. This way Flag State can have a report of IMO Sulphur 2020 infringements. (Steve Roman, 2019)

5.3 Smart ports

As already presented in port ecosystem chapter, there is a variety of stakeholders, functions and activities that are directly or indirectly engaged with a port. The adoption of digitalization can assist in better operation of a port while untangling its complex nature. Environmental matters, administrative procedures, new generation of vessels and supply chain development drive the port ecosystem towards its digital transformation. The idea of the smart port is already adopted by many big ports around the world and the use of smart technologies that we already mentioned in this dissertation is an integral part of their transformation. Below there are presented briefly some trends in the smart port ecosystem:

Cloud: Ports have start using cloud technologies to enable real time exchange of data in a centralized and efficient way. Operations efficiency through these centralized systems that are developed is a top priority for port operators. These systems are called port single window systems and help ports to manage all data exchange and mandatory requirements regarding regulations and other declarations that involved parties input through a single entry. (United Nations Economic Commission for Europe, 2003)

Big Data: In many ports Big Data projects take place in order to exploit the large amount of data produced from everyday operations. This gives the ability to collect, correlate and translate information to monitor movement of ships, weather etc. and improve processes, security, and safety.

Internet of Things: Several ports have started IoT projects, launching IoT platforms that are enabled using sensors and RFID technology on port assets. This way they can monitor port operations and environment, track and improve processes and support decision making. As a result, they enhance their position compared with competitors, improve their performance, and stay safe and secure.

Automation: Automation in port operations and processes is an important factor for the improvement of port performance and efficiency. Innovations like automated gates, drones and automated crane systems are developed to boost port automation. Ports of Amsterdam and Rotterdam have already aerial and naval drones for maintenance, inspections, management of accidents, security etc.

Blockchain: The big number and variety of stakeholders that are related and engaged in the logistic chain of a port brings to the front the need for data trust and privacy. Malicious activities have increased and the adoption of high-tech is an effective way to protect port operations and the numerous interactions and transactions between the involved parties. Blockchain is a promising way to offer trust and privacy in port operations and processes using smart contracts. (Port of Antwerp, 2017)

Analytics and prediction with Artificial intelligence: In parallel with the above smart technology projects, artificial intelligence can strengthen the analysis of data collected and go much deeper, analyzing port operations and processes. The outcome can be a predictive model of the behavior and trend of port operations. Decision making can become much easier, accidents avoidance is further improved and several parameters that affect port operations' efficiency can be controlled effectively. For example, AI can forecast the workload of port workers related to changes in port environment and operations, such as weather, ship arrivals, cargo loading etc.

Cybersecurity: Of course, the smart trend of Cybersecurity cannot be excluded when adoption of digitalization in ports is discussed. All the above-mentioned technologies place IT and OT in the center of port operations. Cybersecurity is important for the continuity and sustainability of port operations. The only way to achieve these preferable conditions is with the corresponding policies and organizational and technical practices. The European Union Agency for Cybersecurity (ENISA) has proposed a list of measures and practices regarding the cyber-resilience of port ecosystem. (ENISA, 2019)

5.4 Autonomous ships

Due to the growing economic and environmental challenges of seaborne trade, many shipping stakeholders are trying to embrace technologies that offer autonomy in their operations. Autonomous ships are in the center of this technological spectrum making their benefits remarkable in the journey of digital transformation. The lately evolution of smart technologies and their combination such as maritime IoT and AI have increased the feasibility and potential economic viability of MASS (Maritime Autonomous Surface Ships) operations. Several projects of autonomous vessels have been launched globally. Finland, China, Japan, Israel, and Italy are some of the countries that MASS projects take place.

In Finland, Rolls Royce develops an autonomous vessel of 60m that will be able to operate for over 100 days. This ship will be able to perform several tasks such as cargo transfer, patrol and surveillance, mine detection and coastline patrol. Also, this autonomous vessel will be able to detect, identify and track objects that it could encounter at sea. This function will be feasible due to the collaboration of Rolls Royce with Google Cloud. The Google Cloud Machine Learning Engine will train Rolls Royce's AI-based object classification system. (Rolls Royce, 2017)

Figure 10. The Autonomous Ship-
Source: Rolls Royce

MASS is a new maritime technology, for some promised to disrupt the shipping industry. IMO is called to examine this innovation in terms of safety, security, and environmental compatibility. For this reason, the Maritime Safety Committee (MSC), senior technical body of the IMO, created a framework for a regulatory scoping exercise regarding ongoing and new MASS projects. According to this framework MASS is a ship which to a varying degree, can operate independently of human interaction. The IMO's degrees of autonomy for MASS can be found in the Table 2 below. (IMO, 2020

Ship with automated processes and decision support	Seafarers are onboard to control and operate vessel’s systems and functions. Some operations are automated.
Remotely controlled ship with seafarers on board	The ship is controlled and operated from another location. Seafarers are onboard and available to control and operate ship’s systems and functions.
Remotely controlled ship without seafarers on board	The ship is controlled and operated from another location and there are no seafarers onboard.
Fully autonomous ship	The operating system of the ship can make decisions and determine actions by itself.

Table 2. IMO’s degrees of autonomy for MASS
Source: IMO

On the road to digital transformation and the vision of full autonomous ships, levels of autonomy are reached methodically through the corresponding contingency management and risk-based approach. As a result, operational models arise according to which unmanned and autonomous vessels can be controlled and operated by a shore control center if needed. MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) concept presents an operational model that is a great example for the above case. It is implemented on a dry bulk carrier which is operated by autonomous onboard navigation and lookout systems while it is monitored from a shore control center. Humans on the shore are not directly remote-control the entire operation of the vessel as in today’s operations. They only monitor the right execution and function of ship’s autonomous systems to implement the predefined voyage plan. Right below in Figure 11, MUNIN's operational model is presented. (MUNIN, 2016)

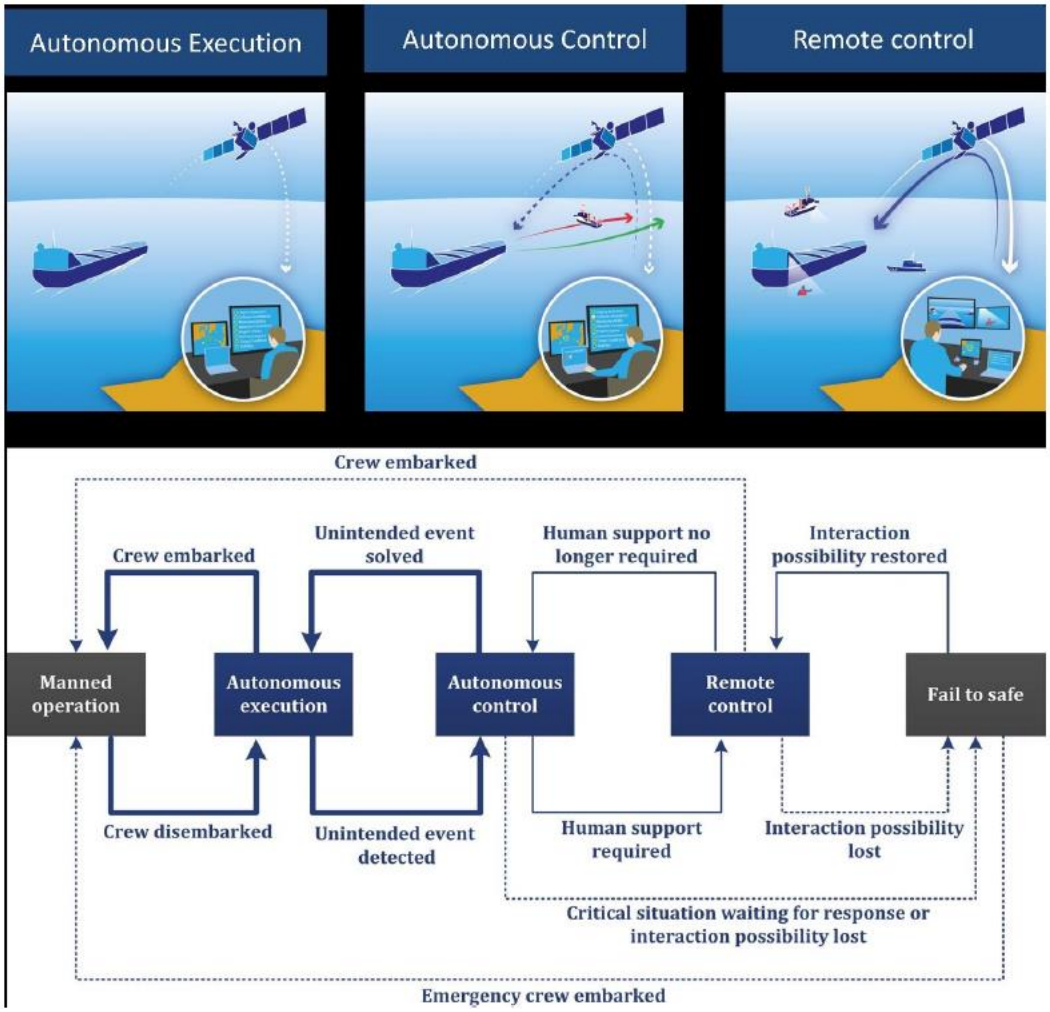


Figure 11. MUNIN operational model-
Source: Fraunhofer CML

It is a fact that the sector of autonomous ships and the greater spectrum of advanced technologies that are implemented in MASS can offer a great value in the overall shipping and logistics supply chain. Higher earnings, attractive payback, reduced risks, greater flexibility while adapting easier to market demands and significant emission reductions are some of the benefits that the adoption of autonomous ships can promise. Although there are a lot of issues that need clarification such as areas of usage, regulations and liability issues, autonomous vessels will be created, used and probably disrupt the shipping industry like nothing before.

6 Voyage Analysis-A performance monitoring solution by Metis Cybertechnology

6.1 Introduction to basic voyage analysis

Chapter 6 comes to conclude the two previous chapters, going deeper in vessel performance monitoring and optimization, analyzing a specific service that Metis Cyberspace Technology SA offers in the prism of the wide spectrum of company's service portfolio. This service is the "Voyage Analysis" integrated solution. For the purpose of our example it is essential to firstly set a definition of voyage analysis in shipping and how it was used to be implemented in the past years in shipping operations.

Voyage analysis is used to monitor and evaluate the performance of a vessel during a voyage. To achieve this, ship operators and engineers try to understand the impact of the different elements that affect vessel's performance, mainly regarding Fuel Oil consumption. Analyzing the deviation between expected and actual efficiency is the basic and most effective way to approach this problem. Identifying underperformance and the respective causes, helps decision makers to take the appropriate decisions and make corresponding actions to minimize performance loss. There are several variables that affect vessel's performance. They can be responsible for power losses and therefore an increase in FO consumption. Wind, wave, swell and rudder are external forces that are causes of power loss. Hull and propeller fouling is also a very important factor that is responsible for power losses of the vessel. We call these variables resistances. HP fouling resistance is the most important factor that affects negatively vessel's performance and can leverage costs regarding FO consumption, but in the same time it is something that could be monitored and fixed. As it is analyzed in the next paragraphs it is obvious that monitoring accurately FO consumption due to both HP fouling and external forces and get valuable insights from the respective estimations, is not an easy case. To further proceed with our example it is essential to explain how the main engine (M/E) performance curves are used to traditionally monitor vessel's performance.

6.2 Traditional performance monitoring

After the building of the ship is completed and before handing it over to the owners, sea trials are taking place to test that the ship is able to deliver the contractually guaranteed speed. The primary purpose of the sea trial is to determine the speed of the ship with reference to the RPM and the power produced for the same. Apart from the sea trial of the hull part of the ship, the important machinery of the engine room such as boilers, auxiliary engines and the main engine are also tested. Machineries have a test record apart from the sea trial data, which is done in the manufacturing plant and is called test bed data. This data pertaining to sea trials/machinery trials, shop trials/ test bed trials and the obtained performance curves enables the Chief Engineer to run the ship safely and economically. The main engine has to perform satisfactorily and give the rated power at the rated RPM within narrow but allowable limits of temperature and pressure and with correct specific fuel oil consumption (SFOC). In addition to all these the lubricating oil and cylinder oil consumption must be kept to minimum and the engine maintenance must be up-to-date to match the engine with the performance curves given in the shop trial. During the test bed or shop trial the performance curves of the engine are plotted. The performance curves are the graphs of different parameters on x-axis plotted against engine power or load on the y-axis. (Marine Insight, 2019) These main plotted curves are as follows:

- Engine RPM vs. Load
- Mean effective pressure vs. Load
- Maximum pressure vs. Load
- Compression pressure vs. Load
- Scavenge air pressure vs. Load
- Exhaust gas temperature in receiver vs. Load
- Exhaust gas temperature after exhaust valve vs. Load
- Exhaust gas temperature after turbocharger vs. Load
- Total excess air ratio vs. Load

- Specific fuel oil consumption vs. Load

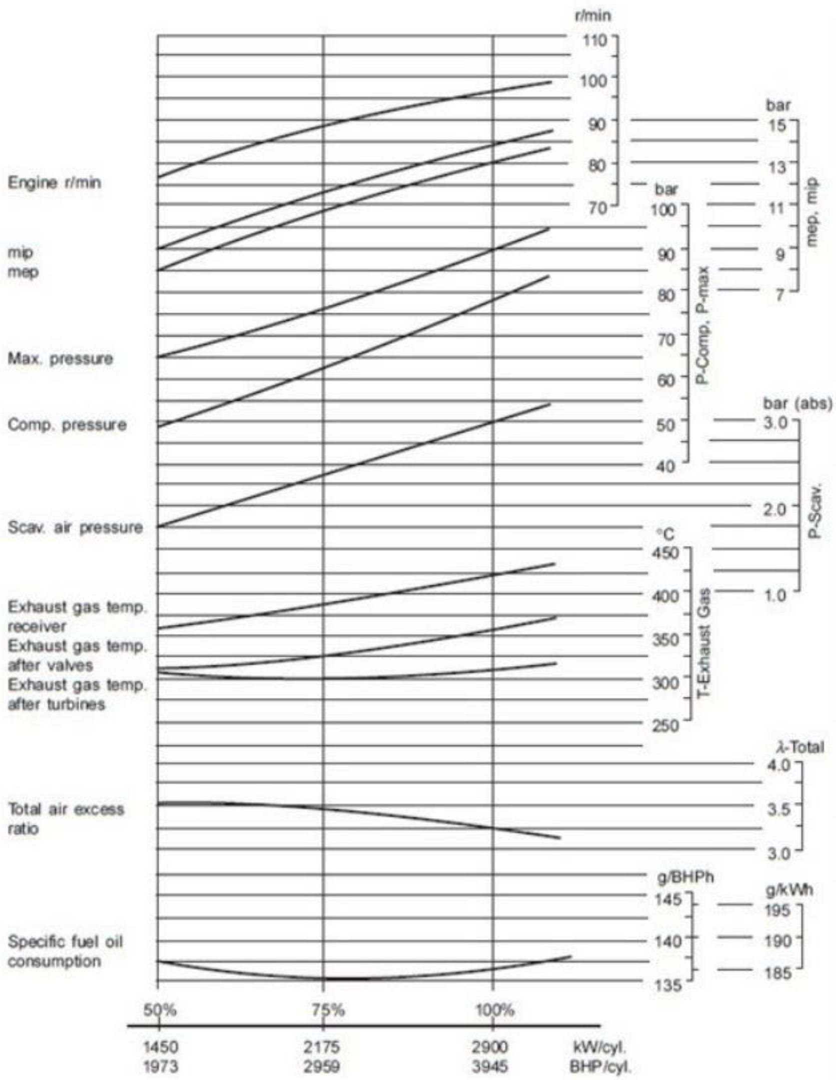


Figure 12. Performance curves from sea trials
Source: Marine Insights

During the lifetime of the ship the performance will decrease e.g. the fuel consumption will increase at a certain state or the speed will decrease at a certain power setting. This is mainly due to fouling of the hull and propeller. Traditionally the performance has been evaluated by rather simple procedures and empirical methods, where the daily fuel consumption has been reported in the "Noon Report" together with distance traveled over the last 24 hours, the corresponding average observed speed and a single weather observation. Performance reports are also used and are usually produced monthly. They contain information regarding the operation of the ship's main engine such as pressures, temperatures, turbocharger (T/C) speed etc. An empirical approach is used, calculating a theoretical propulsion power for the actual condition using standard empirical resistance and propulsion methods, according to which the measured parameters are imprinted on the sea trials performance curves and compared with them to find potential abnormalities. . (Benjamin Pjedsted Pedersen, Jan Larsen, 2008) Therefore the reasons of underperformance are further investigated. An example of the comparison in standard M/E loads is given in the figure below.

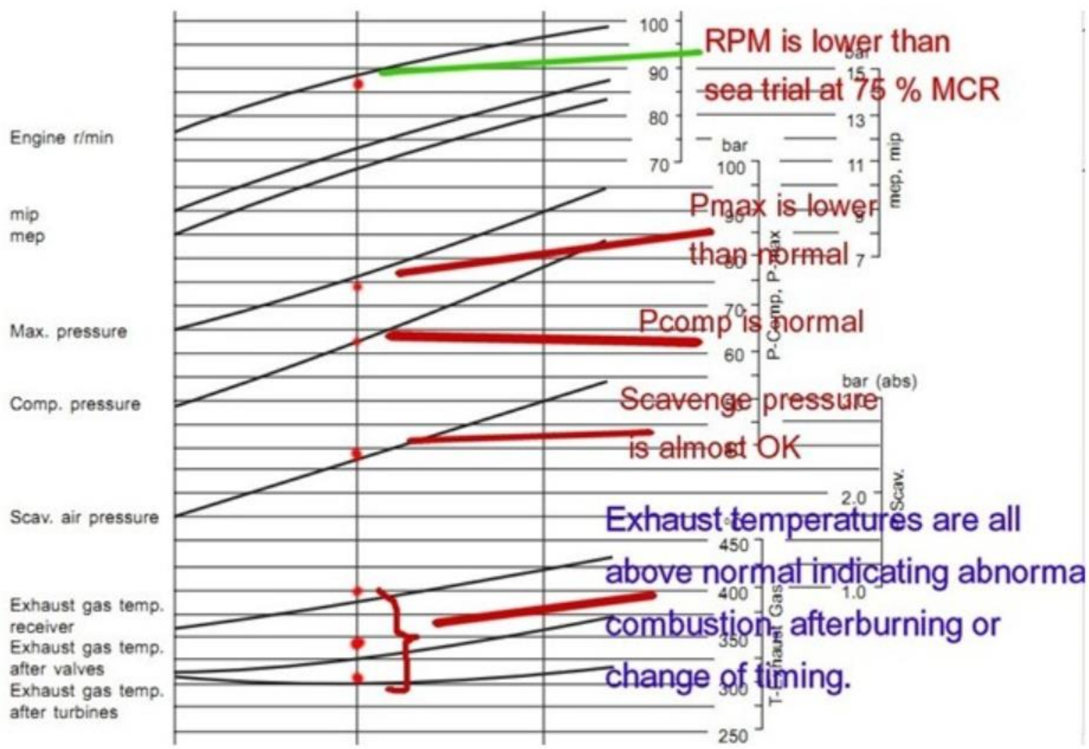


Figure 13. Comparison with performance curve of M/E
Source: Marine Insights

These methods give a limited number of observations since there is a maximum of 365 observations per year. (without subtracting days at port, maneuvering etc.). As it is easily obtained, to implement such methods the vessel has to be in the exact same situation more than ones in her lifetime. Since a ship is subjected to external factors such as wind, waves, shallow water and change in sea water temperature, this assumption is almost impossible. Also external factors can be difficult to measure accurately and thus the detection of a similar situation is problematic. As a result, the production of a single curve during sea trials is far from adequate for the entire ship's lifetime, and such a curve is truly theoretical rather than practical. In addition, the operators do not have an analytical and systematic method to come up with a more accurate, updated curve, which is applicable for aged ships, not only for new ones. (Nikolas Bialystocki, Dimitris Konovessis, 2016) Referring on the above methods, a high accurate estimation also for HP fouling, which is the main factor responsible for power losses and increased FO consumption, is not easily achieved. HP fouling cannot be measured by sensors, although it is possible to get indications by calculating the slip. This method does not give actionable insights of the fouling, thus operators and engineers cannot proceed to the antifouling actions. The fouling effect needs to be "isolated" to be distinguished. (Michael Foteinos, Efstratios Tzanos, Nikolaos Kyrtatos, 2017) To do this, resistance factors other than fouling should be calculated. The precise resistances' estimation and therefore a highly accurate power loss and FO consumption estimation demands more evolved, innovative and effective methods that will serve this purpose. The last years there have been many remarkable efforts to approach the above challenge, developing several models and using big data and statistical analysis. Metis Cybertechnology comes to face this challenge, also by exploiting and leveraging the power and capabilities of true artificial intelligence. One of the impressive outcomes of this disruptive approach is the Voyage Analysis service that will be analyzed.

6.3 ISO19030

Having set the difficulties for FO consumption monitoring, it is important to mention that the need for a common ground for hull and propeller estimation resulted in the generation of the standard ISO19030. This standard establishes general principles for the measurement of HP performance (including sensor requirements) and settles a set of performance indicators for hull and propeller maintenance, repairs and retrofit activities. (ISO, 2016) The performance indicators are the following:

In service performance: This indicator is related to the average change in hull and propeller fouling during the dry-docking intervals and it is useful for estimating the effectiveness of the underwater hull and propeller solutions i.e. the coating system that is used.

Dry docking performance: This indicator provides information on the effectiveness of the present out-docking by comparing the average performance with previous out-dockings.

Maintenance trigger: With this indicator the estimation of the appropriate time for hull and propeller maintenance is approximated easier. To achieve this, the performance of hull and propeller at the start of a dry-docking interval is compared with a moving average at reference point in time.

Maintenance effect: This indicator is used to measure the effectiveness of the maintenance of hull and propeller. To achieve this a comparison between the HP performance before and after the event takes place. (Metis Cybertechnology, 2019)

The general principles and performance indicators that ISO 19030 sets are applicable to all ship types driven by conventional fixed pitch propellers, where the target is the comparison of HP performance of the same vessel to herself over time. (ISO, 2016)

6.4 Voyage Analysis – A module of Metis Space

In this subchapter we are going to analyze the Voyage Analysis service by Metis Cybertechnology. Firstly, a small introduction of the company will be made and its role in shipping industry will be presented. Furthermore, chapter continues with the applied technologies that Metis has utilized for the commercialization of its products in order to understand the architecture behind Voyage Analysis. The main part comes for the analysis of the specific service, giving attention to estimation of FO consumption due to HP fouling and to user experience. The analysis concludes with an overview of the unique value proposition of Voyage analysis and suggestions of future research. (Metis Cybertechnology, 2020)

6.4.1 The role of Metis in shipping industry

Metis Cyberspace Technology specializes in the development of innovative solutions that empower shipping companies towards their journey to digital transformation. As long as the transition to smart shipping is a necessity for the sustainable evolution of maritime, Metis role is to ensure the success of this change in shipping companies, while minimizing the transition time period, the risk of investment and leveraging benefits to the maximum. Metis exploits the power of Artificial Intelligence and Machine Learning to provide Metis Space, a cloud-based system designed and developed according to the principles of Cloud Computing and microservice programming. In Metis Space, users get in touch with the system and they can extract advanced insights and intelligence using the different modules (i.e. Voyage Analysis) that Metis provides. This way employees and executives of shipping companies are able to perform their everyday tasks and plan upcoming events, diagnose problems, resolve issues and make good decisions. Adopting and using Metis Space helps shipping companies to achieve operational efficiency, optimize FO consumption, enhance planned maintenance processes and ensure regulatory compliance while managing environmental footprints, charter party agreements and claims. (Metis Cybertechnology, 2020)

6.4.2 The network architecture of Metis Space

Voyage Analysis module is offered as a service inside Metis Space. Before we go deeper in the specific module analysis we consider important to explain how Metis Space is built and analyze the network architecture behind it.

Metis Space consists of two systems that can be operated independently of each other. This offers great flexibility to the users, making possible the adoption of the microservices that best match the specific needs of them. On the one hand there is the onboard system that is developed for data acquisition and support of the crew onboard, called METIS Ship Connect (MSC). On the other hand we have the cloud analysis system for the implementation of the services that the platform offers.

Metis Ship Connect (MSC): The main key behind MSC are the Wireless Intelligent Collectors (WIC) of Metis. WIC are smart IoT devices that collect all data from several equipment onboard (torque meters, flow meters, AMS), offering interconnection with any device of any maker. WIC is able to support several operations like the pre-processing of data, the generation of synthetic data for real use case simulation and the logging of QoS parameters. WIC network is specialized in effective fetching, cleaning and storing data for a long period. In the figure below, the architecture of a WIC network installation onboard and the corresponding main functions that it offers are presented. (Metis Cybertechnology, 2020)

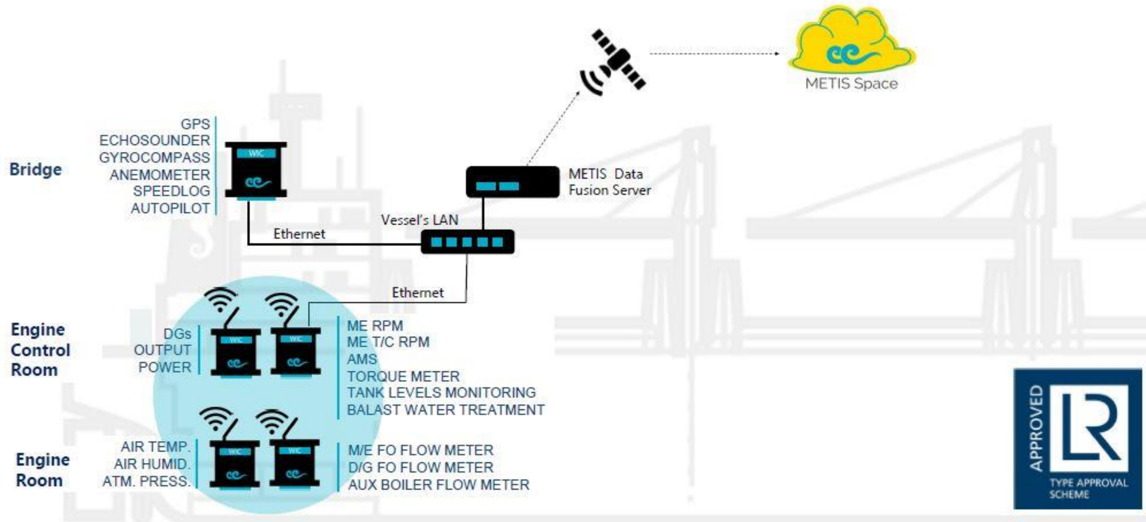


Figure 14. Architecture of a WIC network
Source: Metis Cybertechnology

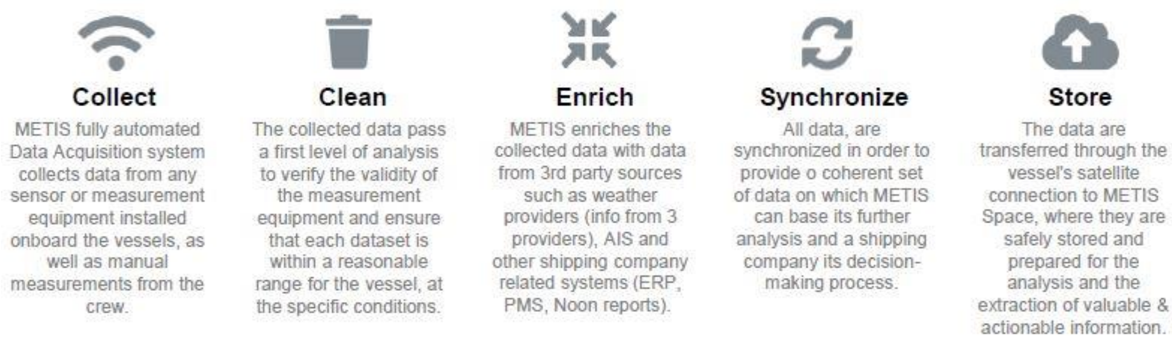


Figure 15. Main functions of WIC network
Source: Metis Cybertechnology

Briefly and comprehensively, MSC offers Data acquisition, advanced sensing, real time dashboards, manual reporting, interoperability with 3rd party systems or software and inspections and audits. Operational quality is accomplished through accurate error estimation and time-synchronization of measurements, data transformation and formatting (through edge computing), self-check monitoring, data backup, and remote programming and updating. Also additional sensors can be installed such as sensors for measuring pitch and roll, sound sensors, power analyzers, vibration sensors enabling condition-based monitoring, weather sensors and more.

Cloud Analysis System

Gliding from MSC to the Cloud Analysis System (CAS), the six layers that the microservices of Metis Space are organized into the CAS are presented below.

Data Sources: These include all the microservices that transfer data from several sources in the Metis databases (DBs).

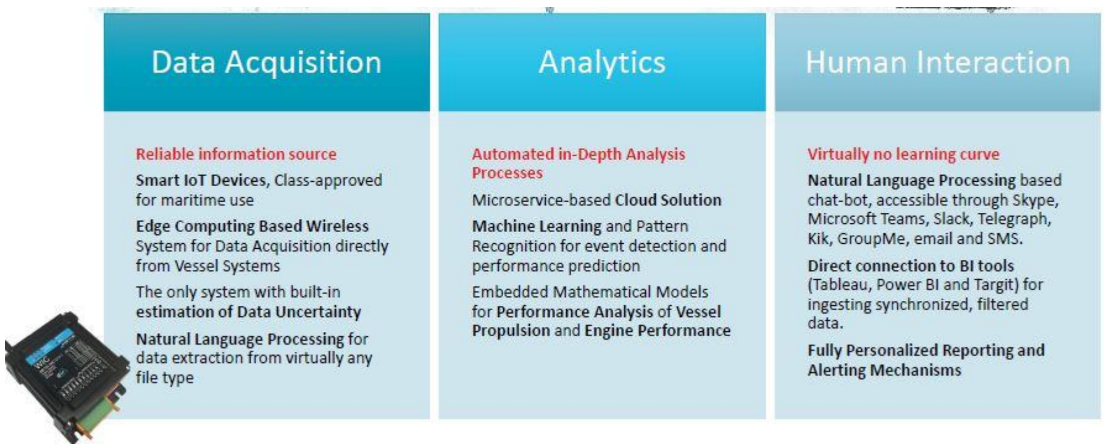
Data Processing and Storage: Parameters are calculated and synchronized by stream-processing engine that work in parallel. After the filtering, data are stored in NoSQL databases for analysis. Also GIS servers are used to provide location-based services for vessels.

Analysis Engines and Artificial Intelligence: This main layer of CAS is comprehended of various computational engines. Their purpose is to make statistical analysis an effective, accurate procedure. They achieve it by running models for physical parameters and fluid dynamics, visualizing data and modeling and enabling incident detection. The capabilities are leveraged to maximum with the use of Machine Learning for robust parameter estimation and specialized AI-driven root cause analysis.

Services: Domain information, their aggregation, formation and presentation is implemented by the microservices of this specific layer. Depending on the nature of the analysis that is required microservices are organized in special purpose Virtual Agents. Examples include weather Agent, M/E agent, Hull Agent and FO Agent.

Human interaction: The user interface of Metis Space is built with the principles of Natural Language Processing. This offers minimization of time that is required for easy usage of the interface and the corresponding training. All the accessible services that are provided by the Agents are provided through messaging channels (i.e. Skype, email, Team etc.). Application connectors are also employed for the choice to use Business Intelligence tool for several analyses. Lastly, reports and alerts that match the preferences and requirements of the users are easily assembled and sent by Metis. (Metis Cybertechnology, 2019)

Closing with Metis Space we will use a comprehensive table and an analytical figure, both from a white paper (Metis Service Packages) of Mr. Serafeif Katsikas, CTO of Metis, to comprise and visualize all the aforementioned. It is essential to have an overview of how Metis combines and exploits these new age technologies, so we can continue with deeper analysis of Voyage Analysis module. (Serafeim Katsikas, n.d.)



Data Acquisition	Analytics	Human Interaction
Reliable information source **Smart IoT Devices**, Class-approved for maritime use **Edge Computing Based Wireless** System for Data Acquisition directly from Vessel Systems The only system with built-in **estimation of Data Uncertainty** **Natural Language Processing** for data extraction from virtually any file type	Automated in-Depth Analysis Processes Microservice-based **Cloud Solution** **Machine Learning** and Pattern Recognition for event detection and performance prediction Embedded Mathematical Models for **Performance Analysis** of **Vessel Propulsion** and **Engine Performance**	Virtually no learning curve **Natural Language Processing** based chat-bot, accessible through Skype, Microsoft Teams, Slack, Telegraph, Kik, GroupMe, email and SMS. **Direct connection to BI tools** (Tableau, Power BI and Targit) for ingesting synchronized, filtered data. **Fully Personalized Reporting and Alerting Mechanisms**

Table 3- End to End IoT solution by Metis- Source: Metis Service Packages

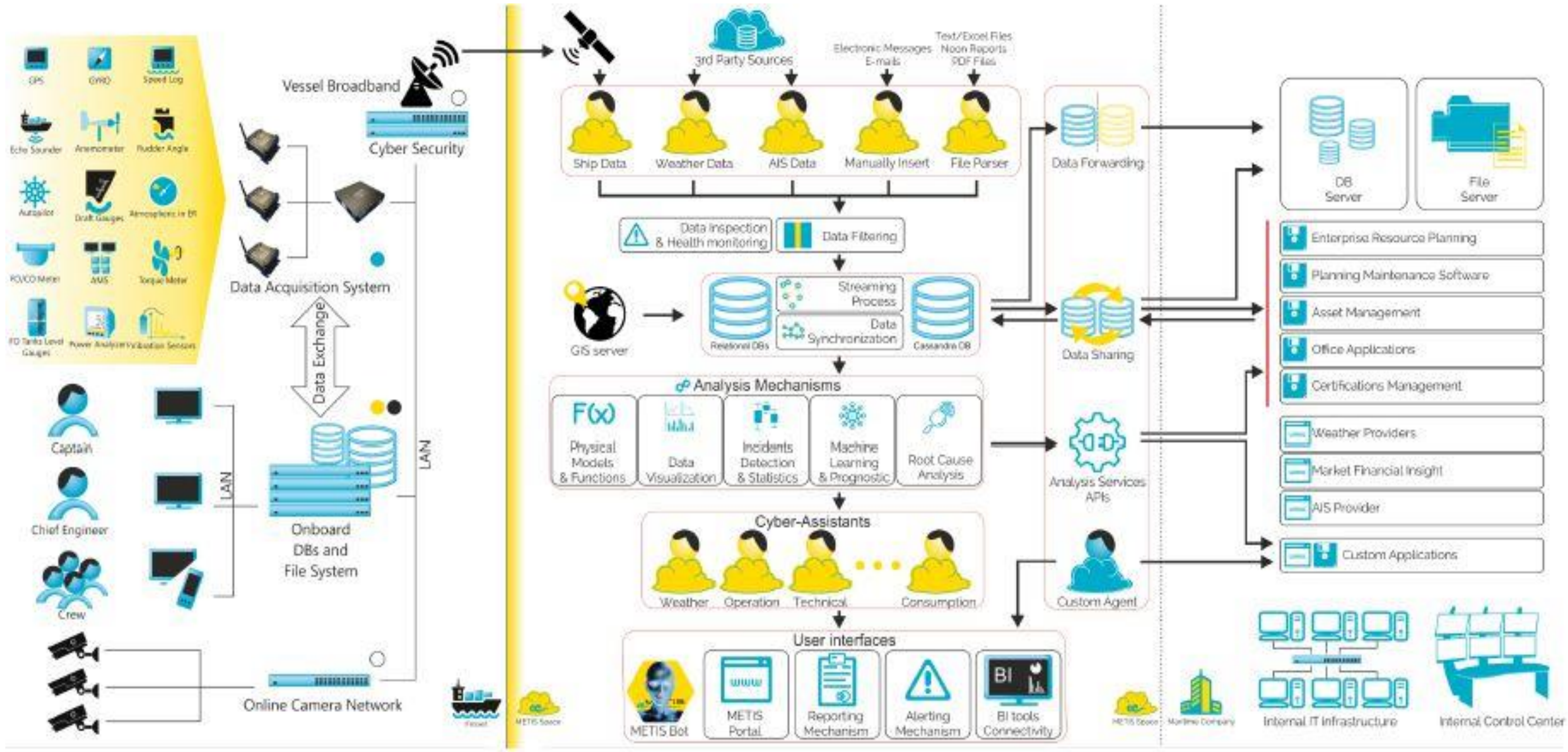


Figure 16. Metis Space Network Architecture
Source: Metis Service Packages white paper

6.4.3 The unique value proposition of Voyage Analysis

Voyage Analysis is a service offered by Metis through Metis Space and consists of import of data, analysis, evaluation and planning. Metis imports automatically all the information that are related to past or ongoing voyages through the Interconnection with the ERPs and other systems such as email. With the provision of detailed metrics and KPIs by the system, shipping company executives can evaluate the performance of each voyage/trip/leg, identify areas of underperformance, perform route cause analysis and understand the reasons of underperformance, quantify the effect of it and make the best decisions that are based on valuable data to optimize vessel's operation. (Metis Cybertechnology, 2020) The metrics and KPIs that Metis provides for Voyage Analysis, some of which will be further analyzed in this chapter, are the following:

- Sailing time
- Distance between successive ports and vessels' route
- Speed
- Weather conditions
- Power analysis (mainly M/E and Hull & Propeller Conditions)
- Fuel Oil Consumption

Below it is presented a crop from Voyage Analysis report in order to have a clearer view of which and how KPIs and parameters are provided to the user. (Serafeim Katsikas, n.d)

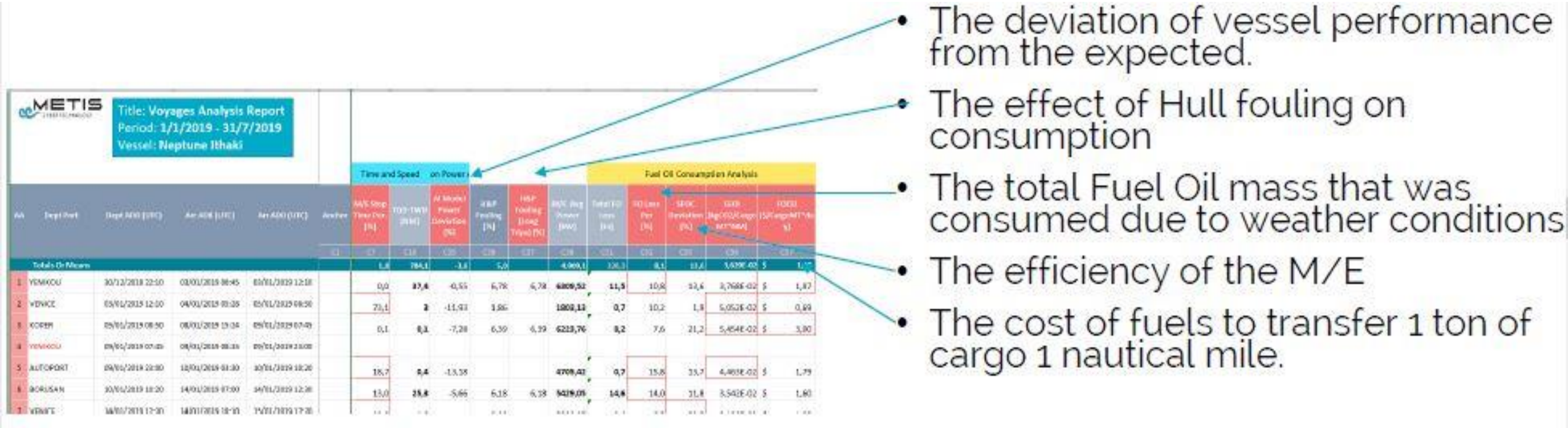


Figure 17. Voyage Analysis report Source: METIS Service Packages white paper

As it is observed in the above figure Metis quantifies all the elements that affect FO consumption, the factor that indicates the levels of performance of the vessel. It is already mentioned that the measuring of power losses due to HP fouling and external factors resistances is a big challenge for the specialists and at the same time a necessity for high reliable performance monitoring. In this case study is will be explained how Metis gives highly accurate estimation of these elements and succeeds in performance evaluation.

6.4.4 An overview of basic calculations

The collected data from MSC provide to the system all the valuable information to perform calculations according to standard ISO19030 in order to make the estimations due to external factors (waves, swell, wind, rudder, etc.). Thus, given the vessel propulsion input each time, which is the most important parameter for HP fouling estimation, the user can benefit the output of power loss due to hull and propeller fouling. Although it is impossible to measure the HP fouling, it is estimated by calculating the resistances that determine the movement of the vessel. Propulsion resistance, wind resistance, wave resistance, swell resistance and rudder resistance. To calculate the above, data from loading and weather conditions, vessel structure and navigational conditions are used. The sequence that analysis follows starts from energy space, continues with power space and forces space and finishes with the calculations of the actual work and power losses.

Hull and Propeller fouling percentage

Hull and propeller fouling power losses estimation is based on ISO19030. To calculate the HP fouling percentage, we subtract from the resistance of vessel's propulsion (F_{prop}) the resistances (calm water resistance, wind, wave, swell, and rudder) that act on the longitudinal axis of the moving vessel and the change of speed (a_l) in the same axis and we divide the outcome with calm water resistance (R_{CW}). The final outcome multiplied by 100 gives the HP fouling percentage.

$$HP_{foul} = 100 \cdot \frac{F_{prop} - R_{CW} - R_{AL} - R_{WL} - R_{SL} - R_{RL} - a_l}{R_{CW}}$$

Calm water resistance could be measured from sea trial results, as depicted in the power versus speed curves, after correction of the various parameters such as the drift angle, the water temperature and water density.

All the analysis for HP fouling is run by metis in real time. The resistances and power losses are estimated and the results are presented in dashboards, reports, or messages from Metis Chabot using NLP. Below there is an example of some related dashboards provided by Metis.

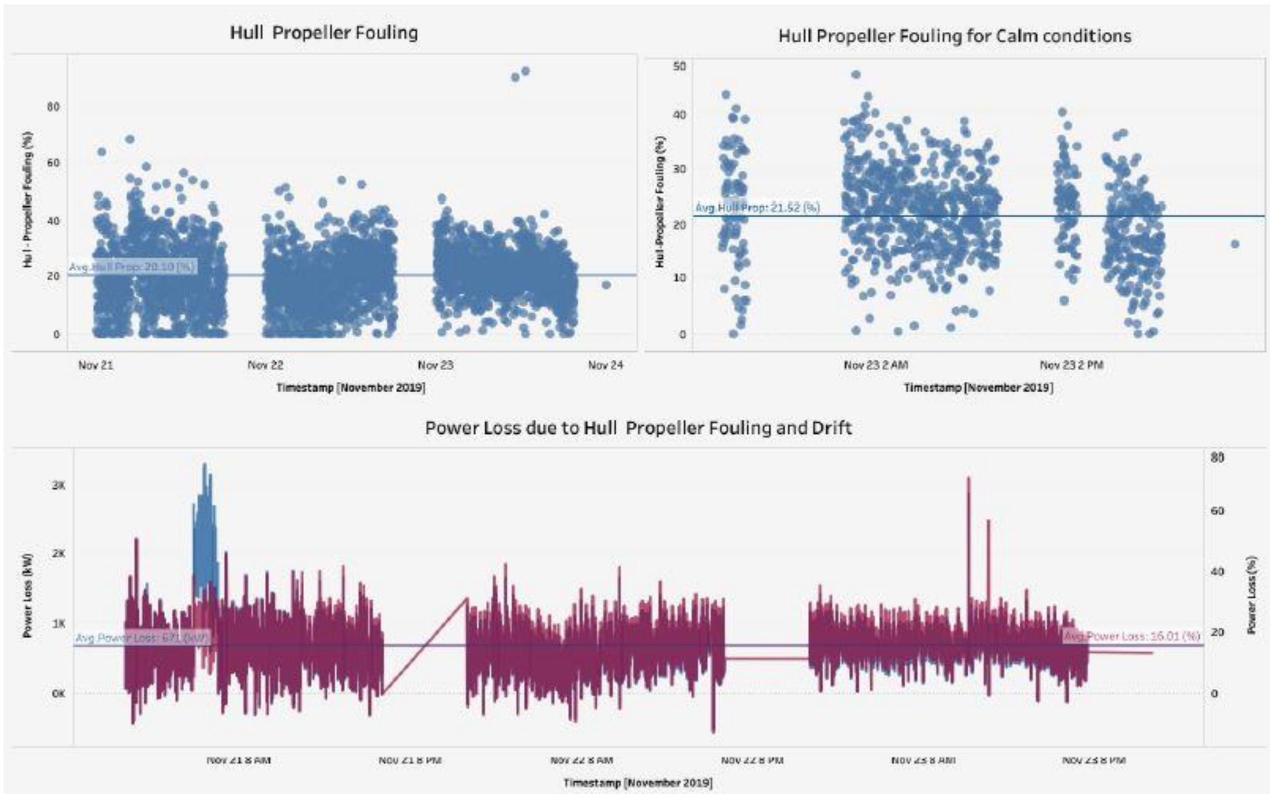


Figure 18. Dashboards providing by Metis HP fouling Mechanism
Source: Metis Cybertechnology

6.4.5 Utilizing Artificial Intelligence and Machine learning principles in the process

For successful power loss calculations and accurate monitoring of FO consumption and CO_2 emissions Metis has utilized the power of Machine Learning and Artificial Intelligence in the processing chain of HP fouling estimation. The purpose of applying the principles and technics of this high technologies is to increase the accuracy of the results, the sustainability of the services and the support of the high-end decision-making procedures. Of course, the physical models still play an integral part of the processing chain. With a brief explanation, ML models are applicable in:

- Detection of anomalies on measurements
- Replacement of data with high level of uncertainty and missing data
- The development of models regarding the relation of the propulsion power with the fuel oil consumption, considering the attrition of the related aged equipment, the operational efficiency of the equipment and change of the environment

The figure below presents the placement of the ML models in the HP fouling estimation process.

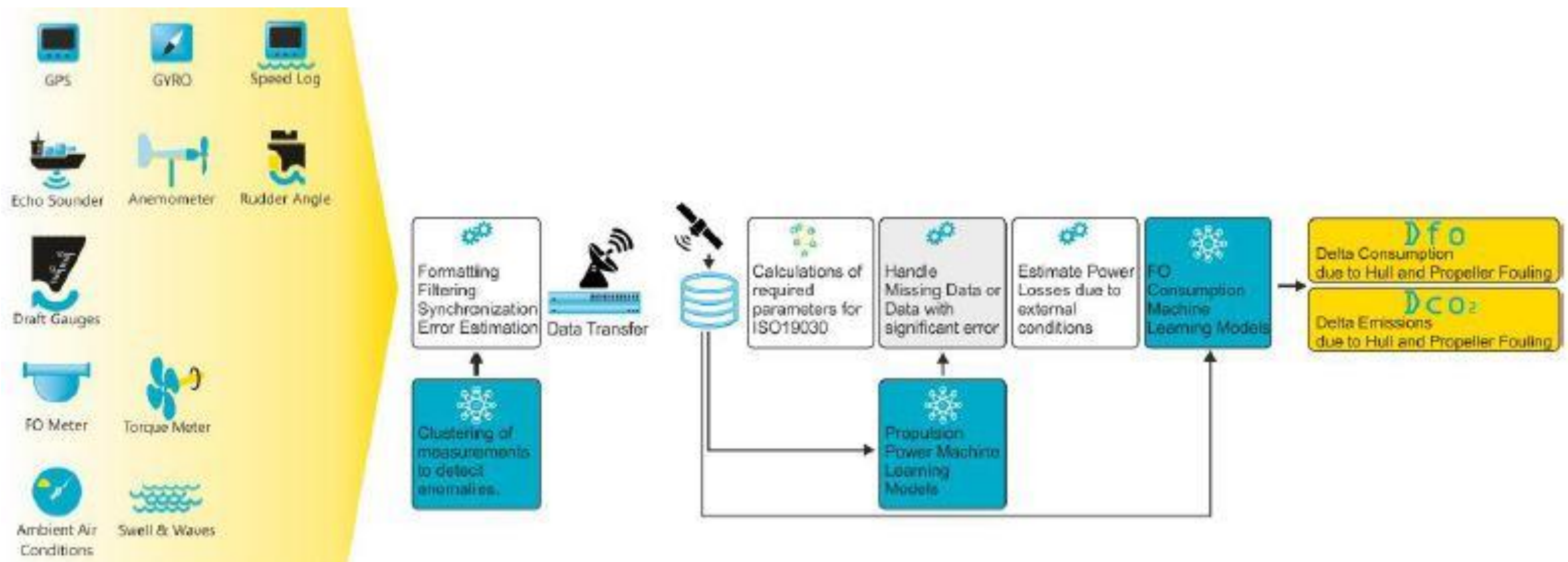


Figure 19. AI and ML steps in the Hull Fouling estimation process

Source: Metis

With the help of Metis executives, this thesis is able to provide an explanation of the complex ML models for Propulsion Power and FO Consumption. (Serafeim Katsikas, Georgios Manditsios, Dr. Sotiris Mallios, Ioannis Stratakos, Isaias Vrakidis, Georgios Gousios, Panagiotis Goulas, n.d.)

Propulsion Power ML Model:

The suggested method for measuring the propulsion power is either with a torque meter on the shaft of propeller or by recording continuously the pressure on the cylinders of the M/E. Although, there are high possibilities to lose data or get data with poor quality due to uncalibrated sensors. To overcome these issues Metis develops Propulsion Power ML models for vessels using data of navigational and weather conditions and measurements of the propeller shaft power. For the performing of regression analysis several algorithms may be used in the ML model such as K-nearest neighbors, artificial neural networks, deep neural networks, linear regression, as well as combinations of methods.

In the plot below we will see an example of a visualization of a polynomial regression model for Shaft Power under specific ranges of each ML model’s parameter. The inputs that are used are propeller RPM, wave and swell significant height, wind true speed and angle and hull draft. The selection of these parameters is customized for this specific vessel, while several other ML models have been evaluated to result in the aforementioned set. For the minimization of distance between the sample point and the fitted polynomial line a second order degree polynomial is fitted to past data.

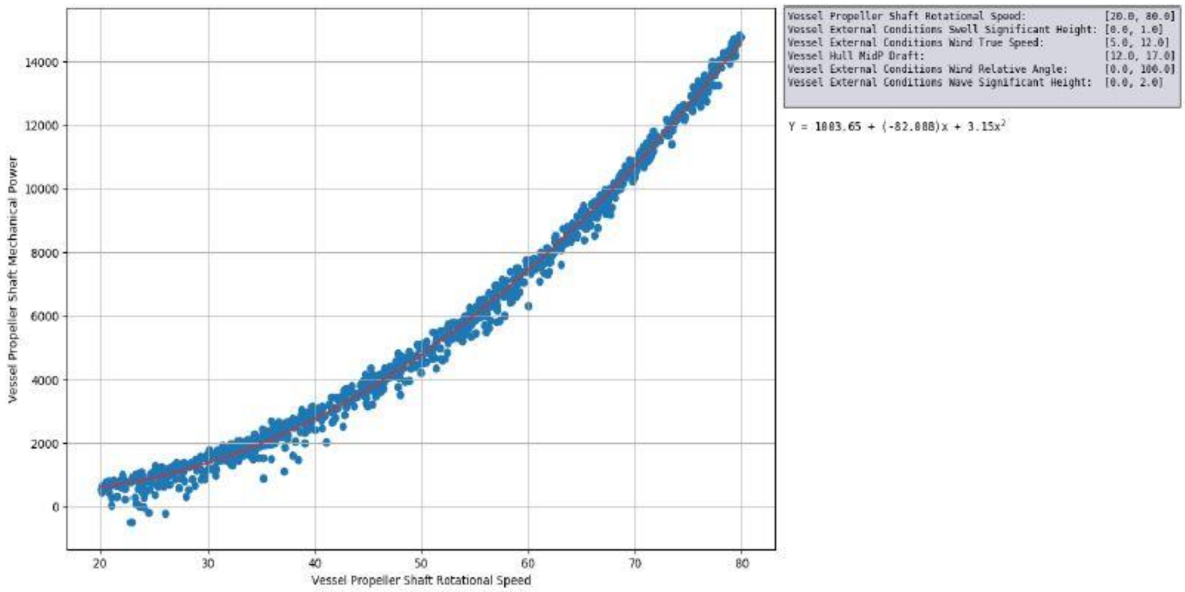


Figure 20. Visualization of ML model for shaft power under specific ranges for each parameter
Source: Metis Cybertechnology

Considering the information given by Metis executives this model was trained with data of two months period and the mean error of the model is less than 1.6 %. As we understand this is a great achievement. On the same context the output values of the model (estimated) are plotted against the measurement of the torque meter for a 15 days period and are presented in the following graph.

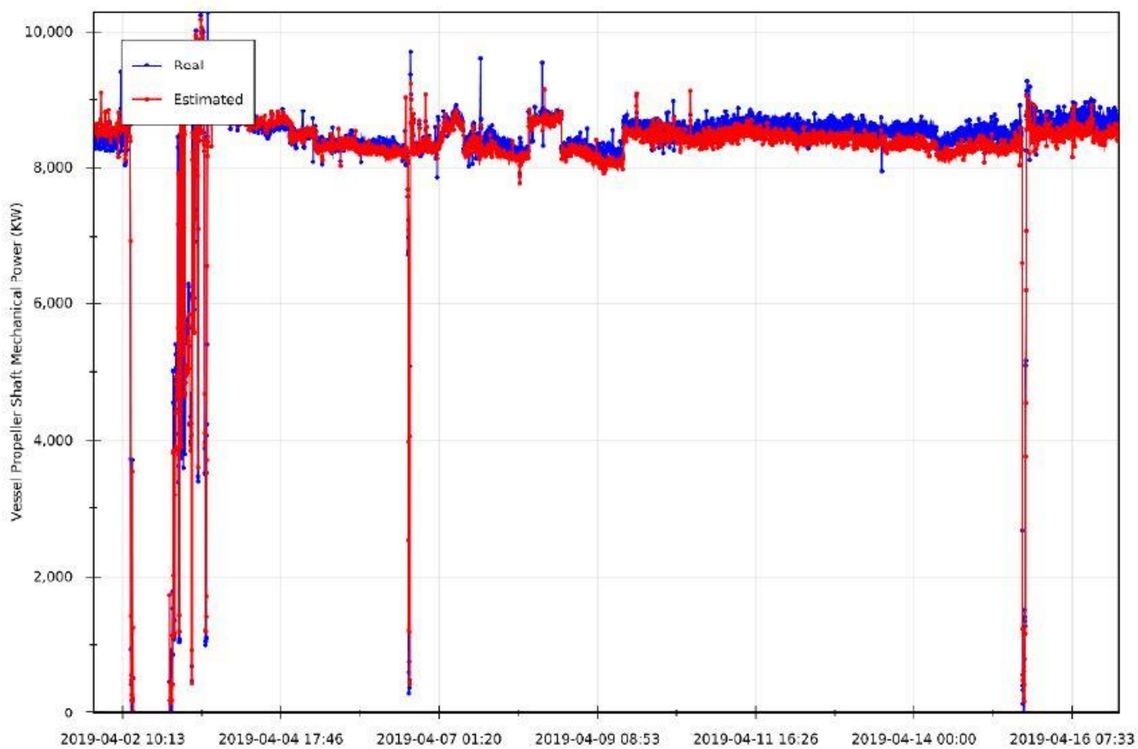


Figure 21. Estimated Shaft Power using ML model against the actual measurements of the torque meter
Source: Metis Cybertechnology

The model is retrained automatically every month and the mean error is estimated also automatically once per week. In case these models are missing data, the analysis service addresses to the model which in turn fills the gaps.

In addition, these ML models are used to understand the effect that several parameters have on the propulsion power. Through the user interface, the user can input various ranges of specific parameters and have a visualization of polynomial functions that combine for example the propeller shaft power with the shaft speed under various conditions (weather and navigational). Also highly accurate predictions can also be made with the use of the ML models. In the example below there is a crop from the user interface that the user inputs different parameters to get a specific visualization of the relation of Propulsion Power with Vessel Hull through water longitudinal speed.

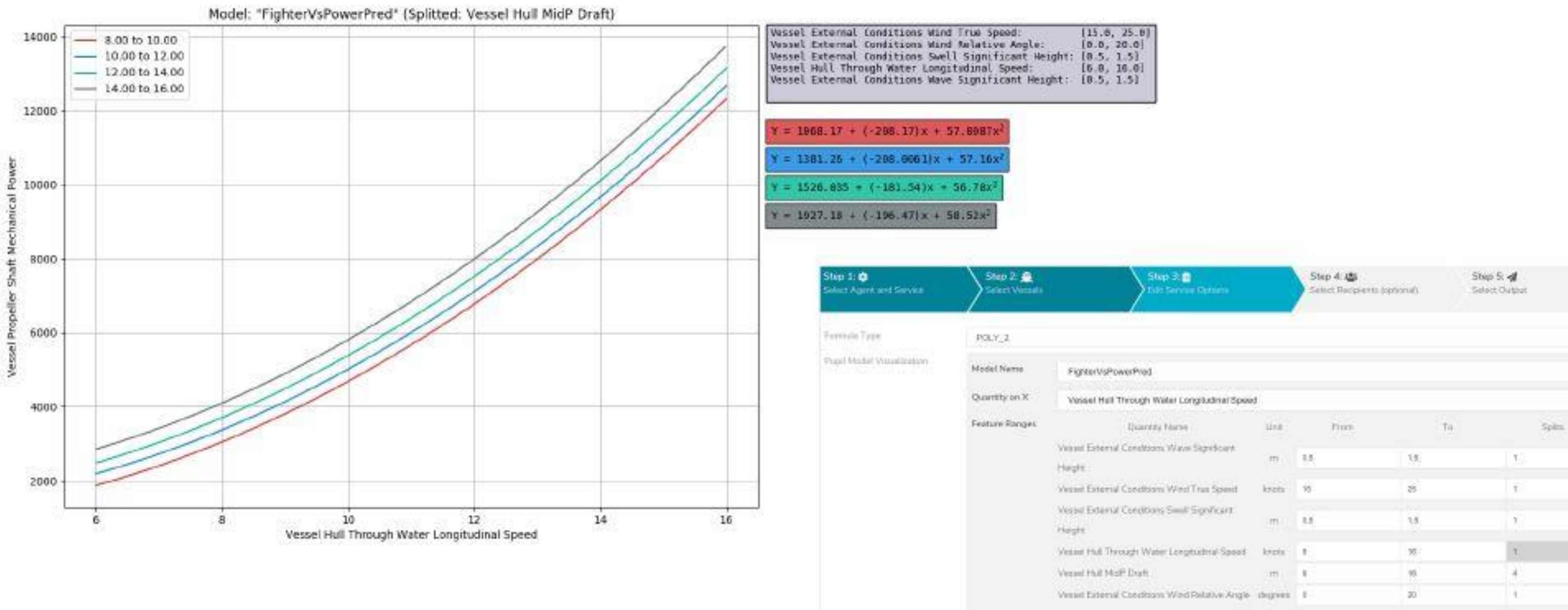


Figure 22. Prediction of vessel’s performance under any condition
Source: Metis Cybertechnology

Fuel Oil Consumption ML model

For the calculation of the effect that hull and propeller fouling has on FO consumption, Metis uses a ML model that is consistently retrained considering the shaft power, fuel oil calorific values, ambient temperature and sea water temperature. According to Metis this model can achieve accuracy of prediction higher than 97%.

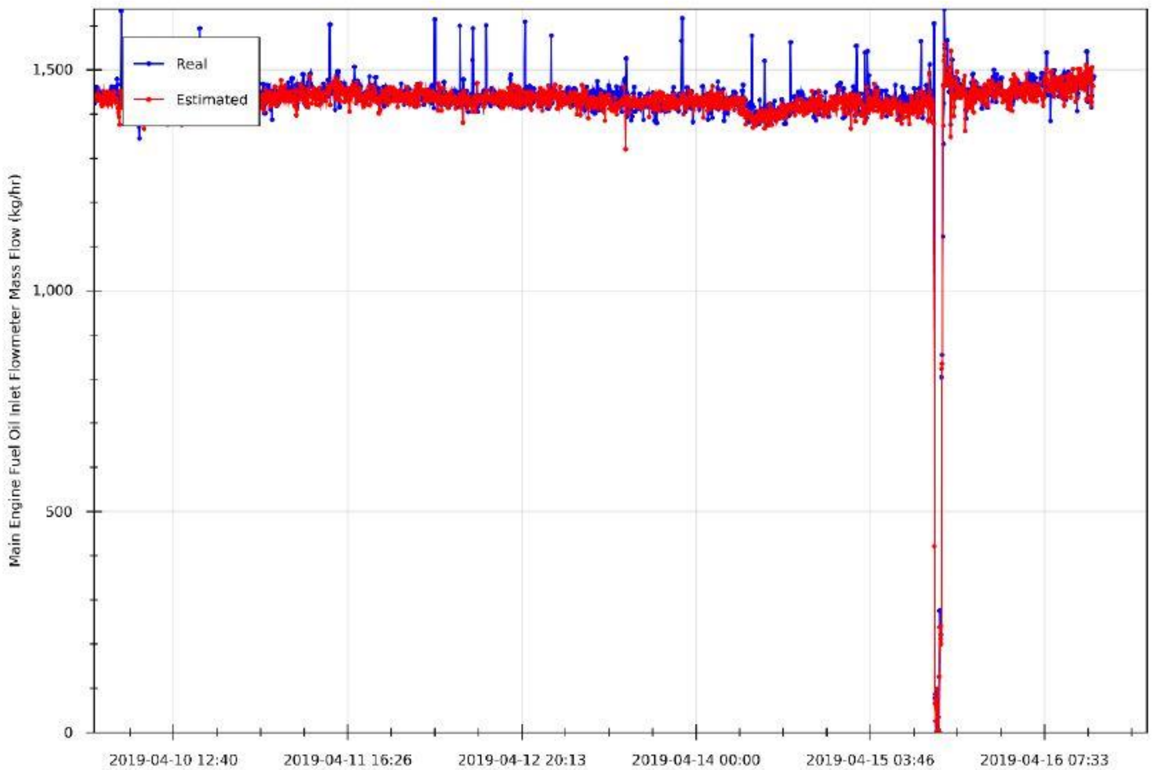


Figure 23. Estimated FO consumption on ML model
Source: Metis Cybertechnology

The HP fouling power losses can be converted into Fuel Oil losses using the ML model of FO consumption. At the example we will see below the power losses due to HP fouling are estimated with the mechanism that was presented in the start of this subchapter and with the help of the ML model that was created for this vessel. The additional fuel mass the was consumed by the vessel on account of the HP fouling is estimated by the difference of the FO consumption for the actual propulsion power and the theoretical propulsion power without the increase due to HP fouling. The following graphs give a clear view of the above.

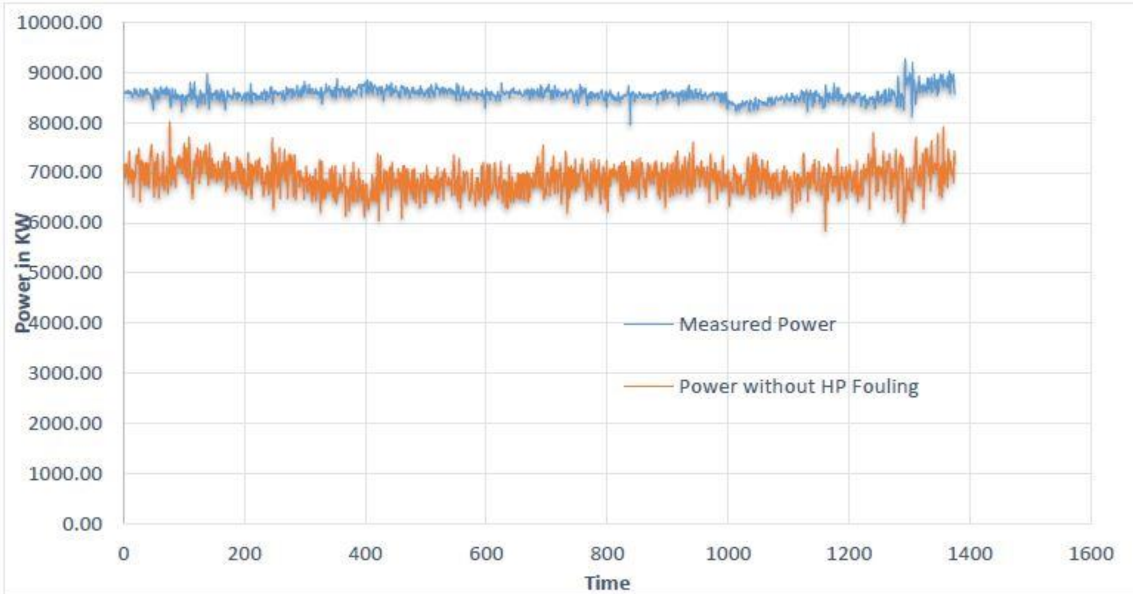


Figure 24. Propulsion Power and Propulsion Power without the HP fouling
Source: Metis Cybertechnology

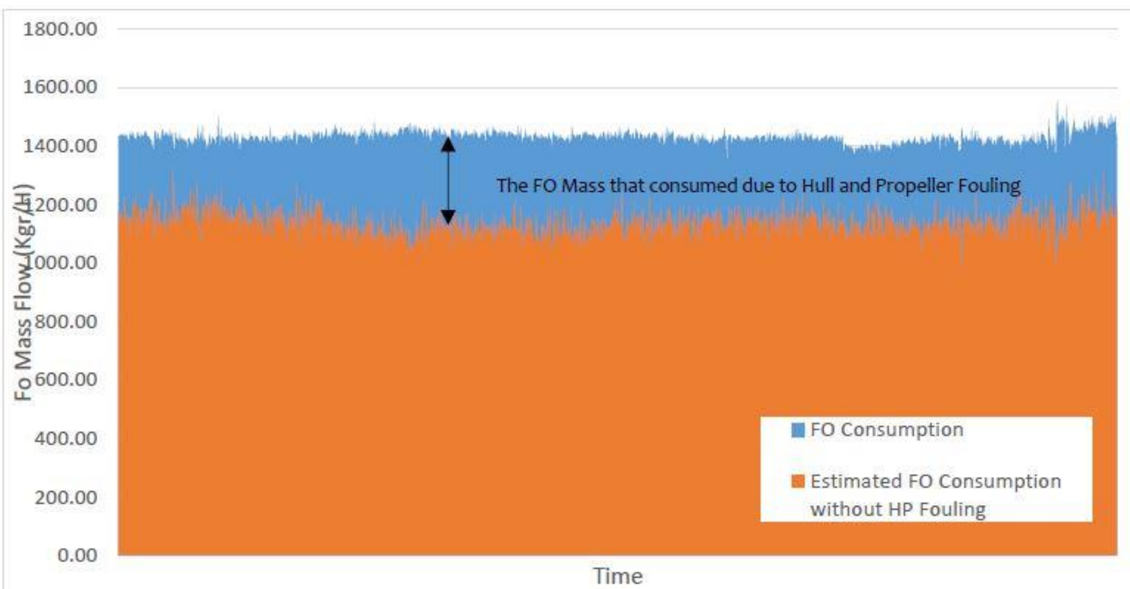


Figure 25. Fuel Oil Consumption against the estimated consumption without the propeller fouling
Source: Metis Cybertechnology

Metis's results in these cases give an estimation that the HP fouling in a sailing period of seven days is 24.77 %. This fouling caused an increase in Propulsion Power by 19.58 %. Due to this, HFO was in increased on an average of 297.19 kg/h. The total cost of the sailing period (7 days) was 49928.59 kg of HFO. This quantity is translated in 20575 $ with the current oil prices. We understand that this is a huge amount of money that burdens the shipping company. It is a fact that adopting and using the application of Metis Voyage Analysis can help decision makers take the appropriate decisions and proceed to the corresponding actions to prevent further loss and optimized the performance of the vessel.

6.4.6 Using the API of Voyage Analysis and interacting with Metis Virtual Personal Assistant

Voyage Analysis as well as any other service that Metis offers in Metis Space is enriched with Metis Virtual Personal Assistant. The human-centric approach of Metis regarding the effectiveness, convenience, immediacy and speed that the interaction between the platform and the user takes place is unique in the maritime industry.

The virtual personal assistant interacts with the users in English. Utilizing the capabilities of NLP and AI technologies Metis offers instant respond to any request of the users through the Chatbot. Users can receive any kind of information related to Voyage Analysis through their phones, web chat, Skype, email, etc. (Metis Cybertechnology,

2020)

Figure 26. Result of Power Analysis in message format
Source: Metis Cybertechnology

In the above figure we can see a request of the user in just a plain text message. Although a very comprehensive report in message format from Hull performance agent is presented, enriched with the available related attachments for download and graphs. This way of interaction with a digital shipping platform is quite disruptive in today's maritime business and a truly useful tool for any shipping company on any stage of adoption of digitalization.

Metis Cyber Personal Assistant comes to leverage the already super user-friendly and comprehensive Voyage Analysis interface. User has all the useful information that he/she needs in order to go over the voyage analysis of the preferable vessel with several filter applied if desired. A map with the routes and all the useful information regarding the specific voyage/trip/leg is on the main page. All the valuable information for each voyage is presented on a clear table in the middle of the interface related to operation, external conditions, power analysis, fuel oil consumption analysis and more. Access to graphs and dashboards is more than easy from the main interface page and the personal virtual assistant is always by user's side with a click on the corresponding text icon. (Metis Cybertechnology, 2020)

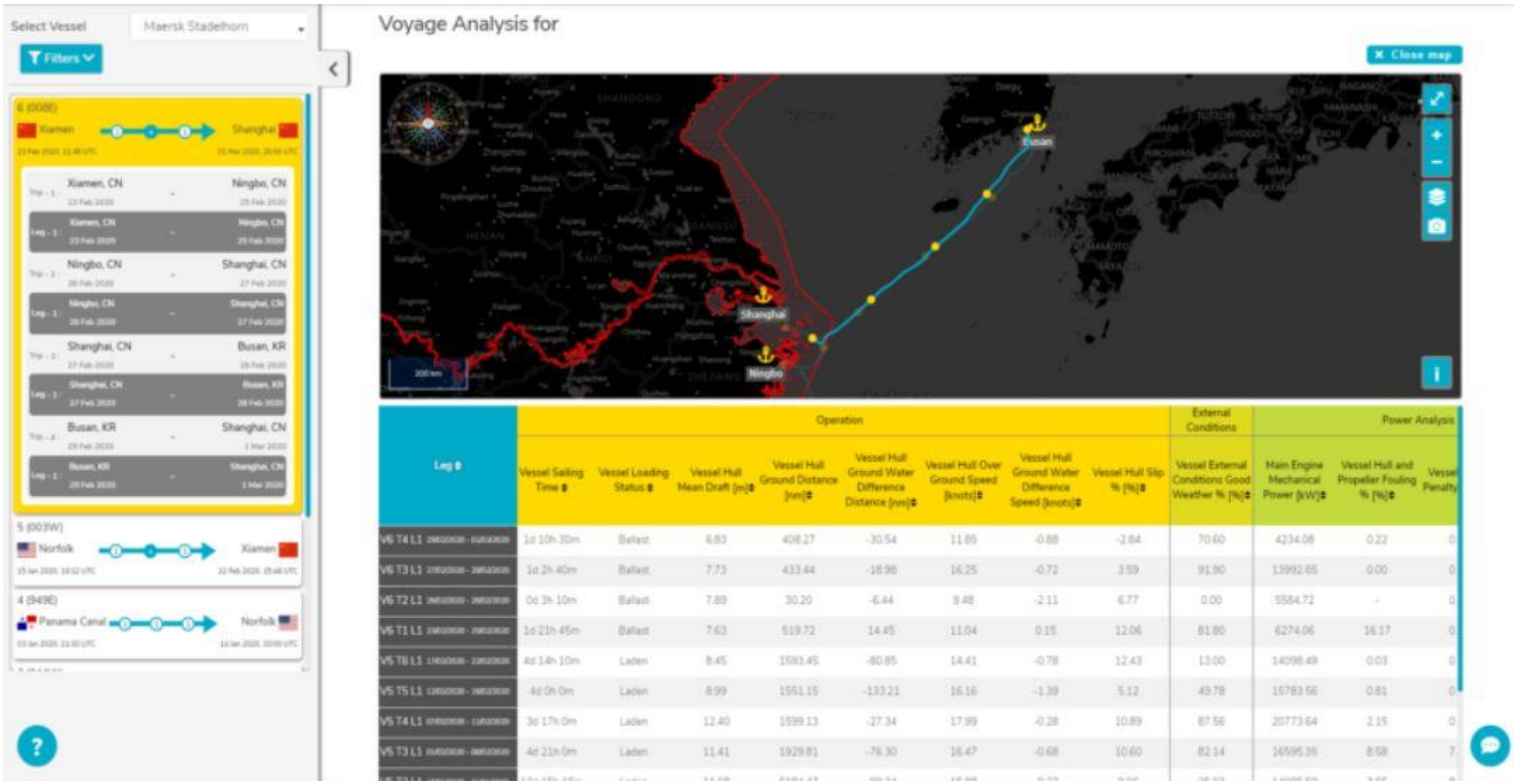


Figure 27. Interface of Voyage Analysis
Source: Metis Cybertechnology

6.4.7 Suggestions for future research

After the analysis of the Metis Voyage Analysis module and the deeper understanding of the general Metis Space infrastructure and capabilities, this subchapter tries to address a problem observed in shipping operations. Considering the high level of technological know-how and tech power of Metis it is believed that it may worth investigating it.

The problem:

When a spare part on the vessel needs replacement due to malfunction or damage, it takes valuable time for the spare part to arrive on board. This time is precious and can cost thousands of euros to a shipping company for several reasons such as non-compliance with environmental regulations and charter party agreement. Especially for newly adopted onboard systems the claims regarding replacement of equipment is quite big.

The solution:

Utilizing the power of intelligent collectors similar to Metis's WIC, smart sensors and Machine Learning, a Software As A Service could probably be developed that would use several parameters and models to offer a digital customized on board inventory solution that could help decision makers decide for the appropriate kind and number of spare parts that should be stored in the inventory of each specific vessel.

Suggested variables to consider for the development of the ML models:

- Details of failures (i.e. frequency of failure) and previous replacements of specific spare parts (pressure transmitters, flow meters, etc.) by the supplier and the ship owners
- The "criticality" of the failure of each spare part (how affects for the operation of the ship and what is the financial impact and risk for the Shipping company)
- Material failure (causality, correlations) and lifecycle of spare parts
- The number of each spare part that already exists on the installed systems

- Live and continuous updating of the status of the components of the systems of each vessel (if it is possible)
- The duration of the voyage
- The environmental conditions that vessel will face during each voyage and the upcoming strain of spare parts (i.e. bad weather, dirty waters)
- The technical and empirical knowledge of vessel's crew
- The possible human error. (crew training)

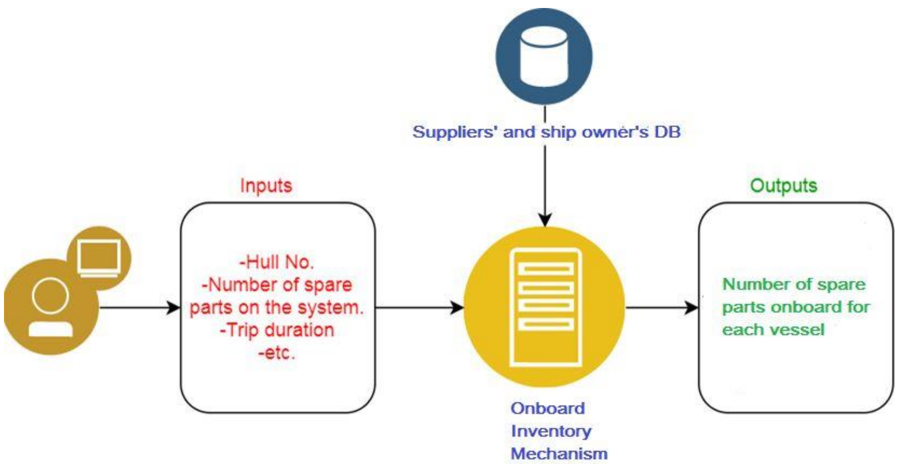


Figure 28. Onboard Inventory SaaS

7 Main drivers of the adoption of digitalization in shipping and challenges that rise from it

Having set the key challenges in shipping and analyzed the smart technologies and their applications in shipping industry it is essential to set the main drivers of adoption of digitalization and the key challenges that this adoption brings. The road to digital transformation is a long one, promising and same time challenging. New benefits and new challenges come on surface as technologies develop and applied in maritime sector. Regarding this, observation, agility, and adaptability are important in this fast-paced environment. In this chapter we will sum up the main drivers for adoption of digitalization in shipping and set the challenges that this phenomenon creates.

7.1 Main drivers for adoption of digitalization in shipping

Drivers are factors that cause the phenomenon of digital transformation in shipping to develop. It is important to understand the reasons and motives based on which the stakeholders are encouraged to proceed to digital transformation of their organizations. Below the main drivers for adoption of digitalization are summed up and presented:

Regulatory compliance: Using smart technologies to control ship's emissions and systems' performance helps ship owners to comply with environmental and other kind of regulations and standardizations.

Meet customers' and business partners' expectations: Traceability and condition monitoring of freight and safety of cargo and transportations can be a reality with the use of smart technologies. Fast and effective communication with customers and 3rd party vendors is also a fact that shipping stakeholders can benefit from the adoption of digitalization. The "environmentally friendly" demand and the security between transactions and general interactions in shipping is also possible in the smart shipping ecosystem.

Cost efficiency: There is a big number of digital solutions that can improve cost efficiency in shipping. Accident preventing through safer shipping operations, predictive maintenance, and degrees of autonomy with PMS, automated processes and autonomous vessels are some of them. Also, the biggest cost of shipping operations, energy consumption, can be reduced dramatically with the implementation of fuel and emissions monitoring solutions.

Business models and strategic objectives fulfilled: Maritime organizations can develop E-platforms and advanced data analytics services. With cloud technologies and the acquisition of real time and historical data they can use and analyze the correct elements and parameters to transform them to usable knowledge and share it. They can be agile in terms of shipping operations and they can optimize the overall performance of their activities. They can evolve their business models or create new ones and satisfy their strategic objectives.

Digital solutions to deal with "unexpected events": From systems' malfunctions to unexpected factors that affect shipping personnel and crews, such as health problems, digital technologies offer a variety of solutions to continue shipping operations and their sustainability. Augmented Reality (AR) service support, remote working models and integrated human-friendly digital systems can support and maintain sustainability in maritime industry.

Competitive advantages: All these innovative systems and processes create a technology push force and big market pressure as more and more competitors adopt smart technologies in their shipping organizations. As a result, it is crucial for shipping stakeholders to pave the road to digital transformation in order to maintain competitive advantage and meet market standards on time.

Enhanced digital risk awareness: This fast pace digital era we experience opens gaps for risks. If an organization decides to go deeper in digital transformation, transparency is something that will benefit from. Understanding the potential risks that may affect an organizations security is a process that can take place easier and more effectively with the proper use of related technologies and practices. Risk management can hit a higher level of efficiency.

Boosting personnel training: Till today maritime training was taking place either on board, classrooms, or training sites. With digitalization, more and more web-based training courses have been developed, both in the form of synchronous and asynchronous learning. As a result, every individual in shipping industry can expand and enhance their knowledge around several topics, while boosting the business portfolio of the organization.

The need for digital talent: The big rise in number of digital innovations in shipping ecosystem has resulted in more and more digital talent that is willing and is able to engage and support shipping organizations in their digital transformation. These skilled people, according to PWC demand development opportunities within the organization they work for, to evolve their digital skills. (Ian Cornett, 2019)

7.2 Key challenges that rise from adoption of digitalization in shipping

The adoption of digitalization and the desired digital transformation can bring great rewards to shipping organizations. Although with great rewards risks come and challenges rise. It is important to identify these challenges to overcome threats related to the use of smart technologies and obstacles that appear during the digital transformation of shipping organizations. The key challenges that rise from adoption of digitalization in shipping are presented below.

New technologies-New threats: As already mentioned, the adoption of digitalization and the use of new technology brings new threats. Organized crime networks and new profit-driven groups can use new means in the cyber environment for the same malicious purposes. It is a fact that cyber threats have established their existence in the digital world. Shipping industry should maintain high priority for the minimization of these threats and the consistent enhancement of its cyber-resilience.

Resistance to change: Digitalization and digital transformation bring tremendous changes in the way shipping stakeholders operate and perform business. Shipping industry is considered a traditional industry in which changes are not easy to take place. Shipping stakeholders are content with the way changes effect processes and implement business models. Thus, coming up with ways to push and establish change in maritime is really important for the smooth digital transformation journey.

Lack of clear vision: It is observed that the clear vision of adoption of digitalization, which is based in understanding and embracing the value proposition of digital transformation, is in scarcity in shipping organizations. It is really important to have specific needs, expectations and awareness of the unique value propositions new technologies can bring. This way digitalization is adopted effectively and its exploitation becomes efficient throughout operation and business processes. This dissertation aims to offer a clearer digital vision regarding shipping industry.

Digital skills requirements: As technological innovations develop fast, a big demand for digital skills rises. Training methods should be created and adapted properly in order to catch up with the pace of smart technology development. Training is one of the most important factors for the successful adoption of digitalization in shipping.

New technology-New claims: As technology in shipping develops fast to leverage performance and regulations' compliance of shipping organizations, a big rise in claims regarding the innovative digital technologies is observed. Companies that develop and supply shipping organizations with digital solutions, especially the ones that are engaged with onboard smart technologies, sometimes face big claim demand in the early stages of commercialization and adoption of their products. There are many reasons this happens. Lack of effective claim management techniques, unsuccessful communication between stakeholders and a pour action plan regarding effective TRL (Technology Readiness Levels) completion could be some of them.

Phased approach implementation: In order to overcome challenges, the phased approach should be adopted by the organizations. This is a challenge itself as the traditional way of working in maritime is an obstacle for integration of new technologies, skills, cultures and mindsets in this not so "willing to change" industry. (LMA Smart shipping Course, 2020)

Analysis and exploitation of the large amount of data collected: Due to lack of skills, agile processes and knowledge management techniques, the huge amount of data collected during operations are not analyzed and shared properly to generate insight and valuable knowledge. Shipping companies overall, while implicating tradition management strategies, don't take advantage of the power of big data analytics, AI, and knowledge mobilization capabilities. This is a big challenge, connected directly with the aforementioned, that if it is overcame, it will truly enable the digital transformation of shipping.

Who to set regulatory framework and what regulations should be included?: IMO has set the regulatory framework for environmental and safety and security issues. Although, several stakeholders are not convinced that IMO is the appropriate instrument to take action regarding regulations for the adoption and use of the new smart technologies that are consistently introduced to shipping industry. Also, an important question is which and what kind of regulations should be created and applied to the smart maritime ecosystem. Ships cross many sea borders and shipping is incredibly international. From place to place, legal issues may vary. Considering the complexity, and variety of digital technologies and their implementations, setting the right regulatory framework and the best strategy to implement it, is a great challenge.

Increasing threat from early digital adopters: A variety of new entrants and start-ups adopt digital technologies to offer end to end solutions to customers. Most of them form an assetless or low-cost business model which gives them a great competitive advantage. Many of them recognize an opportunity and disrupt the industry. A remarkable example is Amazon who has developed an E-platform and operates as an assetless cargo forwarding company. Indeed, as we can see in Figure 29 more than 2900 billion dollars have been invested in E-Platforms comparing with a total of 3.3b $ that are invested in the whole digital start-up ecosystem from 2012 to 2017. (Camille Egloff, Ulrik Sanders, Konstantina Georgaki, Jens Riedl, 2018)

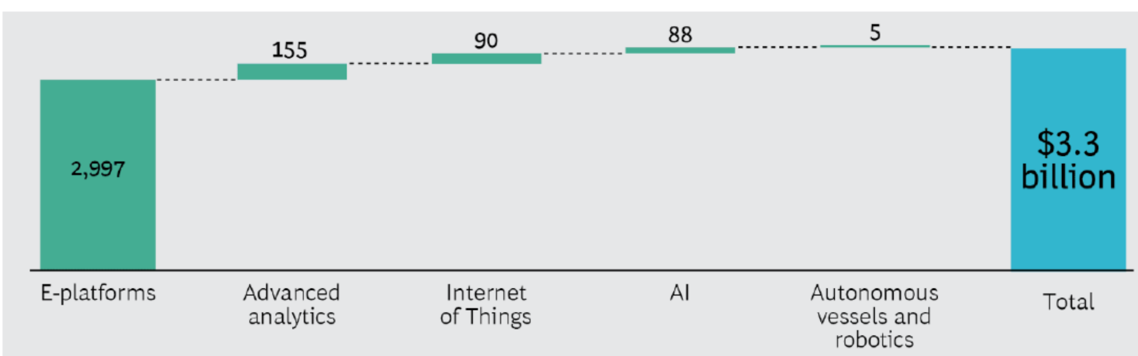


Figure 29. Investments in shipping and logistics digital startups-
Source: PitchBook Data and BCG analysis

8 Factors and topics to consider for effective digital transformation of shipping

Closing with the main chapters of this dissertation it was assumed necessary to set and analyze some factors and topics that if considered seriously, they could enable the digital transformation of shipping industry. In the following subchapters the below topics will be discussed:

- The human factor
- The value of information sharing
- Tacit knowledge mobilization
- The importance of value proposition
- Digital culture
- Management of change

8.1 The human factor

We already set the definition of digital transformation and underlined the human-driven characteristic of it. There is a perception by several scientists that digitalization will remove humans from the physical displacement of persons and goods. Although, it is a fact that technological evolution cannot be disengaged by the human factor. We could take the chance to state that sustainable evolution through digital transformation cannot be achieved without placing the human at the epicenter of this process. For example, human operators cannot be taken out of the operational loop of autonomous ship systems, as long as a high level of trust in autonomy is required until MASS are widely accepted. Cyber risks cannot be minimized, unless people are trained for it and developments are made human-friendly rather than user-friendly.

From the Idea stage of a TRL graph of a digital innovation, humans in the supply chain and their characteristics should be perceived as a high weigh parameter directly affecting and getting affected by every TRL stage till commercialization and beyond. Humans can be operators, customers, office staff etc. They have skills, talents, expectations, personality, personal roles (i.e. family members), social intelligence, culture, environmental impact, psychology and vulnerabilities as we lately experienced with COVID-19.

Digital transformation can be used to boost effectiveness, productivity and safety in shipping to make a huge impact on the “sustainable evolution” milestone. Humans should be the main factor for the enablement and acceleration of a smooth digital journey. Shipping industry is already establishing mechanisms to introduce new policies, services and norms in daily shipping operations. The management of change is one of them, focusing directly on human factor. Younger generations that are tech enthusiasts and digitally familiar should be at the forefront of the implementation of these mechanisms, opening the road to digital transformation.

8.2 The value of information sharing

The development and use of new technologies combined with the evolving connectivity between systems introduces new threats and claims to shipping stakeholders. Threats and claims regarding IT and OT systems can appear within an organization or between organizations. They can affect from one part of the shipping industry (I.e a ship owner) to the whole maritime ecosystem (ship owners, 3rd party vendors, the environment etc.). Threat and claim management can be more easily applied to IT systems than to OT systems. This happens because IT, in several cases, is managed by the organizations internally. On the contrary, OT security and after-sales support usually rests with the 3rd party vendors and the makers.

In order to minimize risk, solve claims, develop digital innovations and adopt digitalization in shipping it is essential to share information within shipping organizations and between them. Early mentioning of a cyber-incident or a potential threat could prevent a cyber-attack or a future threat that may cause malfunction of a ship system, loss of life, steal of data etc. Quick reporting of a technical problem, fast technical correspondence and effective communication could help solve a claim regarding IT or OT that could affect regulatory compliance, continuity of operations and customer satisfaction. Sharing knowledge in shipping ecosystem could boost the development process of innovations and give birth to new ideas that would fit better the customer’s needs.

Considering the above, if we add the will to share information regarding new digital systems and their use, the adoption of digitalization could be a much easier and innovative process. In order to enable this state of mind in shipping ecosystem we have to consider the human factor as we mentioned on the previous chapter. Shipping is a traditional industry that lacks of trust between its stakeholders, sociability and extroversion. Although, with the right mechanisms and management techniques this approach can be implemented. Therefore, shipping stakeholders get a much better understanding of the systems they use, thus greater benefits. On the other side, manufacturers and 3rd party vendors develop innovative systems and are much more aware of the vulnerabilities and threats of both IT and OT. Indeed, the efficient interconnectedness (between systems and between stakeholders) and finally the term "smart maritime ecosystem" can only exist if shipping organizations are willing to be part of it. The way to achieve it is to add 'information sharing' as an indispensable part of the management strategies and the culture of the organization.

8.3 The value of tacit knowledge mobilization in smart shipping ecosystem

Another factor to consider that is directly connected with the previous one mentioned, information sharing, is tacit knowledge mobilization. Knowledge can be explicit or tacit. "Explicit knowledge is knowledge that can be easily articulated, codified, stored, accessed and transmitted. "(Helie, Sebastien; Sun, Ron, 2010). For example, an environmental legal code, the exact position of a ship, COVID-19 related instructions, a manual for ship equipment etc. On the other hand, tacit knowledge is "The kind of knowledge that is difficult to be readily expressed, locate, and transferred". It is widely held by individuals and it resides in their minds, behavior and culture. It is based upon observation, experiences, practice, senses, emotions, values and other intangible factors. Typically, it is shared through discussions, analogies and human interaction. Its effective mobilization is strongly based on the efficiency level of cognition of the parties trying to interact in order to acquire, transfer and use tacit knowledge. Michael Polanyi, the father of tacit knowledge, mentioned in his book ("The Tacit Dimension" 1958) two aspects of tacit knowledge that affect and can raise the level of cognition of the involved parties and the overall effectiveness of mobilization of tacit knowledge. Focal awareness and subsidiary awareness. In Polanyi's book, focal awareness is referred to the use of systems of meaning to express and interpret what we see, hear or read. Subsidiary awareness is connected with our past experiences, which drive our ability to analyze and understand what it is we are experiencing. (Michael Polanyi, 1966) Some examples of tacit knowledge are:

- Captain's description of the storm that vessel's crossing.
- Insecurity of different office employees and seafarers that is related to COVID-19 pandemic.
- Unexpressed complaints and dissatisfaction of an employee regarding the working hours of his job.
- Soft skills of a superintendent engineer that could help solve a particular problem but nobody has identified it, even himself.
- The knowledge of know-how or an invention that can be used to deliver innovations when connected with the appropriate need.

Having set a long prologue and examples of tacit knowledge we can say that tacit knowledge mobilization is interconnected with the adoption of digitalization in shipping and that offers multiple values. It can enable and be enabled by the adoption of digitalization, drive and scale up digital and smart developments and innovations, support regulatory framework development and implementation and enhance operational efficiency and competitive advantage of shipping organizations. More analytically tacit knowledge mobilization can:

Enable and be enabled by adoption of digitalization in shipping: On the one hand, identification of the skills and perspectives concerning digital systems, as well as a deep awareness of the difficulties of use regarding new technologies, should help smoothen the development of smart systems and enhance change management techniques.

In addition, the consistent mobility of tacit knowledge between different stakeholders of the smart shipping ecosystem should help identify needs, challenges and threats that arise during the adoption of digitalization. Therefore, the creation of solutions would become an easier and more efficient process, supporting the digital transformation of shipping and its sustainable evolution.

On the other hand, smart digital innovations can already enhance the acquisition of tacit knowledge and its mobilization. Some great examples include the use of Augmented Reality technologies for more efficient mobilization and use of tacit knowledge. Verizon's AR headset for training on field tasks is one of them. With this system field engineers can simultaneously learn on the job, access and/or record training content, create a training video and share practice. (Verizon, 2020) Another example is Wartsila's AR and smart glasses for supporting maintenance ship systems even remotely. Using this headset while on field, offers access to the information and expertise that Wartsila has accumulated and real-time communication with Wartsila experts who can see and hear exactly what happens on board through cameras, microphones etc. Alongside the user of the headset can be guided remotely through sound, photos, video, and written content just in front of his eyes through displays in order to solve problems while on field. (Wartsila, 2018)

Drive and scale up digital and smart developments and innovations: In the continuous process of tacit knowledge mobilization, experiences, questions and answers are shared between individuals within or between organizations. This open exchange of knowledge allows people to see things from different perspectives, research more, learn and probably get an "eureka" moment. Alongside, the waste of time in ideas that doesn't work is minimized, while the involved people save their energy and the organization manages its resources efficiently.

Going a bit deeper in innovation management it is important to mention that TRL (Technology Readiness Levels) and the smooth transition from one to another is directly impacted from tacit knowledge management. From the idea stage till commercialization of an innovative system in shipping, considering the hidden knowledge that could be used to support the new product development is a key recommendation. For example, making a pilot test before the scaling up of a digital technology, while considering factors and parameters that may be tacit knowledge, should help get better results and feedback. Therefore, technology transfer could occur more effectively. An example in shipping is the pilot test of a navigation system by actual navigators and captains and the recording of the tacit findings to further use them for technology scale up.

Support regulatory framework development: In the intercultural environment of shipping someone can find many and big differences between cultures of individuals and/or organizations. These differences affect the capabilities of obligation in regulations of each organization. Developing maritime regulatory frameworks (I.e. Sulphur 2020) whose compliance from stakeholders is enabled by the structure and content of the legal code is not an easy case. The tacit knowledge contained in different cultures and perspectives of organizations can support regulatory framework development in a way that its effectiveness and compliance from stakeholders is boosted.

Even organizations internally can exploit tacit knowledge to create effective rules and sequences of instructions and obligations. The connection between personnel and organization's regulatory framework should be formed and enhanced by the extraction and use of tacit knowledge within the organization. In the same context, finding or retaining talent that fit the culture of the company could also be supported by tacit knowledge management.

Enhance operational efficiency and competitive advantage of shipping organizations: The flow of tacit knowledge within a shipping company helps inner teams and external collaborators and customers to solve issues that could affect negatively shipping operations and customer satisfaction. An integrated knowledge management system full of know-how and the corresponding problem solvers (I.e. after sales support, engineers, researchers, operators etc.) could support cyber resilience (predict and encounter cyber threats) of a shipping organization and claim solving regarding systems' malfunction. As a result, the continuity of operations and their efficiency would be enhanced, therefore customer satisfaction could be increased too. Combining the above with the imprint that expertise in tacit knowledge mobilization has in organization's brand, a big competitive advantage for the organization itself rises.

Shipping works in traditional ways and is an intercultural industry. Therefore, understanding the value of tacit knowledge mobilization and use tacit knowledge as a management asset with plenty of capabilities is not an easy issue, although it is a great challenge. Considering all the aforementioned, human factor has to be in the epicenter of tacit knowledge mobilization. The management of change should give the proper attention to the tacit asset and its characteristics, capabilities and vulnerabilities in order to make the most out of it.

8.4 The importance of value proposition

For effective technology transfer and adoption of digitalization in maritime, shipping organizations have to be convinced to embrace change and start marching on the road to digital transformation. Considering this, the benefits of the different smart developments, their positioning in the market and the competitive advantage they offer have to be clear to the eyes of shipping organizations and their employees. To explain this, we take the chance to refer to METIS CYBERSPACE TECHNOLOGY SA. METIS is a Greek company that develops products that apply the technologies of the 4th industrial revolution in maritime transport. The value proposition and the human-centric approach that METIS proposes is a perfect example that has a positive input regarding the digital transformation journey of shipping organizations. In the next paragraph and the next three figures we can see the value proposition of METIS.

Value proposition of METIS CYBERSPACE TECHNOLOGY SA. :

Solution of METIS: "METIS sets Information Intelligence at the disposal of the Global Maritime Industry. METIS has been designed and implemented to address the requirements of Technical & Operations Departments of Maritime Companies. The solution, powered by Artificial Intelligence incorporates fully automated, accurate and reliable Data Acquisition combined with the novel idea of virtual cloud-based agents, which analyze operational or engineering processes and provide useful feedback in the form of analysis conclusions and events detection reporting to multiple users. METIS Agents are highly experienced Virtual Personal Assistants, that can work restlessly 365/24/7 and automatically inform the appropriate employee in the proper way and at the right time. All information is provided in real time through a conversational user interface specifically adapted to the requirements of the maritime sector." (METIS CYBERTECHNOLOGY, 2019)

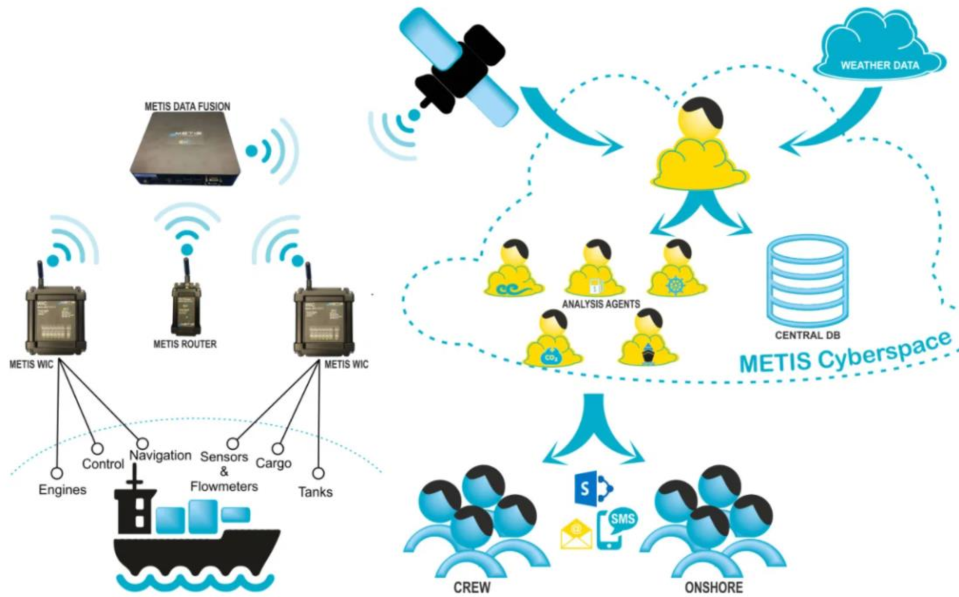


Figure 30. METIS platform network architecture-
Source: METIS CYBERSPACE TECHNOLOGY

Reading the comprehensive solution of Metis and observing the network architecture of the platform, we can clearly realize the benefits that this innovative development has to offer. Continuing to emphasize on the importance of the value proposition, we can see below the differentiation of METIS regarding their competitors in a simple 6-icon figure.

Figure 31. Why chose METIS-
Source: METIS CYBERSPACE TECHNOLOGY SA

Figure 31 reveals the human-centric approach of METIS regarding its value proposition, not only because of the human-centric interface service but from all the differentiations-benefits that come with the adoption of this unique digital solution.

Lastly, the competitive advantage that the use of METIS smart technology brings to maritime companies is presented on Figure 32. Remarking the ROI (Return of Investment) that METIS declares, the unique value proposition of our example is perfectly concluded.

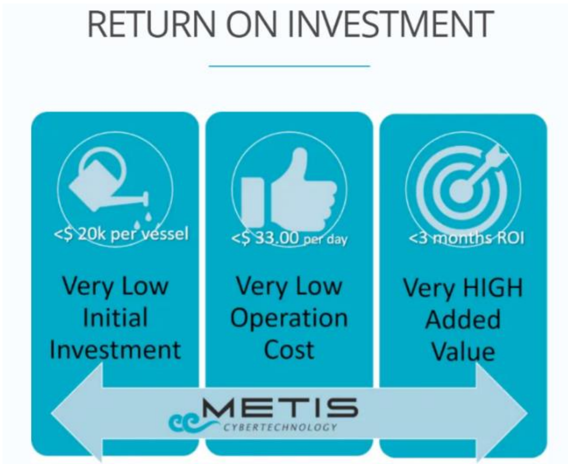


Figure 32. METIS ROI
Source: METIS CYBERSPACE TECHNOLOGY SA

From the development of new digital systems to the appropriate presentation of their value proposition it is important to consider to whom we are referred to. Metis is a great example of a company that has the awareness of needs regarding digital transformation of shipping companies. It develops human-friendly systems to satisfy human-driven motives. This approach, as we already mentioned, is integral for the effective digital transformation of shipping and the sustainable evolution of the sector.

8.5 Digital Culture

One of the most essential factors to focus while adopting digitalization in shipping is the continuous development of digital culture within the organizations. Digital culture is related to many things and can have several applications. Although we will focus only on one regarding the purpose of this dissertation. The relationship between humans and technology. As we already mentioned technological evolution cannot take place without giving at least the same caution to the human factor with the one we give to technology's application.

For shipping organizations, the challenge of creating a digital culture is big and it is mainly enabled by the awareness of individuals and organizations, regarding how digitalization can operate for customers and the organizations themselves. It is about creating the appropriate environment to identify the issues and pain points of the customers and organization and embrace the value of new technologies to create the desired solutions. Therefore, when referring to digital culture we must include the aforementioned recommendations. Human factor, information sharing, tacit knowledge mobilization and the importance of value proposition are indispensable for the development and sustainability of digital culture within maritime organizations.

Of course, there are more factors and actions to consider for this culturally transformation process:

- Training: An effective way to raise digital awareness of employees or to approach digital specialization of them is through learning and development programs. Personalized training for each work role could enforce the positive input of individuals and empower the organization in the digital area.
- Risk comfortability and risk awareness: A work environment that inspires people to try new things while applying risk management techniques should help develop the foundations of a unique digital culture in a shipping organization. Although shipping companies work in traditional ways, it is a challenge to adopt more holistic approaches to leverage the advantages that digital technologies can offer.
- Inspiration and guidance from leading roles inside an organization: High executives should be digitally aware, even enthusiasts. The burden is on them regarding the cultural transformation of the working teams and individuals; thus, they should be ready to adopt holistic approaches such as the phased approach, and guide the others to embrace digital culture.
- Collaboration: Between teams of a company or even between organizations the encouragement for collaboration could boost the interactions and therefore the exchange of ideas and questions. Effective collaborations can help generate, share

insights and improve workflow. Especially, implicating a phased approach while encouraging collaborations within an organization, digital culture could be easier diffused throughout the different departments.

To sum up with digital culture, we will use a statement of Nakul Malhotra, Vice President of Technical Solutions & Marketing Marine Products for Wilhelmsen Ships Service, from Shipping 2030 report: "Embracing a Digital Culture". So,

"Adopting a digital culture isn't a simple case of copy and paste. It needs to be relevant to the individual organizations and the people in those organizations. It requires a complete culture shift in terms of work processes, tools and statements are not enough to construct a digital culture. It's a lot of work and it also needs a lot of ambassadors to make sure you are truly working in that way." (Nakul Malhotra, 2020)

8.6 Management of Change

Although shipping is familiar with changes and has got through many of them throughout the years successfully, it is not verified that the industry itself has a big will to change. On the contrary, shipping has a traditional culture that willing to change is not a part of its main characteristics. We already analyzed some recommendations for an effective digital transformation. These key recommendations are part of this change process. Their role is a scalable. Firstly, they appear as challenges, but with an effective management of change they can become enablers and even the biggest strengths of a SWOT analysis of a company doing business in smart shipping ecosystem.

Change management in shipping should address the human side of digital transformation and the issues that human factor can bring on surface, while effectively involve people to take part and support this change. In shipping ecosystem change management refers to changes within the organization's offices or/and onboard vessels. It includes company's policies and sequences of actions to decide on proceeding on a change and implement and monitor the corresponding processes. These processes should be based on guidance, authorization, report and appropriate division of duties and responsibilities.

Although change management should be considered a personal matter for each organization and be developed considering organization's issues and targets, the vision of a digitally transformed maritime ecosystem is a common matter. Change could be more effective and smoother if shipping organizations start embracing transparency, sociability, and extroversion. Regulatory frameworks from the appropriate authorities could enable this change. Although, stating about which should be the appropriate organization (I.e. IMO) to set global standards, frameworks and guidelines regarding MOC for digital transformation, is still questionable.

The phased approach, is suggested by Lloyd's Maritime Academy in "Smart Shipping" course for the implementation of management of change. Phased approach is recommended also in this dissertation. Although, referring to the previous paragraph it worth investigating a possible combination with a systemic approach implementation. Closing with MOC, a puzzle graphic from Piktochart with 30 useful key ways for effective lead to change is presented. (Safety4Sea, 2018)

Figure 33. 30 useful key ways for effective lead to change-

Source: Piktochart

This chapter was the last one of the "Factors and topics to consider for effective digital transformation of shipping". All the analyzed topics are interconnected and should be given the appropriate caution and eagerness to take full advantage of their capabilities and live the experience of digital transformation to the maximum. Next and final chapter will refer to an example that takes into consideration the aforementioned topics trying to offer some value to shipping stakeholders.

9 "Anyclaim": An example of application considering the human-centric nature of digital transformation.

Anyclaim is a platform in a form of both a mobile app and a website that connects people from the world of maritime. Through Anyclaim maritime companies and the people within them (shipping companies, marine equipment companies, marine security companies, individuals etc.) can connect with each other in order to solve claims regarding equipment (exp. scrubbers, ballast water treatment systems), security (exp. piracy, cyber-attacks) and share information and knowledge at any time they want.

It is a fact that innovative maritime equipment and cyber-attacks generate many claims and problems respectively that can be costly for the shipping companies if they are not solved in time. Another fact is that working hours vary from place to place(time zone correspondence) around the planet, hence it is not always easy for shipping companies to find the appropriate person to solve a claim/problem of a vessel or to order some spare parts.

Anyclaim connects the claim/problem with the solver. The solver can be available any time he wants or arrange with his employers, for example after his working hours of his everyday job, on holidays or at night. The solver can be a freelancer or a maritime company employee. The solver and the company he works for are paid from our E-platform. Anyclaim draws income from the subscriptions of shipping companies that vary depending on the number of claims that want to be able to generate. Different pricing strategies are also invested.

Closing, Anyclaim will operate as a social & knowledge network for people working in the maritime sector (officers, naval engineers, field engineers, crews and shipyard employees). Through the platform people from this intercultural sector will be able to share knowledge, experiences and data.

On a scale up scenario Anyclaim could collaborate with AR specialists and/or suppliers to provide a more efficient claim solving experience. Blockchain could also be used for the enablement of secure and efficient transitions and accesses through Anyclaim platform.

Anyclaim will be available for free to register and download. This platform refers to the maritime sector, targets the shipping companies, the maritime equipment companies and the marine cyber-security companies. Anyclaim takes position among the shipping companies that use new innovative equipment and/or are targets of cyber-attacks. The revenue will come from subscription of shipping companies. The team consists of one person for now and the platform is in the stage of idea.

Below in Figure 34 the network architecture of Anyclaim platform is presented:

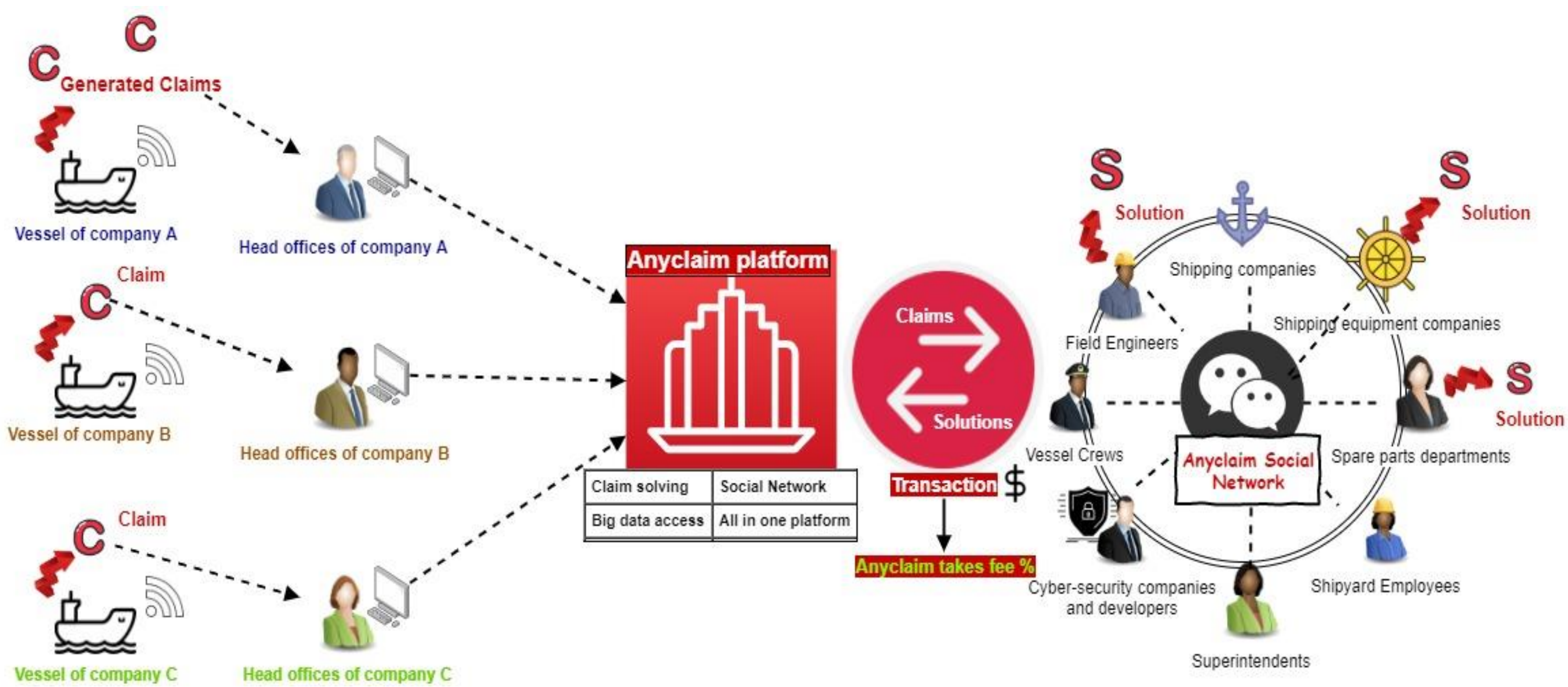


Figure 34. Network Architecture of Anyclaim.

Source- Anyclaim

A short comment about the Anyclaim idea is that “Anyclaim” is an example of how digital technologies can embrace a human-centric approach to:

- offer unique value propositions,
- enhance the digital culture of the shipping ecosystem
- and enable the effective adoption of digital technologies

10 Conclusions

Pushing future sustainability and evolution in shipping operations and also predict, act and adapt in difficult situations such as COVID-19 is a huge challenge. This dissertation underlines the importance of awareness regarding applications of digital technologies in shipping and challenges of the sector. It also analyzed some factors that worth considering during the digital transformation journey. As challenges and opportunities in the digital area are directly connected with humans, so should be the approach regarding regulations and the corresponding authority that will implement them. Although, is arguable who should regulate the digital transformation and which the regulations should be. Regarding this dissertation we could suggest that the smart maritime regulatory framework should include milestones about long term sustainability of the maritime ecosystem and the operations that take place inside it. To achieve these, considering factors that interact with human nature, their correlations and therefore their impact in the industry should be in the action plan. One last question that could be involved in this conclusion is: “In under which criteria the appropriate combo of humans and technologies inside a shipping organization is formed?”

Do we need humans with specific psychometric characteristics and skills that show they can deal with COVID kind situations and being able to use the applied smart technologies on board and/or onshore to continue efficient operations? Do we need smart technologies and smart systems architecture that give high significance to the human factor from their initial stage of development (idea stage) till their commercialization and use in shipping industry, under any "unpredictable situation"? Or do we need something completely different? A brief answer in this question would be abstract. Although whatever the answer is, it should be derived from the precise definition of digital transformation that was given in the earlier stages of this thesis:

“**Digital transformation** is a human-driven strategic, business, and social transformation under the prism of the adoption of digitalization, management of change and digital culture development, in the form of a long-term investment aiming at sustainable evolution.”

11 References

Bibliography

George Vekinis (2014), Technology Transfer in Practice: from Invention to Innovation

Jakki Mohr, Sanjit Segupta, Stanley Slater (2010), *Marketing of high technology products and innovations 3rd Edition*, Pearson Education inc., New Jersey

Lloyds Maritime Academy (2020), *Cyber-resilience in smart shipping*, Smart Shipping Course

Lloyds Maritime Academy (2020), *Regulatory Framework, Best Practices and People*, Smart Shipping Course

Michael Polanyi (1966), *The Tacit Dimension*, Doubleday & Company Inc., Garden City, New York

Nikolaos Bilalis (2018), *MTIM-Product/Service Development*

Metis Cybertechnology (2019), *Introduction to Metis*

Metis Cybertechnology (2019), *METIS Hull and Propeller Fouling Estimation and Monitoring white paper*

Metis Cybertechnology (2020), *Metis Ship Connect white paper*

Metis Cybertechnology (2020), Shaping the future of digital shipping

Serafeim Katsikas (n.d.), Digital Transformation

Researches

Benjamin Pjedsted Pedersen, Jan Larsen (2008), *Modeling of ship propulsion performance*, https://imare.in/media/30638/paper-no-4a-3-mr-bp-pedersen.pdf

Daogui Tang, X. P. Yan, Yupeng Yuan, Kai Wang (2015), *Multi-agent Based Power and Energy Management System for Hybrid Ships*

Helie, Sebastien; Sun, Ron (2010), *Incubation, Insight, and Creative Problem Solving: A Unified Theory and a Connectionist Model*, PubMed

J. Scott Brennen & Daniel Kreiss (2016), *Digitization and Digitalization*, Leonardo Vanneschi, Mauro Castelli, 2017*), Prediction of ships' position by analysis AIS data: An Artificial Intelligence approach*

Magnier-Watanabe, Caroline Benton, Dai Seno (2015), *A study of knowledge management enablers across countries*

Michael Foteinos, Efstratios Tzanos, Nikolaos Kyrtatos (2017), *Ship Hull Fouling Estimation Using Shipboard Measurements, Models for Resistance Components, and Shaft Torque Calculation Using Engine Model*

Nikolas Bialystocki, Dimitris Konovessis (2016), *On the estimation of ship's fuel consumption and speed curve: A statistical approach*

Radan & Damir (2008), *Integrated Control of Marine Electrical Power Systems*

Serafeim Katsikas, Georgios Manditsios, Dr. Sotiris Mallios, Ioannis Stratakos, Isaias Vrakidis, Georgios Gousios, Panagiotis Goulas (n.d.), *Artificial Intelligence (A.I.) and Cloud Technologies in the service of hull and propeller performance optimization*

Articles

Alexander Love (2020), *AI in shipping: areas to watch in 2020*, https://www.ship-technology.com/features/ai-in-shipping/

Allianz (2019), *Shipping loses lowest this century, but incident numbers remain high*, https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2019.pdf

Bunker Ports News Worldwide (2016), *Bahri relying on Big Data to drive growth and transform maritime industry dynamics*, http://www.bunkerportsnews.com/News.aspx?ElementId=8c4a34df-1950-47ce-a9dc-3f84fee2ebc3

Camille Egloff, Ulrik Sanders, Konstantina Georgaki, Jens Riedl, (2018), *The Digital Imperative in Container Shipping*, https://www.bcg.com/en-gr/publications/2018/digital-imperative-container-shipping

Collen Chapco Wade (2018), *Digitization, Digitalization and Digital Transformation: What's the difference*, https://medium.com/@colleenchapco/digitization-digitalization-and-digital-transformation-whats-the-difference-eff1d002fbdf#:~:text=Digitization%20is%20the%20conversion%20of,new%20(digital)%20revenue%20streams.

ENISA (2019), *Port Cybersecurity-good practices for cybersecurity in the maritime sector*, https://www.enisa.europa.eu/publications/port-cybersecurity-good-practices-for-cybersecurity-in-the-maritime-sector

Futurenautics & Vodafone Maritime (2020), *Near Shore Connectivity Whitepaper*

Futurenautics Maritime (2018), *2018 Crew Connectivity Survey Report*, http://www.crewconnectivity.com/?product=2018-crew-connectivity-survey-report

Hariesh Manaadiar (2019), *Blockchain in shipping overhype?*, https://www.joc.com/technology/blockchain-supply-chain/blockchain-shipping-overhype_20190131.html

Ian Cornett (2019), *3 Key drivers of digital transformation*, https://www.eaglesflight.com/blog/3-key-drivers-of-digital-transformation

Ishaan Hemnani (2018), *6 ways for shippers to reduce bunker costs*, www.shipandbunker.com

Jason Bloomberg (2018), *Digitization, Digitalization, and Digital Transformation: Confuse them at your Peril*, https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/#67cc54b32f2c

Jason Stefanatos (2018), *Cyber security given priority to TMSA3*, https://safety4sea.com/cyber-security-given-priority-in-tmsa3/

Lloyd’s Register (2018), *34 maritime CEOs call sign for action in support of decarbonization*, https://www.lr.org/en/latest-news/34-maritime-ceos-sign-call-for-action-in-support-of-decarbonisation/

Marine Insight (2019), *How to use main engine performance curve for economical fuel consumption on ships*, https://www.marineinsight.com/main-engine/how-to-use-main-engine-performance-curve-for-economical-fuel-consumption-on-ships/

Marine Insight (2019), *How the power requirement of a ship is estimated*, https://www.marineinsight.com/naval-architecture/power-requirement-ship-estimated/

Nakul Malhotra (2020), Shipping 2030 report “Embracing a Digital Culture”, Shipping 2030 events

Security Magazine (2020*), Maritime Industry Sees 400% Increase in Attempted Cyberattacks Since February 2020*, https://www.securitymagazine.com/articles/92541-maritime-industry-sees-400-increase-in-attempted-cyberattacks-since-february-2020

Shipnet (2019), *What are the key elements of TMSA3?*, https://www.shipnet.no/key-elements-of-tmsa-3/

Steve Roman (2019), *Pollution police: How are ship emissions monitored*, https://www.wartsila.com/twentyfour7/environment/pollution-police-how-are-ship-emissions-monitored

Trelleborg (n.d), Use of big data in the Maritime industry

Websites

BIMCO, (n.d.), https://www.bimco.org/about-us-and-our-members/publications/the-guidelines-on-cyber-security-onboard-ships

Bunker Ports News Worldwide (2016), *Bahri relying on Big Data to drive growth and transform maritime industry dynamics*, http://www.bunkerportsnews.com/News.aspx?ElementId=8c4a34df-1950-47ce-a9dc-3f84fee2ebc3

CargoX (2020), https://cargox.io/

DFT Code of Practice (2017), “Cybersecurity for ships”, https://www.gov.uk/government/organisations/department-for-transport)

Georgia Tech Panama Logistics Innovation and Research Center, (2020), *Basic Concepts*, https://logistics.gatech.pa/en/assets/seaports/concepts

Global Maritime Forum & International Union of Marine Insurance (2019), *Survey of Global Maritime Issues Monitor*, https://www.marsh.com/uk/insights/research/global-maritime-issues-monitor-2019.html

Hellenic Shipping News (2019), https://www.hellenicshippingnews.com/the-greatest-challenges-facing-the-shipping-industry-include-flattening-demand-growth-industry-consolidation-forcing-freight-rates-down-and-fuel-emissions-regulations/#:~:text=The%20greatest%20challenges%20facing%20the,regulations%20%7C%20Hellenic%20Shipping%20News%20Worldwide

Hellenic Shipping News (2019), https://www.hellenicshippingnews.com/the-greatest-challenges-facing-the-shipping-industry-include-flattening-demand-growth-industry-consolidation-forcing-freight-rates-down-and-fuel-emissions-regulations/#:~:text=The%20greatest%20challenges%20facing%20the,regulations%20%7C%20Hellenic%20Shipping%20News%20Worldwide

IMB's Piracy Reporting Centre (2020), https://www.icc-ccs.org/index.php/1293-crew-kidnappings-surge-in-seas-off-west-africa-imb-reports

IMO (2020), *Autonomous shipping*, http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

IMO (2020), *Sulphur 2020-cutting sulphur oxide emissions*, http://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

International Maritime Organization (2020) *Ballast water management*, http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx

i-SCOOP, (2020), https://www.i-scoop.eu/digital-transformation/digitization-digitalization-digital-transformation-disruption/

ISO 19030 (2016), Ships and marine technology — Measurement of changes in hull and propeller performance, https://www.iso.org/standard/63774.html

Maersk (2019), *Maersk launches new visibility tool "Captain Peter*", (https://www.maersk.com/news/articles/2019/12/03/maersk-launches-new-visibility-tool-captain-peter

Metis Cybertechnology (2020), *Our Solution*, https://www.metis.tech/#adaptablesolutions

Metis Cybertechnology (2020), Company profil, https://www.metis.tech/wp-content/uploads/2020/10/METIS-Company-Profile-Sep-2020.pdf

Metis Cybertechnology (2020), Hull & Propeller Fouling Analysis, https://www.metis.tech/hull-fouling-analysis/

Metis Cybertechnology (2020), Metis Ship Connect, https://www.metis.tech/metis-ship-connect/

Metis Cybertechnology (2020), Metis Space, https://www.metis.tech/metis-space/

Metis Cybertechnology (2020), Virtual Personal Assistant, https://www.metis.tech/metis-chatbot/

Metis Cybertechnology (2020), Voyage Analysis, https://www.metis.tech/voyage-analysis/

MUNIN (2016), *Munin results*, http://www.unmanned-ship.org/munin/about/munin-results-2/

Port of Antwerp (2017), *Smart port with blockchain*, https://www.portofantwerp.com/en/news/smart-port-blockchain

ReCAAP (2020), *Half yearly Report Jan-Jun 2020*, https://www.recaap.org/

Rolls Royce (2017), *Rolls-Royce joins forces with Google Cloud to help make autonomous ships a reality*, https://www.rolls-royce.com/media/press-releases/2017/03-10-2017-rr-joins-forces-with-google-cloud-to-help-make-autonomous-ships-a-reality.aspx

Safety4Sea (2020), https://safety4sea.com/cm-3-key-features-for-shippings-digital-transformation/

Shipchain (2020), https://shipchain.io/

Shipowner (2020), www.shipowner.io

Shippingwatch (n.d), www.shippingwatch.com

Trelleborg (n.d), Use of big data in the Maritime industry

UK government (2017) (http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

United Nations Economic commission for Europe (2003), *The single window concept*, (https://ec.europa.eu/taxation_customs/sites/taxation/files/resources/documents/customs/policy_issues/e-customs_initiative/ind_projects/swannexv.pdf

Wartsila (2018), *Augmented Reality creates a new dimension in marine maintenance services*, https://www.wartsila.com/media/news/31-07-2018-augmented-reality-creates-a-new-dimension-in-marine-maintenance-services

Wartsila (2020), https://www.wartsila.com/encyclopedia/term/propulsion-system-propulsion-plant

Wartsila (2020), https://www.wartsila.com/encyclopedia/term/steering-system#:~:text=A%20system%20used%20for%20of%20steering%20the%20ship.&text=The%20steering%20system%20usually%20consists,a%20signal%20from%20the%20bridge.