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MSc SUSTANABILITY AND QUALITY IN MARINE INDUSTRY

« SAFETY OF MARITIME AUTONOMOUS SHIPS (MASS) »

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Declaration

I hereby declare that the work in this thesis titled “Safety of Maritime Autonomous Ships (MASS)’’ has been carried out by me and the dissertation was not formed to obtain any other degree or professional certification. In addition, I declare that I have acknowledged the work of others by providing specific references to that work.

This master’s dissertation was approved by the three-member advisory committee appointed by the department of maritime studies of the University of Piraeus in accordance with the regulations of the postgraduate studies program. The members of the committee were:

• Ernestos - Spyridon Tzannatos (Supervisor)

• Stefanos Chatzinikolaou

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Abstract

Introduction – To understand the environment in which autonomous ships will operate, it is necessary to define the shipping industry. Maritime transport is an integral part of globalization and the modern world. The shipping industry has a share of more than 80% in international transport goods, while it has been characterized as the backbone of world trade (ICS, 2021). The maritime trade sector is constantly growing, and this can be seen in Figure 2, where the increasing trends of international trade combined with the global gross domestic product, and the global population, in a time horizon up to 2030, are evident.

Aim - Based on the above mentioned, it should be said that the purpose of this thesis is to make an in-depth research about the Safety of Maritime Autonomous Surface Ships (MASS). Secondly, through this study, an effort is made in order to interpret the results of the research, to present the conditions that shape them and to come up with proposals that will improve these conditions.

Methodology - The methodology type which is used for the conduction and writing of the specific dissertation, is concerned to the qualitative as also the quantitative analysis about the Safety of Maritime Autonomous Surface Ships (MASS). According to a different approach, the qualitative research is research that emphasizes and focuses on meaning rather than human behavior.

Results – The 48% of the participants consider the reduction of human errors quite an advantage for MASS, the 31% consider it a moderate advantage and the 16% a big advantage, the 41% of the participants agreed with the fact that the fares of merchandise will lower due to the energy savings of MASS, the 28% totally agreed and the 26% neither agreed nor disagreed and the 30% of the participants totally agreed with the fact that the fares of merchandise will lower due to the savings from the crew cost that will no longer be needed in MASS, the 29% agreed as well and the 25% neither agreed nor disagreed.

Conclusion – As autonomous technology and related legislation will continue to develop, it is important for the shipping community to stay abreast of changes to stay informed and ready for

the shift to autonomous shipping. All the while, opportunities can arise at any time for both shipowners and managers, as well as IT and communications companies, taxonomists, surveyors and shipyards. In addition, the practical approach to the project of autonomous ships is also decisive.

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1.Introduction

Modern history has shown that the rapid scientific and technological development in recent decades has resulted in the replacement of man by machines in several aspects of everyday life. This happens in various sectors of the industry as well as in the shipping industry. In ancient times, there were ships with hundreds of male sailors, while in modern times, large ocean-going ships carrying out sea transport have only a few sailors in their crews. Although the size of modern ships is increasing, the number of crews is decreasing: the largest container ships today are over 400 meters long, carry over 20,000 containers, and usually have a crew of only 20 people (Deloitte, 2011).

In the automotive industry as well, autonomous vehicles have been around for a few years. Examples of autonomy in transportation systems are autonomous parking systems, drone aviation, and driverless taxis. However, in the maritime transport sector the progress of autonomy is slower and with more difficulties in the application of such technologies (Ghaderi, 2020). Although already from in 1957 some robotic autonomous underwater vehicles (Autonomous Underwater Vehicles – AUVs) were developed and some “remotely operated” vessels (Remotely Operated Vehicles – ROVs), their use has been limited to research or even military purposes, while the speed and the depths at which they are operational are very limited. Although these applications have provided the opportunity for testing and development in construction, propulsion, dynamics, control and navigation as well as detection, path planning and communication in small autonomous vessels, unfortunately there are still no large-scale applications (Sahoo, Dwivedy, & Robi, 2019).

The milestone date for the introduction of autonomous ships at an early stage, however, was November 2017. This date was a milestone for the British company ASV Global, which took care of presenting to the public the first autonomous ship that was registered in the English registry and acquired an English flag. The C-Worker 7 as it was named by ASV Global is a flexible, autonomous marine vehicle that was designed and used not naturally for crew transport or the transport of some cargo, since it was a single 7 meter vehicle, but mainly for environmental work and studies. More specifically, some of the main activities of the C-Worker were the detection of hydrocarbons, the collection of useful data in the oceans, the inspection and monitoring of the environment.

The first operational activity of the C-Worker took place on the beach of Egypt. Its basic structure consisted of a single room containing a multi-shot sound system and side-scan sonar. Its purpose was to track the Seven Antares ship through appropriate sensors. The C-Worker activity completed after 37 days. During its operation the vehicle was also monitored by an AsView control system through a station installed on Seven Antares. Their in-house developed ASView software is a control system designed for autonomous control and remote control of unmanned and manned ships. The integrated autonomy computer (ASView-Core) is connected via radio link (UHF, L or S band) or satellite link (V-Sat, Inmarsat) to the parent company. An equally important role in the process was played by the server (ASView-Base), the HMI (Human Machine Interface) and the portable remote controls (ASView-Helm). Vessels can be controlled in four main ways:

- ✓ Remote operation - direct remote control by the operator.
- ✓ Auto mode - autopilot to maintain speed and direction.
- ✓ Mission mode - following the predetermined mission points.
- ✓ Autonomous operation - additional control aid to avoid collision.

The completion of his research produced very important results in terms of its usefulness, its functionality and the amount of interactivity it had and will have in operational actions concerning the sea. First, its presence contributed to the reduction of an additional research vessel at the same time and cost savings. Second, it provided greater operational flexibility due to better endurance than a manned craft. Thirdly, the possibility of research in very shallow waters was now given, and fourthly, the risk for personnel working on small boats was significantly reduced.

2. Literature review

2.1 Introduction – Autonomous Surface Ships – Technology and Automation in Shipping Industry

2.1.1 Basic Terms and Definitions

Within the framework of the Strategic Plan 2018-2023 of the International Maritime Organization (IMO), a specific strategic direction has been developed for the "Integration of new and evolving technologies into the regulatory framework". The aim of the strategic planning is to enable the shipping industry to benefit from new and progressive technologies and to address potential concerns and risks regarding safety, environmental impact and the impact on shipping and its people, both aboard and ashore. So, in 2017, the issue of "autonomous ships" was officially added to the international agenda of the IMO and its member states (IMO, 2021a).

First it is very important to separate the concept of automatic from autonomous. Someone can consider something to be "automatic" when it can perform a process without human control. The human gives an order and the process is carried out automatically. On the other hand, to consider something as "autonomous" human intervention should be absent. In this particular case, while ships already have many automatic systems for many years (most ships carry out transports in autopilot mode) they cannot be considered as autonomous. In an ideal situation, fully autonomous ships will perform all functions without any human intervention, including decision-making processes (Hancock, 2019).

In the context of the IMO strategy that was mentioned, and with the aim of separating AUVs and ROVs, which are autonomous vessels – mainly underwater – for research purposes, from autonomous vessels that perform international maritime transport, the IMO uses the term MASS for the latter – Maritime Autonomous Surface Ships. The term MASS is used to describe a ship which, at some level, can operate independently and without human intervention. Specifically, the IMO recognizes four levels of autonomy as described below (IMO, 2021a):

- ✓ Level 1: This level includes ships with automated procedures but with human decision-making support. The crew on board are responsible for the operation and control of the ship's systems and functions. Some operations may be automated and sometimes unattended, but there are always sailors on board ready to take control.

✓ Level 2: This level includes ships that have the possibility of remote control but also have a crew. Control and operation of the ship is performed from a location on land. The crew is however available on board and can take control and operate the ship's systems at any time.

✓ Level 3: This level includes ships that can be fully operated remotely and have no crew. The ship is controlled and operated from a location on land. There are no sailors on board.

✓ Level 4: Fully autonomous ships belong to this level. The ship's decisions and actions are completely determined by the ship's operating system.

In addition, Lloyd's English Surveyor suggests some more specific definitions and a classification system of ship autonomy levels (AL) from level 0 to level 6, taking into account the degree of each advanced function and the degree of human involvement. The different definition of autonomy levels by the different organizations is a brake on the studies around autonomous ships so far. There is usually no specific acceptable separation, and different functions may be included in the different levels of autonomy. Until autonomous ships operate normally and there is an accepted, by all involved members of shipping and international transport, a categorization of the levels of autonomy, there will be difficulty in their comprehensive study and development.

2.1.2 Today's Shipping Industry

To understand the environment in which autonomous ships will operate, it is necessary to define the shipping industry. Maritime transport is an integral part of globalization and the modern world. The shipping industry has a share of more than 80% in international transport goods, while it has been characterized as the backbone of world trade (ICS, 2021). The maritime trade sector is constantly growing, and this can be seen in Figure 2, where the increasing trends of international trade combined with the global gross domestic product, and the global population, in a time horizon up to 2030 are evident.

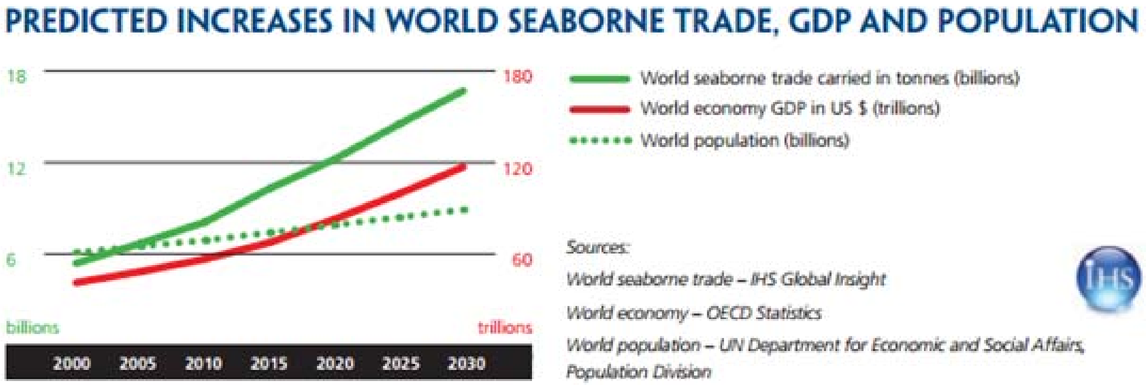


Diagram No.1 - Forecast trend of global maritime trade, GDP and population to 2030 (ICS, 2021)

One of the most basic elements of the shipping industry, is that it is an international industry with a global character. This is also reflected in the composition of the global fleet which at the beginning of 2020 amounted to approximately 98,000 merchant vessels, equivalent to a tonnage of 2.06 billion DWT. The ships of the global shipping fleet are registered in more than 150 different states (ICS, 2021), have flags and crews from all over the world, and operate routes to ensure the maritime transport of goods worldwide. In 2019 in particular, the global merchant shipping fleet grew by 4.1%, representing the highest growth rate since 2014. (UNCTAD, 2020).

Recently, with the outbreak of the coronavirus disease (COVID-19) pandemic, the global interdependence of nations has become more apparent than ever, creating new trends that have played a decisive role in every aspect of everyday life. The shipping industry has not been unaffected, on the contrary, it has found itself in the spotlight, dealing not only with the immediate effects brought about by the pandemic, but also with longer-term concerns, concerning changes in the operation of supply chains and globalization patterns, changes in the world's consumption habits, development new business models, the management and assessment of new risks, as well as an increased global sustainability and low carbon agenda. The sector was also called upon to deal with the effects of growing trade protectionism and inward-looking policies of various states. This recent pandemic has highlighted the importance of maritime transport, which continuously supplies the world's population with basic consumer goods in times of crisis but also in times of recovery (UNCTAD, 2020).

For several years, the term "Fourth Industrial Revolution" or "Industry 4.0" has been used to describe the trend towards automation and connectivity in industries through the exchange, processing and exploitation of data. Taking into account the numerous interpretations around Industry 4.0, we can summarize by saying that it is the effort to completely digital/digitized processes in the production systems achieved by the use of specific tools. These tools are Internet of Things (IoT), Robotics and Automated Intelligence (IR), Cloud Computing (CC), Artificial Engineering (AM), Big Data Analytics (BDA), Augmented Reality (AR) etc. The goals of these technologies are to provide mass customization of products, expand the use of automatic and flexible systems, and facilitate communication between components, systems, and people.

Industry 4.0 enables the optimization of products, the creation of new services and the development of business models for better communication. Therefore, the future of the shipping industry depends on the digital transformation process and requires appropriate systems to acquire, transmit, store and analyze large amounts of data in real time. Digitized and intelligent data exploitation is expected to bring significant benefits to the shipping industry, reducing operating costs while increasing overall revenue, and extending the life of machinery (Sullivan et al, 2020, Aiello, Giallanza, & Mascarella, 2020).

All these developments of the Industry 4.0 era are putting the shipping industry under intense pressure for innovative improvements. Although this era is characterized by unprecedented technological possibilities and developments, the motivation for change is not exclusively technological. In 2015, 193 countries endorsed the 17 goals of the sustainable development as part of the 2030 agenda for sustainable development. This agenda requires action by all stakeholders to eradicate poverty and achieve sustainable development by 2030 globally. The introduction of the 17 sustainable development goals is another source of pressure on shipping and the IMO as a member of the United Nations has started implementing actions to achieve them.

Picture No.1 - The 17 UN Sustainable Development Goals (IMO, 2021b)

By understanding the importance and size of the shipping industry and international maritime trade, and at the same time the pressure the industry is under for change, we can understand the key role of autonomous ships. According to reports, the market for maritime autonomous ships in 2020 is estimated at $1.1 billion annually and is expected to grow by 7% annually, approaching $1.5 billion in 2025. In addition, 96% of the nearly 3,000 patents (patents) related to autonomous shipping technology globally were registered in China. This will lead all nations involved to develop and implement autonomous utilitarianism in the next five years (UNCTAD, 2020).

The autonomous ships mark the gradual removal of humans from their control and operation. To achieve this, use must be made of available technology as well as further development of new innovative and original technologies. So, the first challenge facing the shipping industry that wants to become autonomous is to find the right technology and trust it to replace traditional crews.

There are already several technology systems that contribute to the automation of ship operations. The various risks and errors that can arise from these systems are the same in traditional manned vessels as in unmanned vessels. But the big difference in autonomous ships is related to the technology systems that try to replace human sense and presence. Today, most ships have unmanned engine rooms, whose monitoring and control, for the longest time, is done from a different position on the ship. The real challenge, however, is that the engine room functions can be controlled from some remote station outside the ship or not controlled at all and operate autonomously. Then we will analyze some of the basic systems that are necessary for the operation of the ships and how they can be part of the autonomous ships or to what extent they can contribute to it.

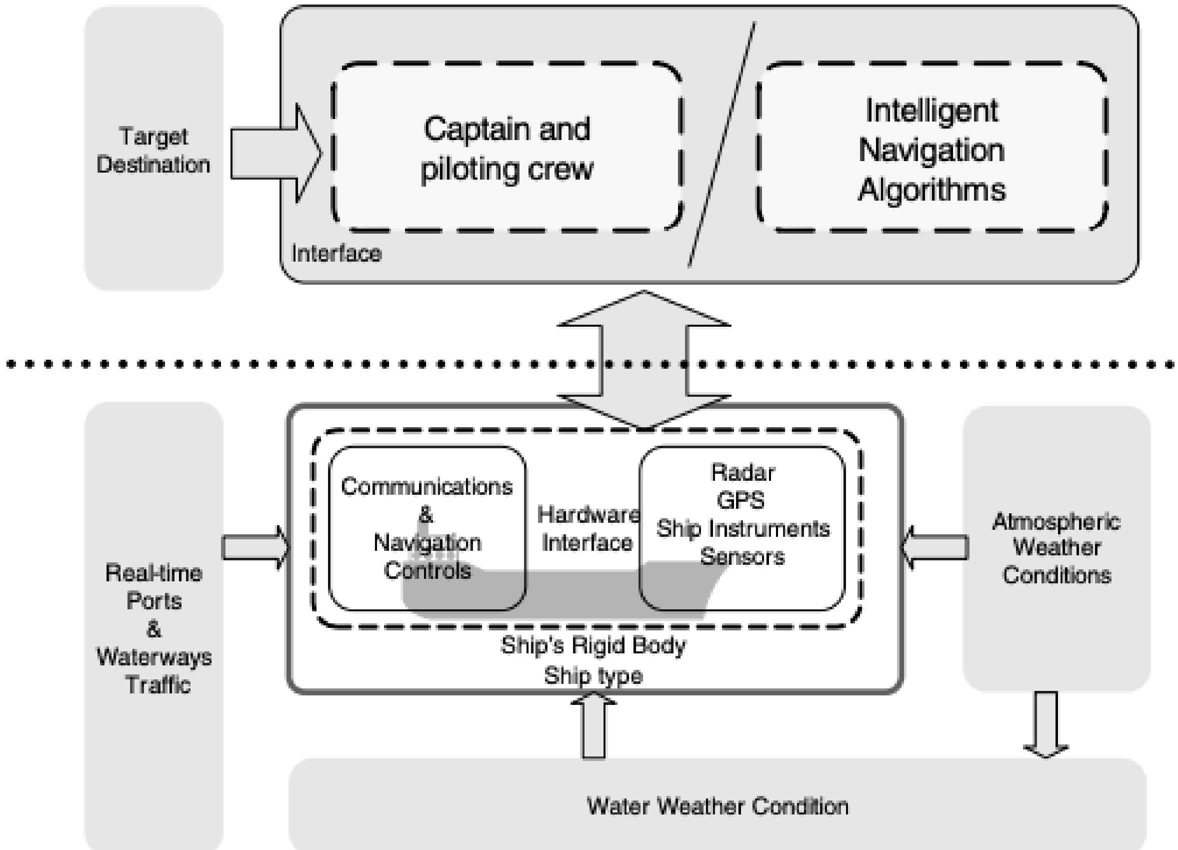
2.1.3 Safe Navigation Systems in Autonomous Ships

In navigation, one of the most important issues facing mariners is collision avoidance. To understand the importance of safe navigation, it is enough to consider that during the period 2014 - 2020, the main cause of most marine accidents was errors in navigation including loss of control, collision and grounding (EMSA, 2020). However, it is a general finding that collision avoidance is a complex problem with multiple factors. The degree of complexity depends on the situation of exogenous factors (traffic, weather conditions, condition of waterways) and endogenous factors (ship type, on-board technologies, crew, etc.), affecting navigation. Also, the crew's degree of ability to reliably navigate depends on both the level of experience and the psychological state of each individual.

The subjective nature of humans is sometimes enhanced by the ship's intelligent support systems such as radar devices, Automatic Radar Plotting Aid (ARPA), Automatic Identification System (AIS), Electronic Information System chart display (Electronic Chart Display and Information Systems - ECDIS) and the global navigation satellite system (Global Navigation Satellite System - GNSS). Also, international regulations for preventing collisions at sea (International Regulations for Preventing Collisions at Sea - COLREGs) have been established with the aim of minimizing the subjective thinking and action of people during navigation. However, even if COLREGs are fully defined, their human interpretation is still subjective, since ship maneuvers are performed in real time and sometimes under demanding extrinsic conditions (Statheros, Howells & Maier, 2007).

Therefore, it is not surprising that the success of autonomous ship navigation is highly dependent on the development of effective intelligent collision avoidance algorithms in real time. Most of these algorithms try to mimic human cognitive navigation abilities. To understand how the "captain" works and to identify its similarities or differences with intelligent navigation algorithms, someone must first consider all human functions performed for collision avoidance purposes (Statheros, Howells & Maier, 2007). To do this we need to analyze all the factors that affect ship collision avoidance.

In Picture No.2, the most important factors affecting safe navigation are presented, such as the type of ship, sea lanes and their characteristics, weather conditions, and available navigation technology. Regarding the type of ship, he can understand that a ship's maneuverability and behavior has a lot to do with its construction and thus different ship types have different navigational requirements. Also, for different types of ship (and cargo) there is traditionally also corresponding training for the crews. In autonomous ships, the algorithms have been developed that "understand" and can provide a prediction of the ship's behavior, but sometimes the navigation situation is too complex for such real-time algorithms to work effectively.



Picture No.2 - Factors affecting safe navigation on ships (Statheros, Howells & Maier, 2007)

Then, in terms of the state of the sea lanes, it relates to shipping traffic and port traffic in real time. Of course, this factor also includes the "movement" at the bottom of the sea, which most of the time is uncertain. For safe navigation based on this factor traditional manned crews rely on COLREG rules. It is important to note that most intelligent algorithms for ship navigation do not communicate with each other or with the traffic control center, unlike the captains who use the available means of communication. Therefore, the algorithms calculate the safest and optimal collision avoidance trajectory based primarily on the current state (speed, direction) of each vessel or obstacle and secondarily on the COLREGs rules.

Regarding weather conditions affecting the safe navigation of a ship, so far captains receive the information from available communication systems and satellites and then decide its course. However, most available algorithms for autonomous ships do not consider real-time meteorological data. Finally, regarding the technology available on board, today the crews have at their disposal a multitude of systems, sensors and instruments that help them navigate safely.

But again, the available algorithms are not yet developed to such an extent that they take data from all the instruments and systems that most modern ships have at their disposal to avoid a collision.

Generally, at an experimental stage, some intelligent ship navigation systems have been developed. Mathematical models of ship collision avoidance are effective when exogenous factors are not extreme. However, in case of extreme conditions the dynamics of the ship is non-linear, which introduces great complexity into the calculations. This complexity eliminates the ability of the ship's autonomous navigation system to act in real time. In addition, a combination of technologies such as neural networks, fuzzy logic, expert system and mathematical algorithms are available that can support an autonomous ship navigation system. Hybrid systems are the ones that look very promising but require a high level of intelligence to harmoniously merge the various AI technologies. On the other hand, machine intelligence does not prove to be fully equal to human intelligence to be established in autonomous ships (Statheros, Howells & Maier, 2007).

2.1.4 Collision Avoidance Systems in Autonomous Ships

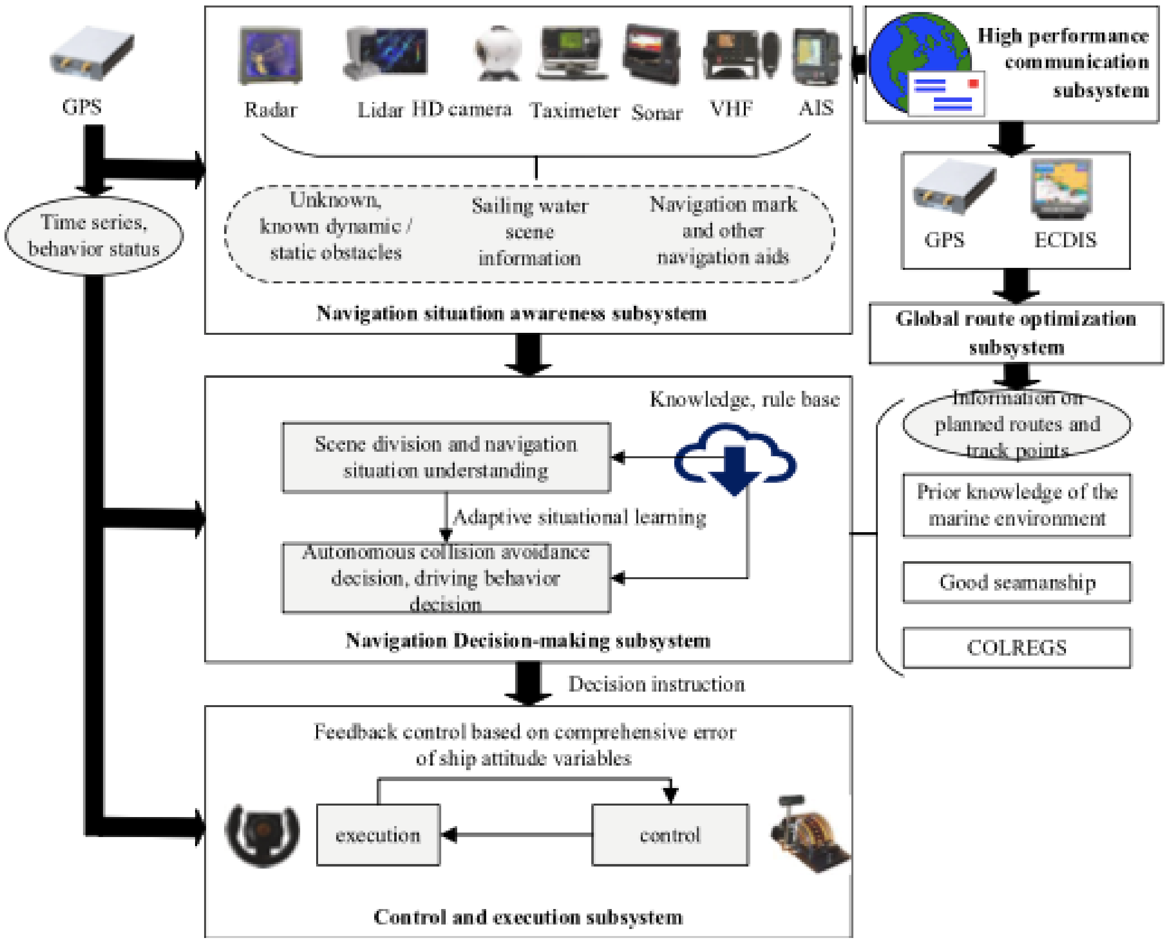
Recently, an extensive study entitled "*Collision-avoidance navigation systems for Maritime Autonomous Surface Ships: A state of the art survey*" was published, which we will then analyze in order to explain and understand collision avoidance systems for autonomous ships (Zhang et al., 2021).

Initially, this study talks about the difficulty of developing intelligent algorithms for safe navigation, due to the uncertainty that characterizes the factors that affect navigation, with the marine environment being the most important factor. The sea and its bottom are vast and human understanding of the sea is very limited. There are many places in the world's oceans that have yet to be studied but even in places where advanced environmental information is available there are always situations that cannot be predicted. In addition, to fully understand the current situation the ship receives a lot of information from internal and external sensors and other tools. Internal sensors refer to the ship's "control center" and provide data on the various onboard systems (such as the propulsion system, autopilot system, collision avoidance system, etc.) but also data such as the amount of fuel. External sensors refer to the GNSS satellite system, sea area, wind speed and direction, water depth, sound and visual signals (e.g. lights of other ships).

Data received from other tools include AIS data, meteorological forecast data and tide log data.

Due to the different characteristics of these three sources of information received by a ship, uncertainties and confusion are likely to arise. Finally, there is also a large degree of uncertainty regarding the accuracy of predicting obstacle motion and collision trajectory. The perception of all sensors and the entire decision-making process or navigation process has distinct space-time characteristics. So far, these sensors cannot detect or report the behavioral intention and movement state of dynamic obstacles, such as direction and speed of movement. Based on the above, it is understood that in an uncertain environment, the navigation decision-making system and algorithms of an autonomous ship should have the ability to evaluate the current situation based on heterogeneous information from multiple sources and the ability to create the optimal navigation strategy in order to face the problems of uncertainty.

In addition, in this study a separation of the collision avoidance system is made into five subsystems: global route optimization, navigation situation awareness, navigation decision making, control and execution) and communication high performance (HP communication). Figure 5 shows in detail the architecture of the navigation / collision avoidance system for autonomous ships and describes the cooperative relationship between the five subsystems, as we will describe them below (Zhang et al., 2021).



Picture No.3 - The architecture of the collision avoidance system (Zhang et al, 2021)

2.1.5 Route Optimization in Autonomous Ships

The route optimization subsystem aims to initially set the guidelines – with the help of ECDIS and the GPS system – to study and plan the best and safest route based on known obstacles and ports. The general principle of optimal routing is to find the shortest collision-free path from the known starting point to the known destination point according to existing information about possible obstacles (e.g. ice, reefs) or weather conditions in the marine environment. In general, this practice is limited to existing data sets, spatial constraints, hydro-meteorological data and COLREGs rules. Of course, whether it is determining the relationship between points, creating a database of coastal points, or using various visualization algorithms to solve the shortest path, there are still problems such as the difficulty of establishing a practical model and the lack of adaptability of models. With the development of Big Data technology and its widespread application in the maritime domain, the optimal route can be achieved by evaluating, classifying, and forecasting the massive AIS track data. Such models and software already exist and are used to optimize sea routes based on global maritime traffic, weather conditions, and factors such as ship speed and consumption.

2.1.6 Awareness of Navigation Status in Autonomous Ships

Navigational situational awareness is essentially the perception of internal and external information about both the ship and the marine environment. This subsystem is the basis for decisive decisions in the navigation of the ship and accurate information is very important. Many kinds of sensors are used such as ECDIS, various radars, LiDAR sensors, high-definition cameras, AIS, etc., which can obtain high-precision information for safe navigation, hydro-meteorological information, dynamic information of other ships and information about ports in real time. This multi-source information is merged and processed, so that static and dynamic obstacles are mapped in ECDIS and sent to the decision-making system.

In general, navigation situation awareness can be divided into three levels: obtaining information about the navigation environment, understanding the path scenario, estimating and predicting the situation. For traditional manned ships, the perception of information about the navigational environment generally refers to the acquisition of the position, course, speed, relative direction, relative distance of the ship and the target ship if any. The assessment and forecast of the situation, are the assumption of a future state of the ship in the dynamic marine environment, including predicting the trajectory and movement of other ships or obstacles. However, existing research on navigation situation awareness is simply related to the analysis of collision scenarios based on COLREGS rules.

No.	property categories	sub-properties	object properties
1	location attribute	longitude	*hasLongitude*
		latitude	*hasLatitude*
2	data attribute	relative distance	*distToEntity*
		direction	*hasDirection*
		speed	*hasVelocity*
		current state	*currentAttribute*
		maximum	*hasMax*
		minimum	*hasMin*
3	relationship attribute	join conditions	*connectTo*
			from
			to
		incorporate relational	*has*
		orientation relation	*hasBehindLeft*
			hasBehind
			hasBehindRight
			hasFrontLeft
			hasFront
			hasFrontRight
			hasLeft
			hasRight
		position relationship	*isOn*
			isFrom

Table No.1 - Characteristics of an ontology model (Zhang et al, 2021)

In the same study, it is proposed that the navigation state awareness subsystem performs the state estimation using ontological features. Heterogeneous information from multiple sources is obtained, defined as specific entities and classified based on their properties. Table 2 shows such a model that includes "entities", such as location defined by data such as longitude and latitude.

2.1.7 Making Decisions in the Operation of the Autonomous Ships

The decision-making subsystem is the most basic part of the navigation system of autonomous ships. The subsystem receives its results as input navigational situation awareness subsystem and collects all information of the navigational situation, including not only the current position, speed and course of the autonomous ship, but also information about potential obstacles. Based on this information it "decides" the route the ship will follow. The decision-making system also receives as information the results provided by the path optimization subsystem. In general, the decision-making subsystem requires further development and is not yet complete. Decision-making algorithms should be "trained" using tools such as artificial intelligence and machine learning to decide the safest path to avoid collisions without human intervention.

2.1.8 Controlling and Running Navigation

After deciding on the sea route, the ship will follow, the navigation is made. Major functions of the subsystem are to control speed, thrust and rudder so that the safest trajectory that has been decided is followed. During the execution of the route of the autonomous ship, some deviations and possible errors between the predicted and the current route are taken into account. This is due to the uncertainty caused by ocean currents, unexpected weather and other environmental factors. Therefore, a feedback control layer is required that will continuously control the motion of the ship based on these errors during the execution of the route. In this way, navigational decisions can be adjusted in real time and re-planned, with the aim of avoiding the dangers that arise without having been initially foreseen.

In terms of controlling the ship's movement, it is not significantly different for an autonomous ship and a conventional ship. Both types of ships have six degrees of freedom in their movement, they follow a certain predetermined trajectory, and the control of these movements is constantly monitored taking into account the error of the current and planned path. The only difference is who will have the control of the ship's motion, the crew on board, the crew ashore or some well-trained algorithm.

2.1.9 High Performance Communication in Autonomous Ships

The high-performance communication subsystem guarantees the exchange of data or safety information between satellite, ship and land. There are four modes of communication with respect to autonomous ships: (1) ship-to-ship, (2) ship-to-shore, (3) ship-to-wireless data nodes, (4) ship-to-satellites. Due to the need to transmit a lot of information from sensors, from system performance instruments, from cameras and radars, the communication volume is large. Therefore, unmanned ships require high-speed, high-performance networks.

When it comes to navigation / collision avoidance, the high-performance communication subsystem is particularly important. It has been found that on busy sea freight routes the increased use of AIS causes overloading of the automatic digital signal exchange network. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) has already started using the very high frequency data exchange system (VHF Data Exchange System - VDES). The VDES includes different communication subsystems such as AIS and Application Specific Messages Archive (ASM) channels. The key feature of VDES is that in addition to direct ship-to-ship communication, it uses a satellite component that can support all the types of communication we mentioned above providing greater data capacity and greater range.

2.1.10 Electronic Navigation in Autonomous Ships

In 2006, the development of an e-Navigation system under the auspices of the IMO began. The e-Navigation system is a system for the coordinated collection, integration, exchange, display and analysis of marine information by electronic means in order to enhance the capabilities of navigation and other related services, improving the level of safety at sea but also the protection of the marine environment. Electronic navigation seeks to integrate existing navigational technology to maximize safety and improve the efficiency of maritime transport. The IMO has developed a Strategy Implementation Plan (SIP) for the implementation of electronic navigation in the following ship processes/functions. As user needs evolve, new e-navigation strategies can be incorporated into SIP as appropriate (IMO, 2021c).

S1: Improved, harmonized and user-friendly ship bridges

S2: Means for standardized and automated reporting

S3: Improving the reliability, durability and integrity of bridge equipment and navigation information

S4: Integration and presentation of available information on graphical displays received via communication equipment

S5: Improved communication of various navigation software

Diagram No.2 - Diagram of the operation of the MCP platform (Zhang et al, 2021)

Upon the development of electronic navigation technology, the Maritime Connectivity Platform (MCP) was also developed and tested, which is a global communication network that enables the efficient, secure, reliable and seamless electronic exchange of information between all shipping stakeholders (Figure 6). The combination of electronic navigation with autonomous ship functions and artificial intelligence technology can significantly reduce the impact of human error and enhance navigational safety and maritime transport efficiency.

2.1.11 Sensor Systems in the Operation of the Autonomous Ships

As was mentioned in the previous chapter, several new technologies are needed for autonomous ships and safe navigation, including sensors. Autonomous ships should be equipped with innovative sensors that will support both the ship itself and the remote-control center or operators loading and unloading goods. Sensors help to "aware" of a situation and are essential for safe navigation in terms of transport quality and protection of the environment in which an autonomous ship operates. Below we will focus on the most common modern sensors used for situational awareness and autonomous navigation as well as the available technologies that can be combined to form part of autonomous shipping (DMA, 2017, Ringbom et al., 2020).

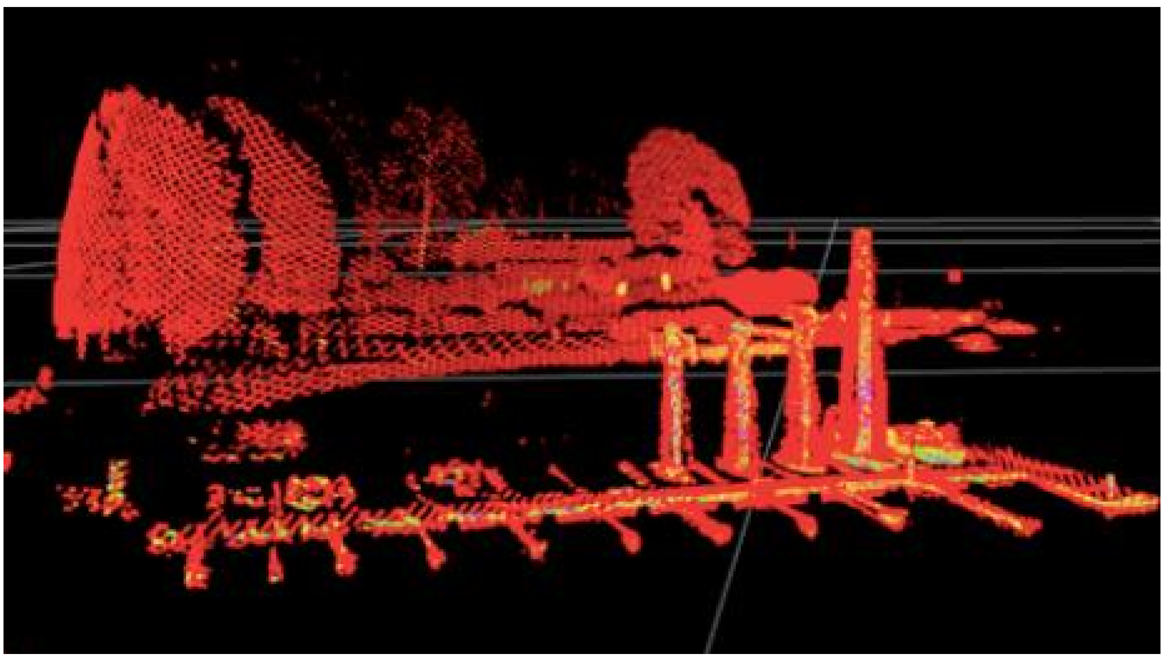
2.1.12 Modern Sensors

The range of sensors available on modern traditional manned vessels typically includes perceptual sensors such as cameras, radar, and positioning sensors such as Global Navigation Satellite Systems (GNSS) and Inertial Navigation Systems (INS). Furthermore, the automatic identification system (AIS) is not basically a sensor but is used as a source of data for the position of ships in real time. Other sensors implemented in autonomous vessel systems may include audio pickup systems to detect and locate external sound signals, weather sensors that can be used to monitor navigational conditions and the operating conditions of other sensors, and sensors that monitor the internal condition of the vessel e.g. engine performance (Thombre et al., 2020).

More specifically, Global Navigation Satellite Systems (GNSS) is a term that covers various satellite navigation systems such as the US-based GPS (Global Positioning System), the Russian GLONASS Satellite System, the European Satellite System Galileo Navigation and the Chinese BeiDou Navigation Satellite System (BDS). GNSS systems rely on receiving radio signals from satellites and using them to determine a ship's position. To improve the validity of position estimation, GNSS systems are often combined with Inertial Navigation Systems (INS) that use Inertial Measurement Units (IMUs) to estimate vessel motion in order to provide correct position estimates (DMA, 2017).

Also, an important information system is the AIS (Automatic Identification System) used to collect and transmit data via VHF radio frequencies as required by the SOLAS Convention (chapter V, regulation 19) for all passenger ships and cargo ships as well as fishing vessels over 15 meters in length. AIS data is useful for situational awareness, but its availability, correctness and validity are not guaranteed for all vessels. Therefore, AIS cannot provide sufficient information for autonomous navigation (Ringbom, et al., 2020).

Then RADAR (Radio Detection and Ranging) and LiDAR (Light Detection and Ranging) sensors essentially measure a range based on radio frequencies and optical or infrared light frequencies, respectively. An important difference between RADARs and LiDARs is in the dispersion of the signal in space. The RADARs use antennas with a relatively large beam width, so there are difficulties in distinguishing small structural details in the objects they detect. Modern LiDARs, on the other hand, rely almost exclusively on lasers and therefore have much better resolution in the signals they receive. Therefore, LiDAR sensors can image a model in great detail, even from a great distance. Their disadvantage, however, is that they are very sensitive to weather phenomena, such as rainfall. In contrast, radio waves penetrate clouds, smoke and fog better and therefore RADARs are the obvious choice as long-range systems on ships. Available LiDAR sensors are generally considered insufficient for most uses on an autonomous ship while their development requires high costs mainly due to the extreme weather phenomena they must support. However, it is likely that the range and resolution of LiDAR technology will improve in the near future, allowing their use on autonomous ships (Thombre et al., 2020).



Picture No.4 - Performance of a marine environment as captured by a LiDAR (DNV – GL, 2018b)

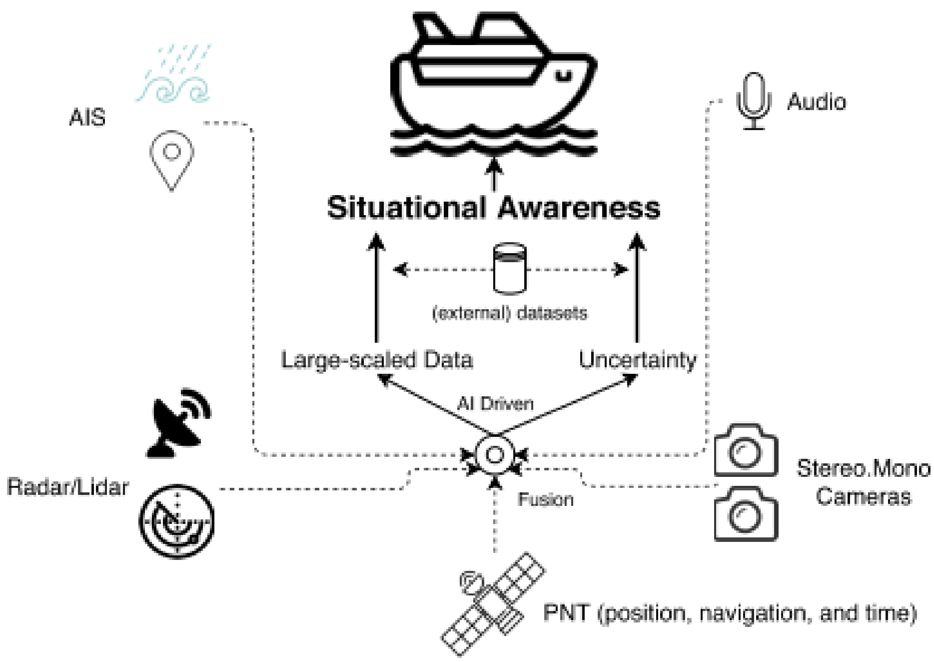
Finally, in sensor systems, various visual and audio sensors are important. By optical sensors we mean all sensors that capture at least a two-dimensional image similar to a human eye, while acoustic sensors are mainly microphones and especially microphone arrays, which have the potential to provide valuable information about the marine environment. In an autonomous navigation system, cameras are used in place of the standard "shift" of sailors (watchkeeping). Different types of camera systems are necessary for different shift work. For example, multiple camera sensor arrays may be needed for 360-degree surveillance around the vessel. The main challenge with camera systems in marine applications is the requirement for increased resolution, which, in turn, increases the requirements for computing capacity, storage capacity and data transfer. As for sound sensors, they can be useful both for describing the ship's environment (e.g. different types of ships could be detected, classified, and tracked by analyzing the sounds they make, such as engine sounds), as well as for the automatic detection of emergencies such as damage detection (Thombre et al., 2020). Remote Control Centers

An important element of the innovation of autonomous ships, in almost all levels of autonomy, are the remote-control centers or shore control centers (remote-control station/center or shore control center). The effectiveness of shore control centers is mainly based on communication with the ship and it is crucial to have properly trained personnel and at the same time have sufficient information available so that the operators are fully aware of the ship's situation.

For a remote operator to gain full awareness of the ship's situation, sufficient information must be transferred from the ship's sensors and systems to the shore control center in a timely manner. This places requirements on the type, volume and latency of the information transmitted and how it is presented to the remote operator. Although the conventional modern sensors that we analyzed in subchapter 2.4.1 are mainly used, the information must be presented in a way that can be understood by the remote operator (DNV - GL, 2018).

The various information in the remote-control center, it could be the same as available on the bridge of a conventional ship. The main problem that arises is the connectivity and telecommunication of the ship with the control center which, although constantly improving, has only been tested in areas with significant communications capacity. The maximum capacity required for real-time transmission of information from sensors and instruments can be several tens of megabits per second depending on the sensors used. Availability, latency and communication capability depend primarily on the telecommunications carrier available at the specific location of the ship, as well as the communication technology used on board and at the control center. Ships operating close to shore will be able to take advantage of ground carriers' telecommunication while ships operating on the high seas must rely on data transfer via satellite communication (DNV - GL, 2018).

In addition, a significant problem arises with the maintenance or repair of communication equipment on board. Since the maintenance of the equipment on board cannot be carried out during the autonomous operation of the ship, the reliability should be such that the maintenance is carried out only during the stay in the ports (DNV - GL, 2018b). For levels of autonomy where navigation relies entirely on the ground control center, the remote operator/navigator must make immediate decisions based on the awareness of the situation at hand or evaluate decisions already made by an algorithm, based on always the safest navigation and operation of the ship. However, in the end, the final decision will depend on the ability, skills and best judgment of a human in the control center, as is the case with traditional manned ships (DNV - GL, 2018b).



Picture No.5 - Operation diagram of a remote-control center (DNV – GL, 2018b)

Picture No.5 shows the basic functions of a remote-control center for autonomous ships. The ship is equipped with various automations such as automatic reports, automatic anchoring/mooring systems and systems that support its fully automatic operation. Then the data resulting from the automations on board combined with the data from satellites are processed appropriately. The control center supports functions such as remote monitoring of the ship, control of mechanical systems, decision making, navigation and piloting, collision avoidance, etc. Finally, the control center can help optimize a ship's operations by helping to save energy and manage fleets for greater profitability.

The safety and quality in shipping has to do both with the safe operation and management of the ship, cargo and crew, as well as with environmental management and the prevention of pollution from ships. The new technologies, systems and equipment intended to be used for the autonomous ships should follow all the safety and quality rules of the international conventions to ensure its safe operation. However, issues that endanger the safety of the ship such as cyber-attacks, but also the effects that the operation of the autonomous ship can have on the environment, are a great challenge for shipping.

2.1.13 Cyber Security in the Operation of the Autonomous Ships

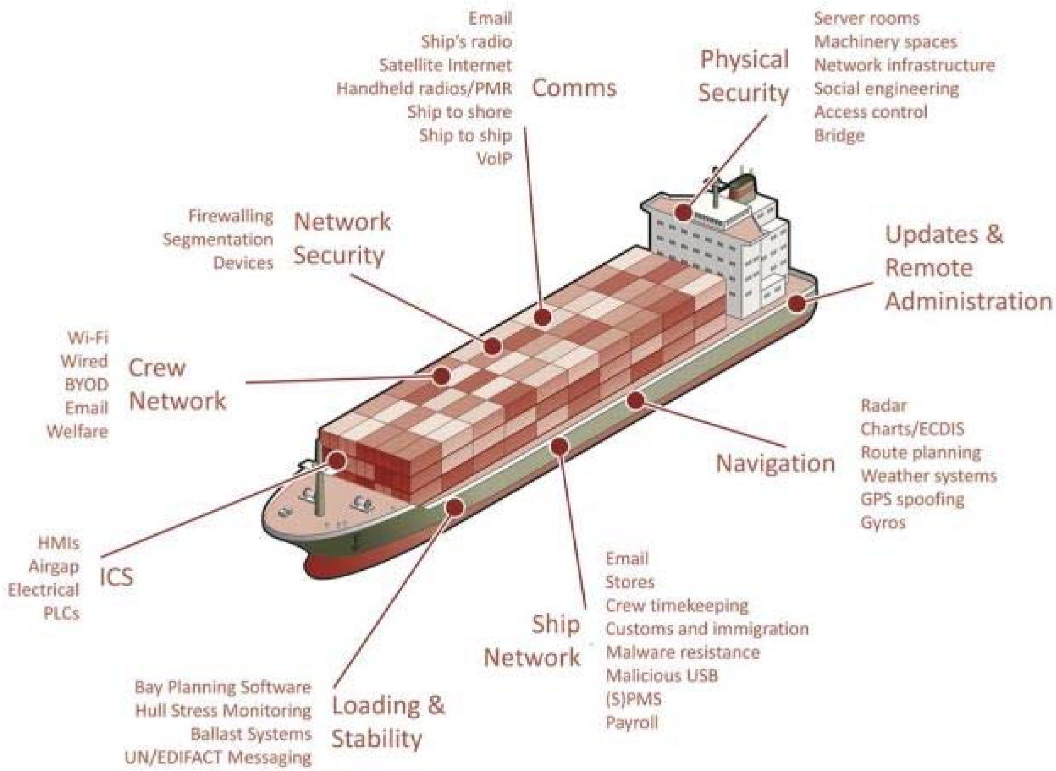
As autonomous ships are heavily dependent on automated systems that require excellent connectivity both with each other and with global satellite networks, cyber threats are among the most worrying in terms of their security. This is an ever-increasing risk in increasingly digitized shipping. Most of the safety issues that autonomous ships face are almost the same as conventional ships. For traditional manned vessels the guidelines for dealing with safety issues are well established and the institutional and legislative framework for good practice in maritime transport already exists. Cyber security is a very recent security issue in shipping and that is why the various parties involved are constantly enriching and strengthening their armor against such risks. It is therefore important to first see what the case has been so far for conventional ships before analyzing the situation for autonomous ships.

In June 2017, it was decided under the ISM Code that from the year 2021 shipowners must have implemented cyber risk management within their ship security management system (SMS) (Tam & Jones, 2018). Already in the shipping community there are concerns and thoughts about dealing with cyber-attacks since there have been several large attacks. The best-known example is the 2017 attack on the shipping company A.P. Moller – Maersk, which fell victim to a major cyber-attack caused by the NotPetya malware, which also affected many organizations worldwide. As a result, Maersk's operations were disrupted with huge implications. Specifically, Maersk's container ships were left "unruly" at sea and its 76 port terminals around the world were shut down. Recovery was quick, but within a short time the company suffered financial losses of up to $300 million (Greenberg, 2018).

So far, efforts have been made by various stakeholders such as ship owners, classification societies and international regulatory bodies, with the aim of shielding the shipping industry from cyber-attacks. A recent survey showed that while the threat may be common, it is treated very differently among industry professionals around the world. Data collected from two sample groups (one in Europe and one in Asia) demonstrated that, based on the stage and level of technology adopted by those involved, cyber security is perceived differently between these two groups while the pandemic of COVID-19 has highlighted these differences more strongly (Karamperidis, Kapalidis, & Watson, 2021).

Despite the increasing number of cyber incidents on corporate networks and data, the maritime transport sector has been slow to respond to them. The fact that cyber risk is somewhat "intangible" means that its consequences may not be obvious and in these cases difficult to identify and address. Many times, computers, software, applications or technology systems on board can continue to operate without noticeable performance problems after attacks. However, there are also cases where a cyber breach, it can affect an organization's entire infrastructure, including its fleet and offices around the world (Karamperidis, Kapalidis, & Watson, 2021).

Figure 10 comes from a British security consultancy and shows in detail the points of a traditional ship that can be the target of attacks. These include sensors, communication systems, connectivity networks, automation, load, ballast, stability systems, navigation systems, etc. As the complexity of ships continues to increase, so do the vulnerabilities of ships. For this reason, each company is asked to study the possible threats and risks based on its ships and then consider the ways of acting and dealing with the attacks.



Picture No.6 - Ship Vulnerabilities in a Cyber Attack (PenTestPartners.com, 2022)

According to BIMCO's cyber security handbook, typical vulnerable shipboard systems are the following (BIMCO, 2020):

• Cargo management and loading systems. The digital systems used for loading, managing and controlling cargo, including dangerous cargo, communicate with various systems ashore, including port terminals. These systems usually include tracking elements of the ship's path of loading, unloading, etc., which are available through the Internet. These communications make cargo management systems as well as cargo and container data (type, quantity, value) vulnerable to cyber-attacks.

• Bridge systems. The increasing use of digital systems connected to satellite networks for information and data delivery makes these systems vulnerable. Non-satellite linked bridge systems can be just as vulnerable as terrestrial sources are used to update them. A cyber incident can extend to disrupting or interfering with an operation and therefore can affect all navigation-related systems, including ECDIS, GNSS, AIS, VDR and Radar/ARPA.

• Navigation systems. The use of digital systems to monitor and control machinery, propulsion and steering systems makes these systems vulnerable to cyber-attacks. The vulnerability of these systems can be increased when used in conjunction with remote monitoring and control.

• Access control and security systems. Digital systems used to support access control to ensure the physical security of a ship and its cargo, including surveillance, ship security alarm and on-board electronic systems are vulnerable to cyber-attacks.

• Administrative and crew welfare systems. Computer networks used for ship management or crew welfare are particularly vulnerable when accessing the internet and email. This can be exploited by cyber attackers to gain access to onboard systems and data. Software used by ship management companies or ship owners is also included in this category.

• Public passenger networks. The various wired or wireless networks installed on board for the benefit of passengers, for example systems entertainment of visitors, should be considered vulnerable and not linked to no system vital to the safety of the ship.

• Passenger service and management systems. The digital systems that used for boarding, servicing and access control may hold valuable passenger data. Smart devices (tablets, portable scanners, etc.) can be used to gain access by hackers to other systems.

• Communication systems. Internet connectivity via satellite and/or other wireless communication increases the risk of attacks, and recent research shows that, for example, VSAT signals are vulnerable to attack. In some cases, encrypted communication systems should be preferred. Some systems also include communication with public authorities to transmit the required ship and cargo reporting documents. Authentication and verification of various documents by said authorities should be strictly followed.

Picture No.7 shows the potential attackers as well as the potential motivations for cyberattacks gathered by BIMCO. It is found that shipping can be faced with a variety of incidents, from simple incidents of crew negligence that may plug in an infected USB, to government organizations or terrorist's intent on harming global trade.

Finally, it is important to separate the ship's systems into two technology categories. The former support Information Technology (IT), in which data is used for information, and include networks, accounts, e-mails, electronic manuals, etc. The latter support Operational Technology (OT), in which data is used for operational processes. OT systems can be SCADA, ECDIS, AIS, GPS, remote support, onboard measurement and control systems. A cyber-attack on IT systems can damage a company's reputation or finances, while an attack on OT systems can lead to consequences that harm the crew, the environment, the safety of the ship (BIMCO, 2020).

Group	Motivation
Accidental actors	■ No malicious motive but still end up causing unintended harm through bad luck, lack of knowledge or lack of care, eg by inserting infected USB in onboard IT or OT systems.
Activists (including disgruntled employees)	■ revenge ■ disruption of operations ■ media attention ■ reputational damage
Criminals	■ financial gain ■ commercial espionage ■ industrial espionage
Opportunists	■ the challenge ■ reputational gain ■ financial gain
States **State sponsored organisations** **Terrorists**	■ political/idealogical gain eg (un)controlled disruption to economies and critical national infrastructure ■ espionage ■ financial gain ■ commercial espionage ■ industrial espionage ■ commercial gain

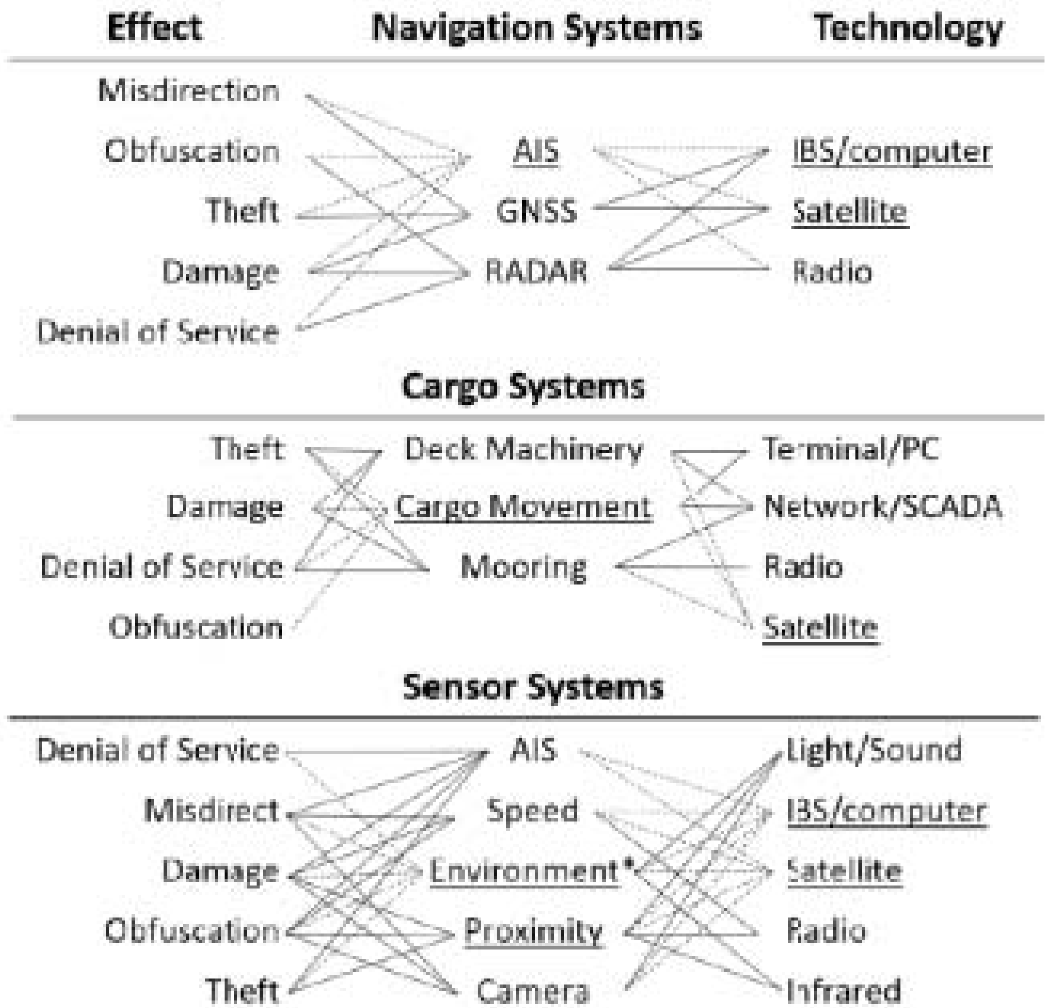
Picture No.7 - Potential attackers and motivations for cyber-attacks on ships (BIMCO, 2020)

2.1.14 Cyber Security for Autonomous Ships

Although the shipping industry is aware of the importance of cyber security, there is still confusion about how serious the cyber threat really is, what the risks are to businesses and what actions can be taken to address them should be taken. Autonomous ships, depending on their level of autonomy, can have little to no crew. This to some means that these ships are not as vulnerable to piracy incidents as there is no crew to take hostage. But this does not reduce the chances of the risk of cyber-attacks. Autonomous ships which basically depend on Information and Communication Technologies, may be the target of attackers who could remotely control the ship, resulting in serious damage or disruption to the ship's functionality.

Picture No.8 shows systems that are considered basic and necessary for autonomous ships, along with their vulnerabilities and possible types of attacks (Tam & Jones, 2018). For example, it is possible for an attack on the navigation systems of an autonomous ship to include course alteration, power failure (obfuscation), cargo theft, damage, etc. Attacks can also be made on navigation systems (AIS, GNSS, RADAR), cargo handling systems (deck equipment, mooring and anchoring mechanisms, engine room), and sensor systems (speed, environment, proximity, cameras).

An attack on the autonomous ship's navigation system enables hackers to gain control of the ship and direct it wherever they wish. Such attacks can cause incalculable damage to international trade. Various studies have been done with possible scenarios and possible countermeasures, in order to inform and sensitize all the relevant agencies in order to create even more secure systems. (Hoyhtya et al, 2017, Kavallieratos, Katsikas & Gkioulos, 2018, Tam & Jones, 2018).



Picture No.8 Cyber Attack Scenarios (Tam & Jones, 2018)

Someone can note that the above systems do not differ greatly from the systems considered vulnerable in traditional manned ships. Therefore, many of the guidelines and procedures followed for manned vessels will also apply to autonomous vessels. However, additional care is needed for systems on land, in case a remote-control center is used depending on the level of autonomy of the ships. It should also be mentioned that training the staff about the risks and how to deal with the cyber-attack will be an additional cost on the balance sheet of the unmanned ship, especially since the shipping company can be held liable if it does not take reasonable measures to protect the information from unauthorized access. Undoubtedly, security from cyber-attacks should be a priority when designing new technologies for autonomous ships.

2.2 Technologies for MAAS – Existing Applications and Systems Contexts

The idea of autonomy in shipping, is not new. In 1973 in the book "Ships and Shipping of Tomorrow", Rolf Schonknecht described the ships of the future as ships that would sail using computers while a captain could carry out his duties in an office building somewhere on land. A little later, in the 1980s, the idea of unmanned smart ships was discussed in Japan, but when cheaper foreign crews became available, the idea was dropped. In the 2000s, the concept of smart ships re-emerged, first through an IMO initiative in 2005 aimed at increasing maritime safety, and in 2007 in a document on the development of the European shipping industry by Waterborne TP.

The IMO vision for electronic navigation (e-Navigation) was defined as "the harmonized collection, integration, exchange, presentation and analysis of maritime information, between ships and land, using electronic means to improve navigation and related services, for safety at sea and the protection of the marine environment". (Burmeister et al., 2014) Through the vision of electronic navigation, the IMO aimed to improve shipboard navigation systems, manage ship traffic information, and improve ship-to-ship and ship-to-ship communication infrastructures with the coast. While the specific vision did not speak of unmanned and autonomous ships, it laid the foundations for the main procedures carried out on the bridge of a ship to be carried out for the most part with the use of technology.

A few years later, the European Union, in order to maintain and strengthen the global leadership position it has held for years in many maritime sectors, developed together with a set of leading European stakeholders related to the sea, the European Platform for Floating Technologies (Waterborne TP). Together with a strategic research program and an implementation plan, they jointly published a vision document for the future development of the shipping industry in 2020 regarding competitiveness, innovation, safety and environmental requirements (Rodseth and Burmeister, 2012).

Based on this vision, Waterborne TP has identified twelve priorities that could help Europe develop its shipping sector. The main project that has been found to combine multiple benefits is the "autonomous ship". (Burmeister et al., 2014) An autonomous ship was defined as a ship equipped "with control systems and communication technology that enables wireless monitoring and control, including advanced decision support systems and capabilities for remote and autonomous operation." (Burmeister et al., 2014) To support this venture, the European Commission funded a new research project on the construction of an autonomous ship in order to investigate the feasibility of this idea from a technical, economic and legal point of view. This project was called MUNIN (Maritime Unmanned Navigation through Intelligence in Networks). (Burmeister and Rodseth, 2014)

2.2.1 Differences Between Conventional, Remotely Navigated and Autonomous Ships

Unmanned merchant ships are one of the newest ventures in maritime technology and many large organizations and companies around the world are researching their potential use and operation. The absence of the human factor is not the only difference between a conventional ship and an autonomous one. An important difference between the two is the processing, management and implementation of the respective decisions that are applied by the crew and the master on a conventional ship. An unmanned ship can be achieved with a combination of remote, automatic and autonomous control.

First, before going into the explanation of the above degrees of control, it should be clarified that there is no generally accepted definition of "ship". Different texts provide their own definition depending on the subject. Therefore, in this work, a ship is defined as one that has its own propulsion and steering system, performs commercially useful transport and is subject to a political regulatory framework. At the same time, it should be pointed out that the term Maritime Autonomous Surface Ship (MASS) was proposed by the IMO Commission as the official general term for autonomous ships. MASS were established as “ships having different degrees of autonomy, they can function independently of human interaction”. (IMO, MSC 99, 2018)

Today, most conventional ships operate with periodically unmanned engine rooms, as many of the engine room systems have automatic done extensively. At the same time, navigation functions today are distinguished by some level of automation as ships have relatively advanced anti-collision radar (ARPA) and common automation systems such as the autopilot and systems such as the Automatic Identification System (AIS) and the Long-Range Identification and Tracking (LRIT) which gather information from the ship's environment. However, the crew is necessary to carry out maintenance work and monitor its operations. (Mogens et al., 2017).

The automation is used as a general term for the processes that enable the ship to perform certain functions and to be able to choose between alternative strategies without human control. In other words, the automatic ship simply has more advanced automation systems than a conventional ship, which can complete certain demanding functions without human interaction. (Rodseth and Burmeister, 2012) An autonomous ship on the other hand, is a ship that has some level of automation and self-management. In other words, autonomy is the result of the application of "advanced" automation to a ship, so that it implements some form of self-governance. A common autopilot, although automatic and possibly quite advanced, does not provide autonomy under this definition. It will always follow a given heading. (Rodseth and Nordahl, 2017)

The limited autonomous ship can operate fully automatically in most cases and at the same time have a predefined option to solve commonly answered problems, e.g. collision avoidance. It also has set limits on the options it can use to solve problems, e.g. maximum deviation from the planned route or arrival time. (Rodseth and Nordahl, 2017). The fully autonomous ship on the other hand, handles all situations by itself. It works with the help of advanced IT systems and sensors and requires no human interaction. This can be a viable alternative for operations at short distances and in highly controlled environments. If no constraints are set, the system could be called "intelligent" and have complete freedom to take actions within its expertise, it is known in advance what the possible outcomes of the decision will be. (Rodseth and Burmeister, 2012)

A remotely piloted ship can be controlled remotely from a control center on land. All the actions it performs follow a programmed sequence and are characterized by a high degree of automation as the system is expected to operate safely by itself. (Rodseth and Nordahl, 2017) Otherwise, if any unexpected events occur or when an automatic operation is completed it will request human intervention. Personnel at the shore control center are always available to step in and initiate remote control where deemed necessary. In order to adopt a common guideline in the categorization of MASS, the IMO proposed the following four degrees of autonomy (IMO, MSC 99, 2018):

1. Ships with automated processes and advanced decision support functions as well as a crew on

board that controls all of its systems and functions.

2. Ships which are controlled and operated by remote control from some remote location, but the crew is still on board.

3. Ships which are controlled and operated by remote control from some remote location, but no crew is on board.

4. Ships that are fully autonomous and can handle all situations without requiring human intervention.

In the first category, the ship's bridge is always manned, and the crew can immediately intervene in the current operations. This will generally not require special regulatory measures as it is not entirely a type of autonomy. It is simply about applying advanced automation systems to conventional ships. In the second category, the ship can operate without a crew on the bridge for limited periods, e.g. in open seas and fair weather, and the crew to be called to the bridge in case of trouble. A critical issue in this case is that it will take some time to assemble the crew on the bridge. Finally, in the third category the ship's bridge is designed for unmanned operation and this means that even in an emergency there is no one on board who is authorized to take control.

2.2.2 Technical Development and Testing of Autonomous Ships

Inside the European Union, there are many research and development projects aimed at the construction of autonomous commercial ships, while recently a Japanese consortium with a similar purpose has appeared. However, thorough testing in real-world conditions is crucial to ensure that the systems being built work properly and to ensure the minimum safety and reliability requirements for the autonomous ships of the future.

At the beginning of 2016, the Finnish collaboration DIMECC was launched, which connects companies involved in the construction of autonomous ships. After many years of research, the companies involved already have some ready-made technical solutions. DIMECC has established a test area for the autonomous, unmanned ships in Finland, which is named "Jaakonmeri test area". The "Jaakonmeri test area" is actually open for testing of unmanned ships, or related technologies, to anyone in the world. The aim of the creation of this area is to accelerate the process of developing autonomous ships, worldwide.

2.2.2.1 The AAWA System in Autonomous Ships

The AAWA (Advanced Autonomous Waterborne Applications) project is a Finnish project, funded by Tekes (Finnish Funding Agency for Technology and Innovation), to the amount of 6.6 million euros, which aims to investigate specifications and preliminary designs required to make autonomous ships a reality. (AAWA, 2016) To achieve this goal, it brought together ship designers, equipment manufacturers, Finnish research institutions and leading members in the shipping industry.

Rolls-Royce, which is the head of the AAWA consortium, in its vision presentation stated that it is interested in building a system that will perform the remote control of autonomous ships. At the same time, he stated that "there will not be an exclusively remote-controlled or autonomous ship, but rather a hybrid of the two that will depend on the type and operation of each ship. As the technologies required to realize autonomous ships are currently feasible, the challenge is to make the technology reliable and cost-effective.” (AAWA, 2016)

As part of the project, a ship control system has already been created, which will be integrated into a satellite telecommunication network as well as land-based systems that will allow the optimal use of existing communication technologies for autonomous ship control. Finferries will support this project by providing the Stella, a 65m vessel, which will be used to test the sensors in a range of operational and climatic conditions. ESL Shipping will explore the implications of autonomous ships in the short sea shipping sector and best practices to ensure its cyber security. In the short term this means that tugboats will be built, which can be operated remotely from a nearby land-based control centre. But in the long term, Rolls-Royce envisages a control center staffed by 7 to 14 people that will be able to monitor and control an entire fleet of merchant ships around the world.

Picture No.9 - Autonomous ship model according to the AAWA project (Source: AAWA, 2016)

2.2.2.2 The MUNIN System in Autonomous Ships

The MUNIN (Maritime Unmanned Navigation Intelligence in Networks), is a research project carried out between 2012 and 2015, with a budget of 3.8 million euros and co-financed by the European Union and eight partners with different scientific and industrial backgrounds in order to study the technical, economic and legal feasibility of an autonomous ship. Its basis was the assumption that "*unmanned ships can sail autonomously on a transcontinental voyage at least as safely and efficiently as manned ships*" (MUNIN, 2013).

While his name is an acronym, it also references a character from old Norse mythology. Munin, meaning memory or mind, is one of the ravens of the god Odin that flies around the world independently during the day and night. less than what he has collected for his master in the evening. Like the crow, the unmanned ship travels autonomously around the world, but returns safely to its home port (Burmeister and Rodseth, 2014).

MUNIN's vision was to develop a platform with the first systems of an autonomous ship, which on the one hand will have the ability to guide the ship autonomously but on the other hand an operator in a remote control center on land, will be able to gain control of each at any time. Speaking to Newsweek magazine, Ornulf Jan Rodseth, director of the Norwegian research institute Marintek that participates in MUNIN, pointed out that the project has both a short-term and a long-term goal. The first considers the possibility of reducing the number of crew to one or two people, since most of the actions will be carried out from a remote center located on land. The second one considers the creation of fully automated ships without any crew, which in his opinion will eliminate maritime accidents of all kinds. Although full autonomy for a commercial ship may be difficult to achieve in the near future, the research conducted will benefit maritime transport in the short term by offering improved navigation systems.

Picture No.10 - Autonomous ship model according to the MUNIN project (Source: MUNIN, 2013)

2.2.2.3 The Revolt System in Autonomous Ships

The ReVolt is DNV GL's project to build a 60-meter-long container ship with a capacity of 100 TEU and an average speed of 6 knots. Instead of using conventional fuel, the ship in question will be powered by a 3000 kWh battery, which reduces operating costs both through fuel savings and by minimizing the number of high-maintenance components on board. The vessel is said to travel 100 nautical miles before its battery needs recharging. At the same time, the energy required to recharge the batteries may come from renewable sources, which will also lead to a reduction in carbon dioxide emissions. Estimating a lifetime of 30 years, this ship compared to a diesel ship could generate a profit of USD 34m (€31.5m). For the purpose of testing this particular ship in practice a 1:20 scale model has been built. DNV GL is currently in a testing phase of ReVolt which started in the third quarter of 2015. DNV GL is building sensors, cameras and radars to monitor the ship's environment, together with the Norwegian University of Science and Technology (NTNU) and Kongsberg Maritime.

Picture No.11 - Autonomous ship model according to the Revolt project (Source: DNV GL, 2018)

2.2.2.4 The Yara Birkeland in Autonomous Ships

In the spring of 2017, the Norwegian companies Kongsberg and Yara International announced that they are developing an autonomous container ship with a capacity of 100-150 TEU with zero gas emissions. The ship is named after Yara founder and pioneer Kristian Birkeland and will be the world's first fully electric container ship. Kongsberg provides high-tech systems and solutions to the commercial shipping, defense, aerospace, oil and gas industries and is responsible for the development and supply of all key technologies required for ship operation.

It is estimated that the ship can replace up to 40,000 diesel-powered truck transports and thereby reduce NOx and CO2 emissions while improving safety. The ship will operate within 12 nautical miles of the coast (Norwegian territorial waters) and between three ports in southern Norway. Distances between ports vary from 7 nautical miles to 30 nautical miles. Since the ship will transport products within a well-defined route from Yara's production plant in Brevik to a facility in Larvik in Norway, it will greatly simplify the task of preparing it. The ship is scheduled to launch as a manned ship with simultaneous land-based control in 2019 and is expected to be able to perform autonomous operations from 2020 onwards. (Komianos, 2018)

Picture No.12 - Autonomous ship model according to Yara Birkeland project (Komianos, 2018) Description of the operation of the MUNIN & AAWA research projects

Early studies of the construction of unmanned commercial ships raised questions among researchers about how well their operational procedures should be designed to avoid incidents that would jeopardize the safety of navigation. It was therefore deemed necessary, that in order to minimize the risks of automation, the transition from today's conventional shipping to the truly autonomous shipping of the future should be gradual.

The case investigated within the MUNIN project was an unmanned dry bulk carrier of 75,000 dwt. This ship was considered the most suitable type of ship for the first applications of autonomy in commercial ships, as it usually operates at low speeds, travels long distances, with only one loading and unloading port, and carries cargo that does not require constant monitoring and maintenance by the human side. (Burmeister and Rodseth, 2014) At the same time, it was decided that the ship will be fully unmanned during the main part of the journey, operating with autonomous navigation and control systems. During approach and mooring at a port, however, a control team will board it and operate it directly from the bridge. (Burmeister et al., 2014)

In the case investigated in the AAWA project, a general cargo ship was selected, which will be unmanned during all phases of the voyage. Therefore the process of approaching the dock and mooring will be automatic or semi-automatic. In order to make this project a reality, the piloting of the ships as it is carried out today, will be changed. Possibly, the first applications will be carried out using VTS and then in order to facilitate the piloting of the ship during the mooring, cameras and radars could be used which will not be on the ship but along the docks, for faster and better connections. (AAWA, 2016)

Despite the autonomous technology on board, in both studies, there will also be a Shore Control Center (SCC), which will be connected to all the ship's systems. The people who will be in the center shore control officers will not perform direct remote control of the ship but will be responsible for monitoring the proper operation of its autonomous systems. Only in exceptional cases is the control center expected to have remote control of the ship. (AAWA, 2016), (Burmeister et al., 2014).

Autonomous control in the MUNIN project is defined as the ability to make complex decisions, which are still constrained within predetermined limits. An example of this might be autonomous collision avoidance as defined by the International Regulations for the Prevention of Collisions at Sea (COLREGs). This could be achieved through the use of automated screening processes, supplemented by other technologies from the field of artificial intelligence. Properly implemented, this type of autonomy will reduce the need for human supervision while maintaining a high and well-defined level of security. The functions of the unmanned ship can be distinguished into five different types (Porathe et al, 2014):

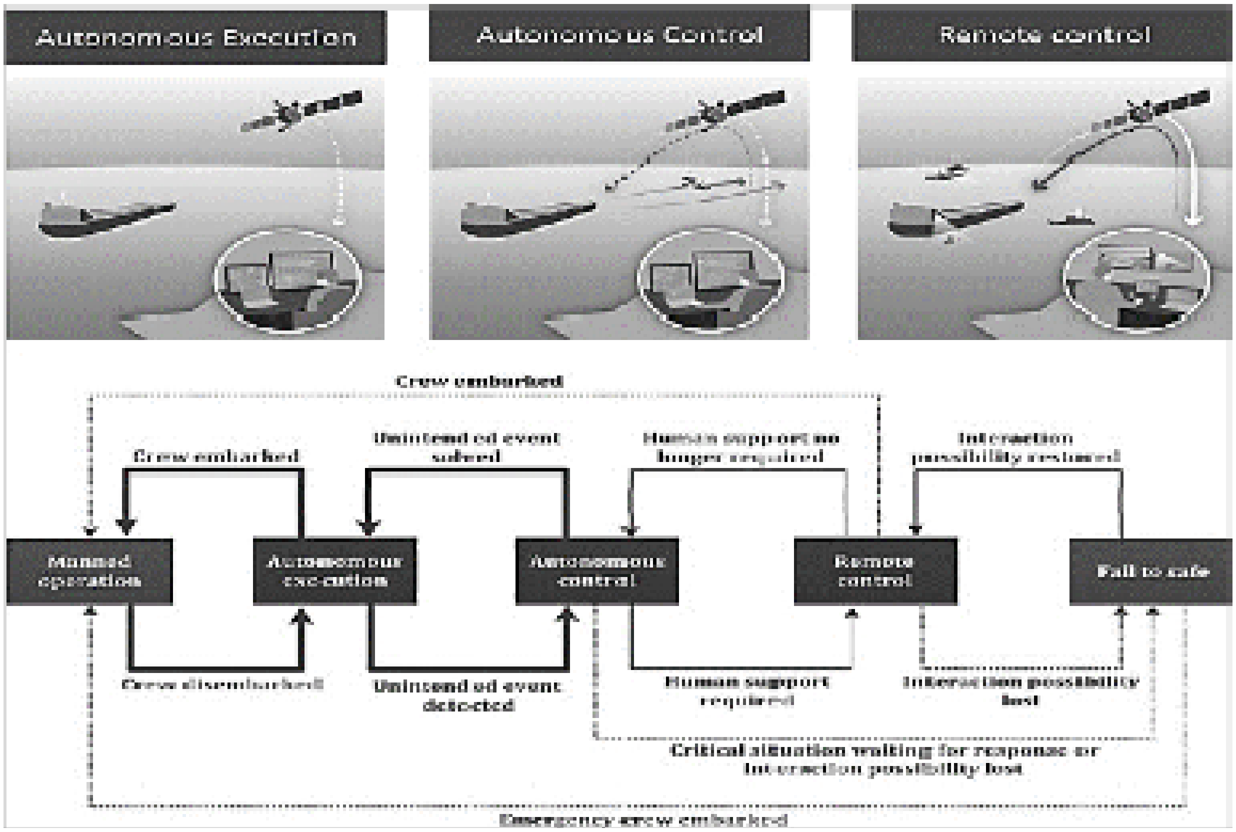
• Manned operation

• Autonomous execution,

• Autonomous control,

• Remote control and

• Operation in fail-safe mode



Picture No.13 - The functions of the unmanned ship according to the MUNIN project (Source: Burmeister et al., 2014)

Manned mode represents the mode where the ship is operated by a normal crew, as reported to occur during the approach to a port. The duties of arriving at, departing from, and navigating high traffic or coastal areas will remain essentially unchanged as they will be conducted by a bridge team. But as the ship reaches the open sea, the crew will disembark and return to shore, leaving it unmanned. (Burmeister and Rodseth, 2014) This point may vary depending on ports, voyages, expected traffic, complexity of the environment, weather conditions, etc. It is also recognized that because of this, unmanned vessels may be forced to remain at anchor due to, for example, the inability of the crew to board in difficult weather conditions. This feature only applies to the MUNIN project.

When the crew leaves the ship, its state will switch to autonomous mode, where systems will constantly check conditions and observe the environment to see if everything is still operating according to the predetermined plan travel. Small speed or course adjustments due to e.g. visibility limitation actions can be performed by the ship's autonomous controller, within a predetermined freedom framework. In addition, regular updates will be provided to the control center so that the people in it can carry out their monitoring tasks with the necessary awareness. As soon as a situation arises which cannot be handled through the autonomous control system, assistance will be requested from the ground control center. The ship will then switch autonomous control to remote, for example due to a passing vessel or changing weather conditions and will be able to be remotely controlled by the crew on board. (Rodseth and Burmeister, 2015)

In addition, there is a function where the ship will be placed in a 'fail safe' state, which is intended to maintain the safety of the ship if control is lost due to poor communication, systems failure or the absence of the operator in the center of land. This 'fail safe' function will apply emergency mooring or some other action to minimize the risks of collision, grounding etc. (Rodseth and Burmeister, 2015). The AAWA project states that the ship operator should determine before each voyage what strategy the ship will follow in the event that a connection is lost or a problem occurs. The strategy could include:

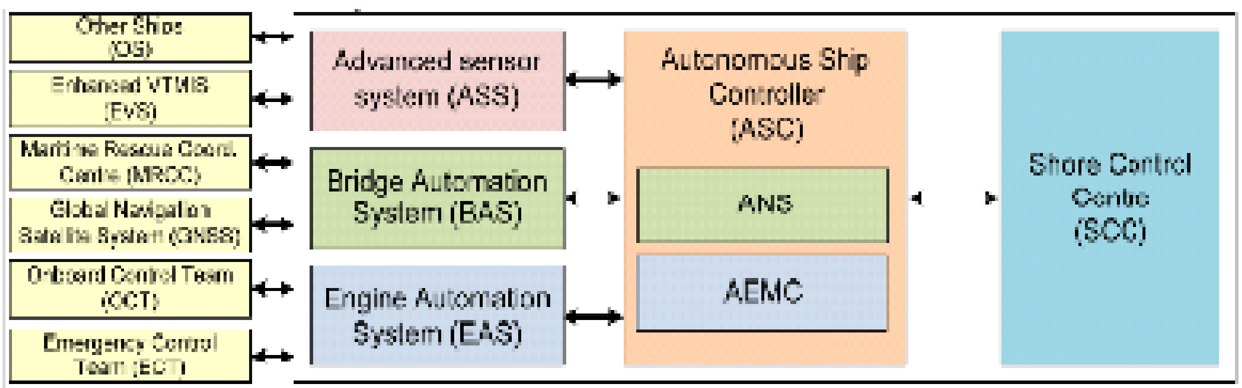
- ✓ Request for the operator to take control, reduce speed and go to the selected port, stop the ship in dynamic state, navigate to the previous port, navigate to a predetermined safe location.

- ✓ Regardless of the situation, the land control center can of course intervene at every stage and can even take direct control for general or special handling of situations. For example, if another ship is detected by the autonomous systems, the control center is not required to implement a direct maneuver.

- ✓ The operator may choose to communicate via VHF frequencies with the other vessel in order for both parties to confirm the situation before any action is initiated. In such cases, autonomous capabilities are disabled and all data is transmitted ashore and corresponding commands are relayed back to the ship. This represents an absolute remote control approach, which is only activated during certain special situations.

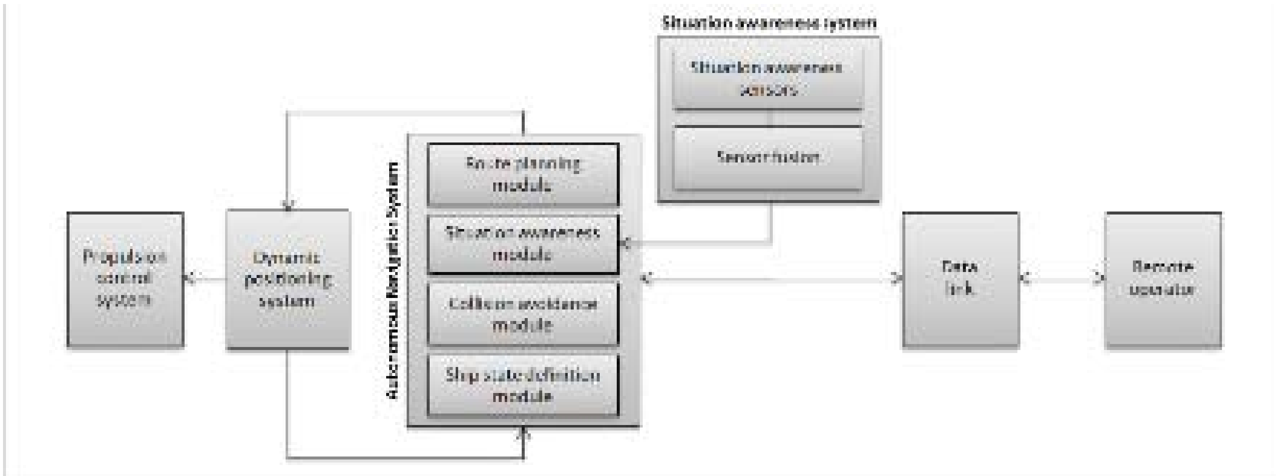
2.2.2.5 The Architecture of the MUNIN Autonomous Ship

The architectural approach of the autonomous ship should ensure that the ship is always monitored and controlled by a control center on land. At the same time, however, the combination of its functional limits and autonomous systems should minimize the burden on the operator at the control center to allow monitoring of a fleet of ships, with the aim of reducing communication requirements and costs. The Engine Automation System-EAS, Bridge Automation System-BAS, Advanced Sensor System-ASS, Autonomous Ship Controller-ASC and the systems responsible for the remote control of the ship (Shore Control Center-SCC) are the main categories of systems required to achieve autonomous operation and are analyzed below as presented in the MUNIN research project. (MUNIN, 2013)



Picture No.14 - The systems architecture of the MUNIN autonomous ship (Source: Burmeister and Rodseth, 2014) 2.3 The architecture of the AAWA autonomous ship

The Autonomous Navigation System (ANS) as described in the framework of the AAWA project (AAWA, 2016) will consist of the following subsystems. A route planning system (Route Planning-RP), a situational awareness system (Situational Awareness-SA), a collision avoidance system (Collision Avoidance-CA) and finally a ship state definition system (Ship State Definition-SSD) . These subsystems will be connected both to each other and to the dynamic positioning system (Dynamic Positioning-DP) and the maneuvering system.



Picture No.15 - The AAWA autonomous ship systems architecture (Source: AAWA, 2016)

First, the ship's status determination unit, or otherwise the Virtual Captain-VC unit, is the most important of the autonomous navigation subsystems. By gathering information from all other systems, it decides in what state the ship will operate. Depending on the data, it decides whether the ship should operate in autonomous, remote or fail-safe mode. For example, if the control center loses all communication with the ship, the VC will be responsible for changing the state of the ship to fail-safe mode.

The dynamic positioning system then allows the ship to automatically maintain its position using the propellers, rudders and thrusters. Combined with satellite systems and sensors, the ship will be able to maintain its position, even in difficult weather conditions. Modern Rolls-Royce dynamic positioning systems, such as Icon DP, also allow maneuvering of the ship at low speeds. The route planning module is a software that is responsible for planning the route from start to finish, through predetermined points, avoiding the obstacles specified in the electronic diagrams. This particular software performs something similar to voyage planning as it is performed nowadays by ship crews.

Additionally, the collision avoidance module is responsible for safe navigation. It uses the data provided by the path planning module but deviates from it if a hazard is detected. At the same time, the situational awareness system mentioned below provides the collision avoidance unit with information about the environment and nearby ships, which the latter then uses to assess the risk of collision and avoid it. Unlike the route planning system which is used as a planning tool, the collision avoidance system is always active and makes real-time decisions depending on the situation.

Finally, the situational awareness unit is an important part of the safe navigation of an unmanned ship as it must be at least as good as the situational awareness on a conventional one. This unit uses different types of sensors to collect information from the environment and combine it. These sensors are thermal cameras, high-definition cameras, infrared cameras that can be used for night vision, sound recording and detection sensors, projectors mounted on a gyroscopic platform capable of providing day and night images, radar and LIDAR. automated surveillance will exceed the capabilities of a human watch, especially at night, and the operator at the shore control center will be able to get an even better picture than if he were actually on board.

2.3 Legal and Operational Risks and Challenges on Safety of Autonomous vs. Conventional Ships

When considering the legal status of unmanned vessels, the first question that arises is what status do unmanned vessels fall under. The specific question arises from the fact that these ships can benefit from the benefits and rights defined in maritime contracts. For example, if an unmanned ship is considered a ship, it must comply with existing duties and regulations and can benefit from established rights in international conventions. Important rights are the right of safe passage, freedom of the high seas, limitation of liability, uniform standards (Komianos, 2018).

If an unmanned ship, however, cannot be considered a ship, it is uncertain whether it can benefit from these rights. In order to determine whether unmanned vessels fall under the maritime law regime, we need to look at the scope of the different maritime conventions. In particular, we need to look at the definitions of the term 'ship' to determine whether a ship without crew on board can still be considered a ship (Rødseth, Burmeister, 2015).

First of all, the law of the sea does not have a clear definition of a ship or a vessel. The United Nations Convention on the Law of the Sea, sometimes referred to as the "Constitution for the Oceans," does not even have a definition of ship. However, this convention is extremely important for the navigation rights and duties of ships. This may be one of the reasons why most believe that unmanned vessels will be equated with ships for the enforcement of the law of the sea. According to this vision, unmanned ships can enjoy the rights and freedoms and must comply with applicable customs duties, which are similar to those applicable to traditional ships.

This view must be supported because there is no indication in UNCLOS that the presence of a crew would be an essential element to speak of a ship. Thus, the rules of UNCLOS, which define the rights and obligations of States, with regard to international shipping, will also apply to unmanned vessels. Also, many other multilateral conventions related to various issues of maritime law do not exclude their scope of application to ships with the presence of seafarers. Most of these conventions have their own definition, tailored to the specific subject they handle.

First of all, under the Hague Rules, a ship means "any ship used for the carriage of goods by sea", and under the Athens Convention, a ship means "only a sea-going ship, excluding an aircraft". The International Convention for the Prevention of Pollution from Ships (MARPOL), for example, defines a ship as "a ship of any type, operating in the marine environment, including hydrofoils, hydrofoils, submarines, floating vessels and fixed or mobile platforms" (Komianos, 2018).

The CLC Convention specifically defines a ship as: "a seagoing vessel and seagoing vessels of any type constructed or adapted for the carriage of petroleum in bulk as cargo. The London Dumping Convention provides another definition. Vessels and aircraft may be "floating or air craft of any type. All these definitions, each tailored to their respective subject matter, are not an obstacle to the application of an unmanned vessel.

In the above selected conventions, crew on board is not a requirement in any of the definitions, so there is no convention that precludes the application of unmanned vessels. It can be assumed that this applies to all international maritime conventions. Thus, unmanned vessels will have all the same rights to perform all the same tasks as traditional manned vessels (Rødseth, Burmeister, 2015).

It is already clear that under international maritime law, an unmanned vessel will be equated with a manned vessel and will be subject to the same international regimes. To determine whether this is also the case in national shipping law, we will look at different definitions from different national legislations. In the United States, the standard definition of a "vessel" states that "a vessel is any description of sea-going vessels or other artificial surfaces used, or capable of being used, as a means of conveyance on water." Identical definitions are used in several other acts, such as the Deepwater Port Act of 1974, the International of Business Services engineering navigation rules 1977 etc. So according to this definition an unmanned vessel will be considered as a vessel. American courts have developed the "purpose test" to decide what a vessel is. This test analyzes,

(1) if the structure is mobile and capable of being transported by water; (2) if subject to the perils of the sea;

(3) whether the structure is designed to be permanently fixed in place; and

(4) whether the status of the vessel is consistent with statutory or other policy issues;

If the question about unmanned vessels were to be put to a US court after this "purpose test", it would likely have 4 affirmative answers, with the conclusion that an unmanned vessel is also a normal vessel. The UK has an even more basic definition of what a vessel is. According to the Merchant Shipping Act 1995, a ship is "any ship or vessel or any other description of ship used in navigation" (Rødseth, Burmeister, 2015).

In French law, a ship is defined as "floating, moving vessel designed for navigation on the ocean" while in the Dutch Civil Code, ships are "*all things, except aircraft, and that by their construction are intended to float or have hovered*». The list of national definitions can be long since they all amount to the same conclusion. But the point is to show that clearly, an unmanned ship will qualify like any other ship. Neither of these definitions mentions anything about crew boarding. Therefore, the presence of a crew is not a necessary element of a ship.

Consequently, unmanned vessels will be subject to existing international conventions and national legislation. Every ship must comply with the International Regulations for the Prevention of Collisions at Sea (COLREGS), which sets out the rules of navigation that ships and other vessels at sea must follow to avoid collisions. In order to comply with the rules, it is necessary to have people on board to make sure that these regulations are followed. With autonomous ships a critical issue in avoiding potential collision is how manned and unmanned vessels interact, especially when operating in heavily congested areas or areas where the environment can change abruptly due to unexpected events. Communications between manned and unmanned vessels are critical and mutual agreement on the course of action to be taken between vessels to manage traffic may be necessary.

An unmanned ship will be limited to the situational awareness required to make appropriate decisions based only on the information presented on the screens. On a remotely operated ship, this primary means of validating the information displayed does not exist. In contrast to fully autonomous ships, which depend on detection algorithms to obey the rules of the sea, will artificial intelligence always make the "right" decisions in potential collision events? Strong situational awareness concerns also apply to weather conditions and their effects on board (Komianos, 2018).

Also, important movements such as docking and moving away from a port are of particular concern for autonomous ships. These and other issues related to the operational safety of unmanned ship navigation are challenges that have yet to be resolved. Security challenges associated with conventional manned ships include ship security, cargo security, maritime traffic security, environmental security and human security. However, the specific requirements-rules may create serious problems for autonomous ships. For example, SOLAS regulations require a master to respond immediately to persons in distress at sea and has a duty to proceed to their rescue. It is debatable whether an autonomous ship can provide assistance as effectively as a manned ship, whether in search or rescue situations.

Also, while autonomous ships will keep sailors in safe places away from danger and harm, there is another the safety risks that will increase as a result of the lack of crew. In the age of unmanned shipping, it would be naïve to expect that pirates and terrorists will disappear from the high seas. They may even believe that such ships will be new and softer targets. Without a crew, an autonomous ship is likely to be at risk of being hijacked for the purpose of stealing cargo or hijacking the vessel for ransom or terrorist purposes.

Especially vessels carrying explosive, flammable or toxic substances could be used as weapons by terrorists. Due to their reliance on automation systems and artificial intelligence, autonomous ships are much more susceptible to hijackers of another kind such as hackers. Even as conventional ships become increasingly connected and dependent on software-dependent systems, cyber security is already receiving increasing attention from shipping companies. With autonomous ships, cyber-attacks will pose an even greater security risk and will require new and innovative ways to defend against such attacks. Global shipping's cyber security vulnerability was recently highlighted by the cyber-attack on container shipping giant AP Moller-Maersk in June 2017, when a cyber-attack knocked out online bookings and other internal platforms, forcing it to shut down operations at some terminal's containers. The cyberattack caused a loss of up to US$300 million and disrupted operations for two weeks (Rødseth, Burmeister, 2015).

3. Methodology Research

3.1 The Aim of the Research

The purpose of this thesis is to make an in-depth research about the Safety of Maritime Autonomous Surface Ships (MASS). Secondly, through this study, an effort is made in order to interpret the results of the research, to present the conditions that shape them and to come up with proposals that will improve these conditions.

3.2 Methodology Research

The methodology type, which is used for the conduction and writing of the specific dissertation, is concerned to the qualitative as also the quantitative analysis about the Safety of Maritime Autonomous Surface Ships (MASS). According to a different approach, the qualitative research is research that emphasizes and focuses on meaning rather than human behavior. Qualitative researchers, according to Willing (2001), are interested in meaning, in the way people experience events. However, there are qualitative approaches that focus on the description of behavior (McLeod, 2001). There are also quantitative studies that do not focus so much on behavior as on some internal structures (McLeod, 1997).

In advance, a different approach mentions that a feature of qualitative research is the rejection of the natural sciences as a research model (McLeod, 2001). In contrast to the positivist science model based on the natural sciences, proponents of qualitative research focus on the study of the socio-historical and cultural context. Proponents of qualitative research attempt to explore the social world in the light of the experience of the subjects participating in this research. Qualitative research is naturalistic, contextual, situated, interpretive (Mishler, 1987).

It should also be mentioned that the qualitative research is considered -emic (emic) and idiosyncratic, in contrast to quantitative research, which is considered -ethical (etic) and legislative. Qualitative research is considered *-emic*, i.e. it focuses on the analysis of a culture based on some internal criteria, emphasizing its uniqueness, while quantitative research is considered *–ethic* in the comparative study of many cultures based on some universal, universal criteria. The *-emic* approach is based on the adoption of an internal approach to behavior within a system. The *-ethical* approach expresses the study of the behavior of a system, as presented to an observer outside the system and uses criteria external to it (Mishler, 1987).

3.3 Research Design

The specific dissertation makes use of the secondary (qualitative) as also primary (quantitative) research upon use of questionnaires, specifically constructed for the particular dissertation. The information has been retrieved in a systematic way from credible and recent sources, which follows the academic needs and rules about the Safety of Maritime Autonomous Surface Ships (MASS).

This thesis has been designed in a way that follows the three objectives with the goal to answer to the research question. Thus, the research philosophy is the pragmatism by using methods that advances researches in the best possible manner. Studies from a wide variety of scientists and organization will be monitoring, analyzed, and presented while conclusions will be made.

3.4 Methodology Procedure

The study makes use of both of secondary and primary research. Already published relevant and appropriate data have been carefully chosen. A wide range of related secondary sources, such as, magazines that present microplastics' effects on the sea environment, credible professional web sites, online newspapers and magazines, professional journals and blogs, and last but not least social media posts and statistics which are the main tool of this research, especially many posts and reviews were used to come up with the desirable result.

3.5 Research Tool

The research tool used in the research to gather the necessary information is the structured questionnaire. It is a data collection tool preferred by researchers, as it ensures the rapid collection of many answers in a short period of time through questions with a uniform structure. It is characterized by low cost, takes the opinion of many and different respondents, collects many different data, ensures the free and anonymous expression of respondents and allows the acquisition of data for features that are difficult to observe (e.g. opinions, emotions). At the same time, the use of the questionnaire as a means of data collection limits in-depth information and the receipt of details. The accuracy of the answers, their honesty and their subjectivity are not checked. The answers to the questions are processed and transferred to special systems for analysis. They are first classified and then coded. A questionnaire consisting of closed-ended questions was prepared for the needs of the present study.

3.6 The Sample of the Research

The sample consists of 100 participants who the 81% of the participants were male and the rest 19% were female, the 51% of the participants were from 25-34 years old, the 38% were from 35-44 years old and the 11% were from 45-54 years old, the 52% of the participants were single, the 43% were married and the rest 5% were divorced and the 50% of the participants worked in the Shipping industry from 6-10 years, the 22% from 0-5 years, another same percent from 11-15 years and the rest 6% from 16-20 years. Finally, the 50% of the participants worked in the office, the 17% were second engineers, the 16% were first engineers, the 14% were third engineers and the rest 3% were Ship captains.

4.Results Analysis

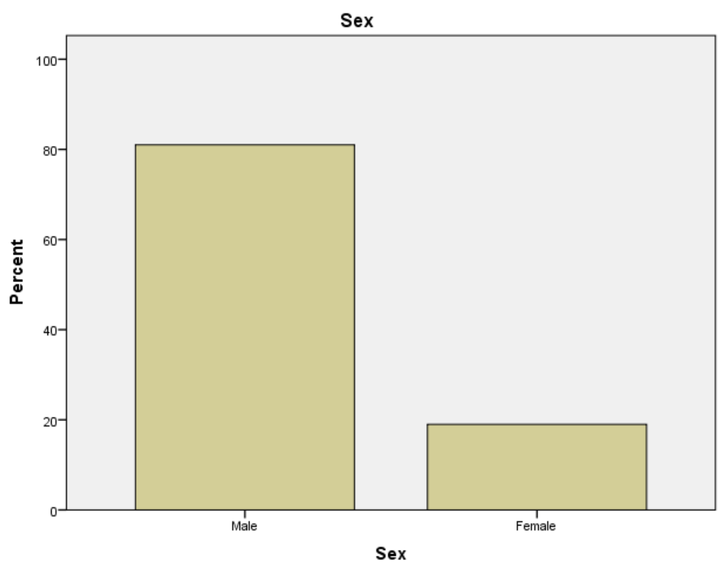
4.1 Analysis of Demographic Questions

Male / Female

The 81% of the participants were male and the rest 19% were female.

Sex

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	81	81,0	81,0	81,0
	Female	19	19,0	19,0	100,0
	Total	100	100,0	100,0	

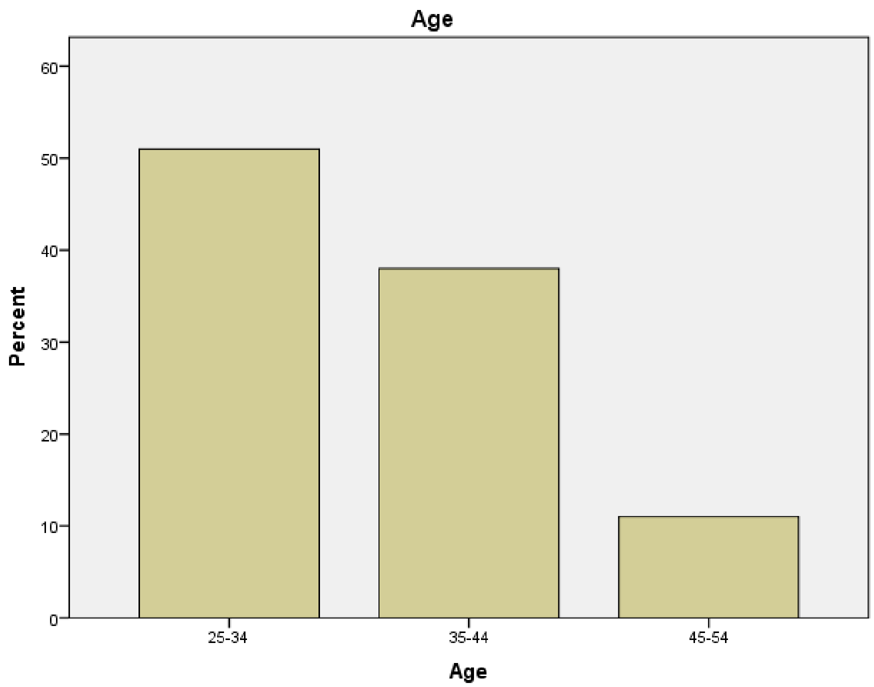


Age

The 51% of the participants were from 25-34 years old, the 38% were from 35-44 years old and the 11% were from 45-54 years old.

Age

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	25-34	51	51,0	51,0	51,0
	35-44	38	38,0	38,0	89,0
	45-54	11	11,0	11,0	100,0
	Total	100	100,0	100,0	

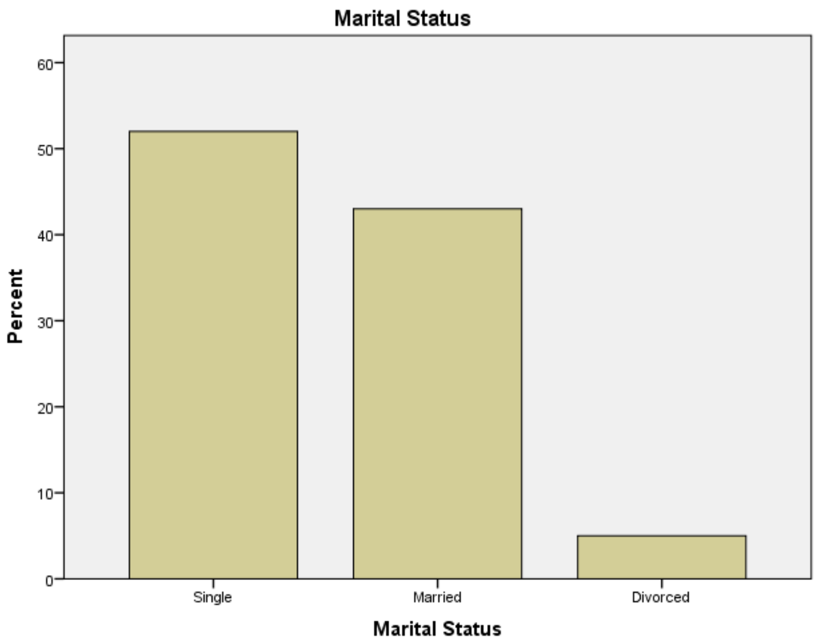


Marital status

The 52% of the participants were single, the 43% were married and the rest 5% were divorced.

Marital Status

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Single	52	52,0	52,0	52,0
	Married	43	43,0	43,0	95,0
	Divorced	5	5,0	5,0	100,0
	Total	100	100,0	100,0	



Work experience

The 50% of the participants worked in the Shipping industry from 6-10 years, the 22% from 0-5 years, another same percent from 11-15 years and the rest 6% from 16-20 years.

Work Experience

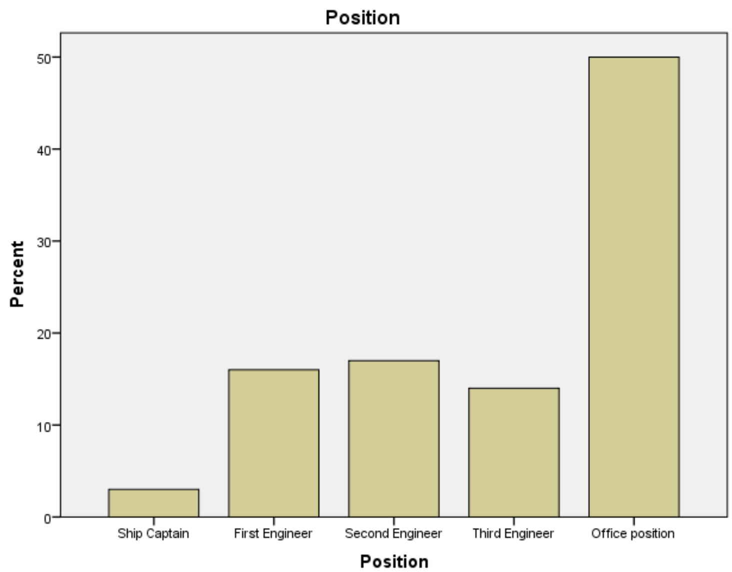
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-5 years	22	22,0	22,0	22,0
	6-10 years	50	50,0	50,0	72,0
	11-15 years	22	22,0	22,0	94,0
	16-20 years	6	6,0	6,0	100,0
	Total	100	100,0	100,0	

Position

The 50% of the participants worked in the office, the 17% were second engineers, the 16% were first engineers, the 14% were third engineers and the rest 3% were Ship captains.

Position

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Ship Captain	3	3,0	3,0	3,0
	First Engineer	16	16,0	16,0	19,0
	Second Engineer	17	17,0	17,0	36,0
	Third Engineer	14	14,0	14,0	50,0
	Office position	50	50,0	50,0	100,0
	Total	100	100,0	100,0	



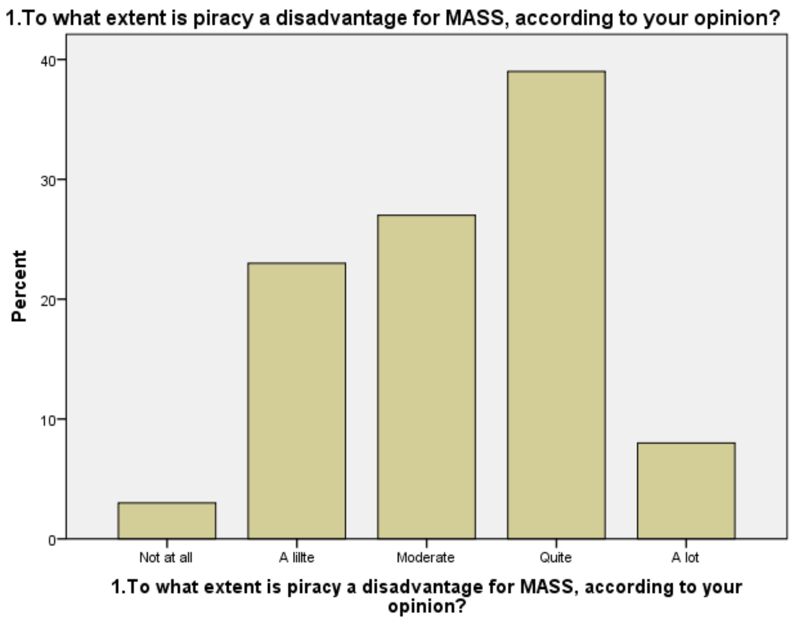
4.2 Main Questionnaire Analysis

Question 1

The 39% of the participants consider piracy quite a disadvantage for MASS, the 27% consider it a moderate disadvantage and the 23% piracy a small disadvantage for MASS.

1.To what extent is piracy a disadvantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	3	3,0	3,0	3,0
	A lillte	23	23,0	23,0	26,0
	Moderate	27	27,0	27,0	53,0
	Quite	39	39,0	39,0	92,0
	A lot	8	8,0	8,0	100,0
	Total	100	100,0	100,0	

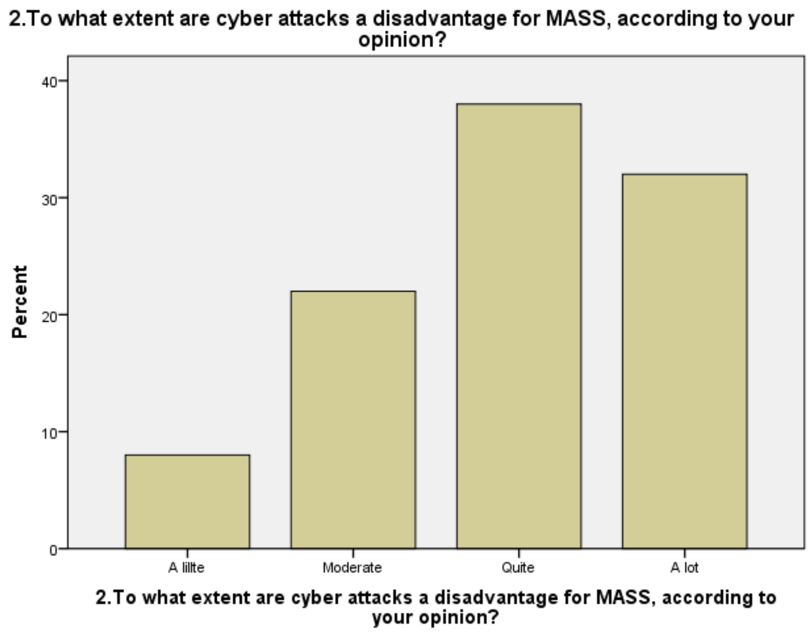


Question 2

The 38% of the participants consider cyber-attacks quite a disadvantage for MASS, the 32% consider it a big disadvantage and the 22% piracy a small disadvantage for MASS.

2.To what extent are cyber-attacks a disadvantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A lillte	8	8,0	8,0	8,0
	Moderate	22	22,0	22,0	30,0
	Quite	38	38,0	38,0	68,0
	A lot	32	32,0	32,0	100,0
	Total	100	100,0	100,0	

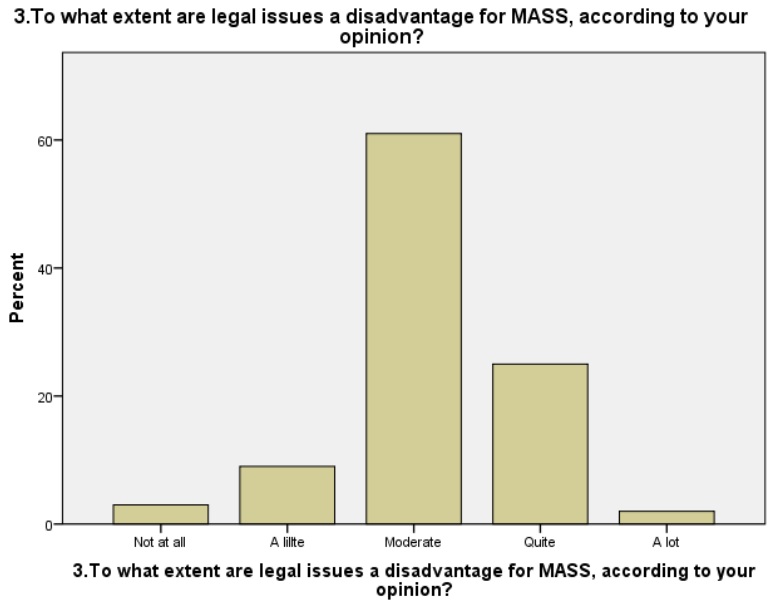


Question 3

The 61% of the participants consider legal issues a moderate disadvantage for MASS and the 25% consider it quite a disadvantage.

3.To what extent are legal issues a disadvantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	3	3,0	3,0	3,0
	A lillte	9	9,0	9,0	12,0
	Moderate	61	61,0	61,0	73,0
	Quite	25	25,0	25,0	98,0
	A lot	2	2,0	2,0	100,0
	Total	100	100,0	100,0	

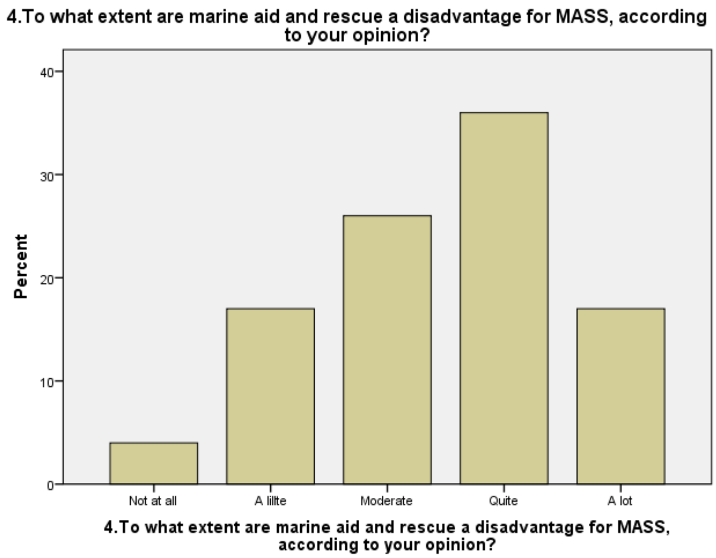


Question 4

The 36% of the participants consider **marine aid and rescue** quite a disadvantage for MASS, the 26% consider it a moderate disadvantage, the 17% consider it a small disadvantage and the same percent consider it a big disadvantage.

4.To what extent are marine aid and rescue a disadvantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	4	4,0	4,0	4,0
	A lillte	17	17,0	17,0	21,0
	Moderate	26	26,0	26,0	47,0
	Quite	36	36,0	36,0	83,0
	A lot	17	17,0	17,0	100,0
	Total	100	100,0	100,0	

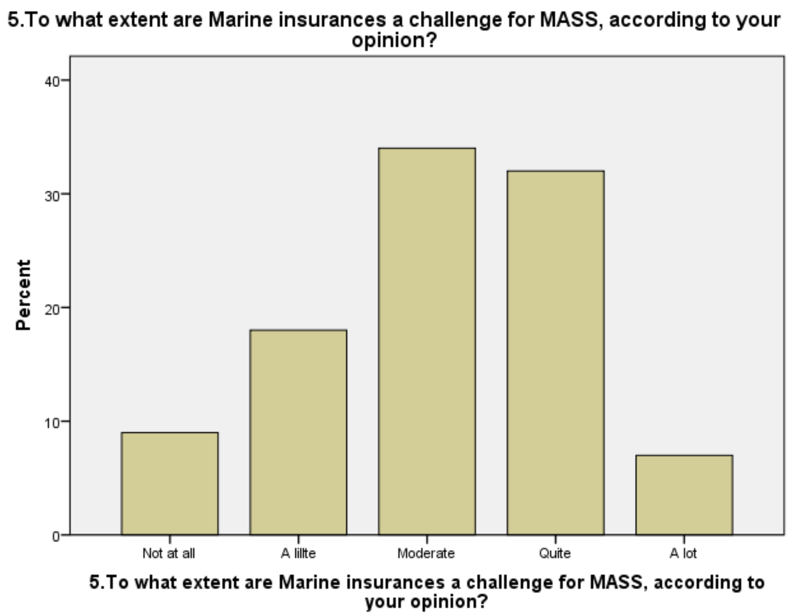


Question 5

The 34% of the participants consider Marine insurances a moderate challenge for MASS, the 32% consider it quite a challenge and the 18% consider it a small challenge.

5.To what extent are Marine insurances a challenge for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	9	9,0	9,0	9,0
	A lillte	18	18,0	18,0	27,0
	Moderate	34	34,0	34,0	61,0
	Quite	32	32,0	32,0	93,0
	A lot	7	7,0	7,0	100,0
	Total	100	100,0	100,0	

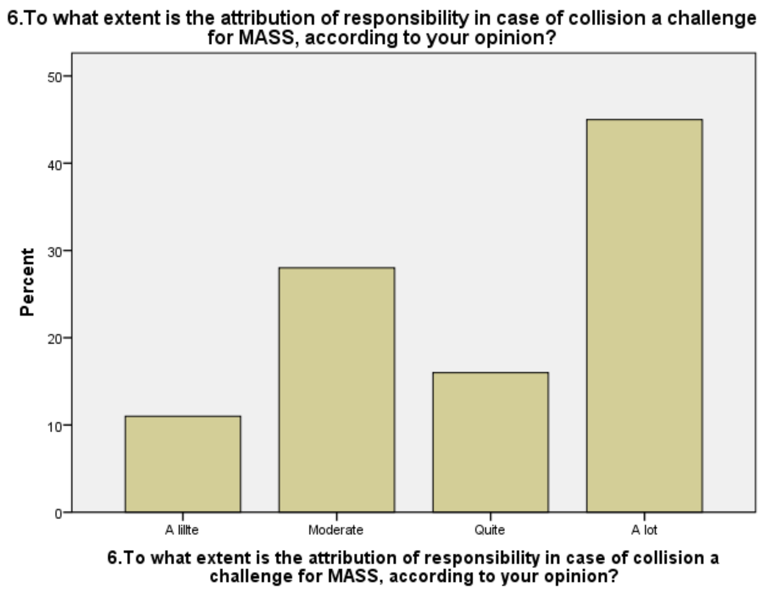


Question 6

The 45% of the participants consider the attribution of responsibility in case of collision a big challenge for MASS, the 28% consider it a moderate challenge, the 16% quite a challenge and the rest 11% consider it a small challenge.

6.To what extent is the attribution of responsibility in case of collision a challenge for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A lillte	11	11,0	11,0	11,0
	Moderate	28	28,0	28,0	39,0
	Quite	16	16,0	16,0	55,0
	A lot	45	45,0	45,0	100,0
	Total	100	100,0	100,0	

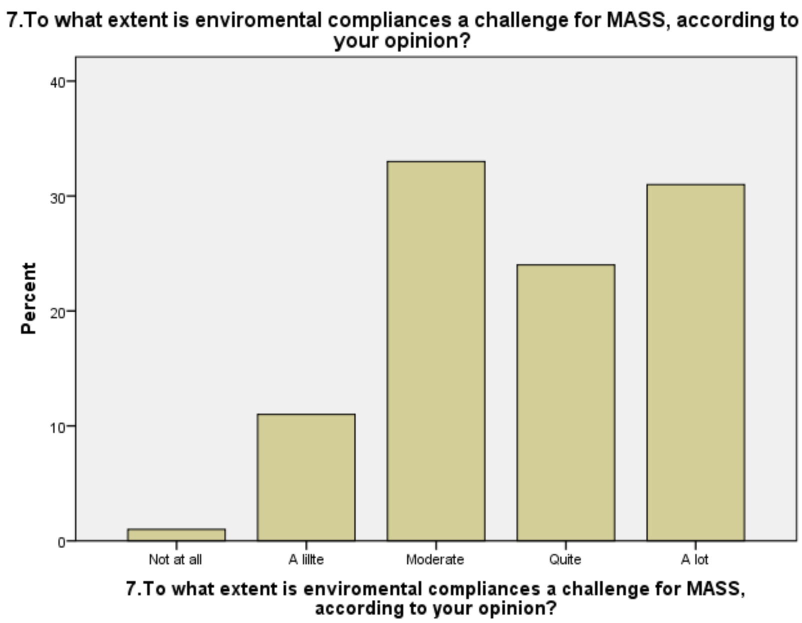


Question 7

The 33% of the participants consider environmental compliances a moderate challenge for MASS, the 31% consider it a big challenge and the 24% consider it quite a challenge.

7.To what extent is environmental compliances a challenge for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	1	1,0	1,0	1,0
	A lillte	11	11,0	11,0	12,0
	Moderate	33	33,0	33,0	45,0
	Quite	24	24,0	24,0	69,0
	A lot	31	31,0	31,0	100,0
	Total	100	100,0	100,0	

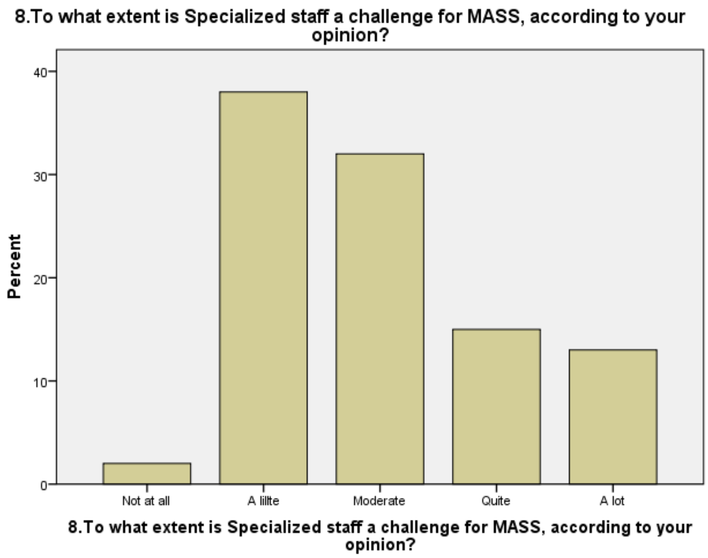


Question 8

The 38% of the participants consider specialized staff a small challenge for MASS, the 32% consider it a moderate challenge, the 15% consider it quite a challenge and the 13% a big challenge.

8.To what extent is Specialized staff a challenge for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	2	2,0	2,0	2,0
	A lillte	38	38,0	38,0	40,0
	Moderate	32	32,0	32,0	72,0
	Quite	15	15,0	15,0	87,0
	A lot	13	13,0	13,0	100,0
	Total	100	100,0	100,0	

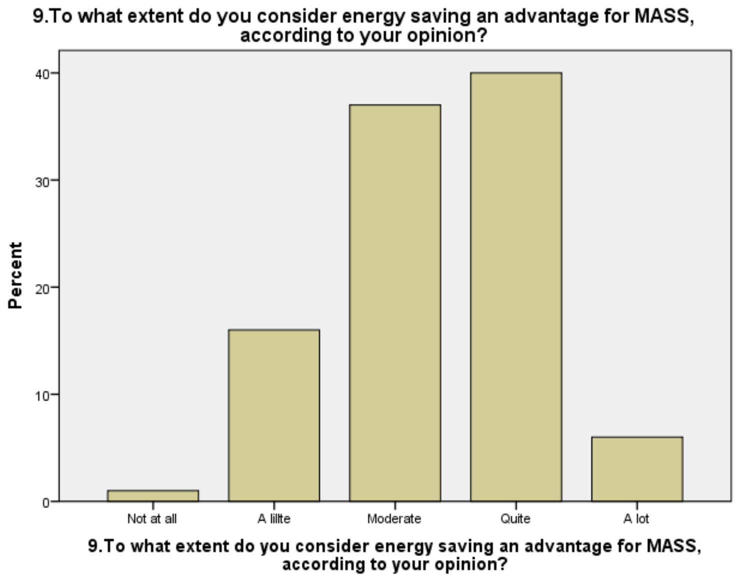


Question 9

The 40% of the participants consider energy saving a quite advantage for MASS, the 37% consider it a moderate advantage, and the 16% consider it a little advantage.

9.To what extent do you consider energy saving an advantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	1	1,0	1,0	1,0
	A lillte	16	16,0	16,0	17,0
	Moderate	37	37,0	37,0	54,0
	Quite	40	40,0	40,0	94,0
	A lot	6	6,0	6,0	100,0
	Total	100	100,0	100,0	

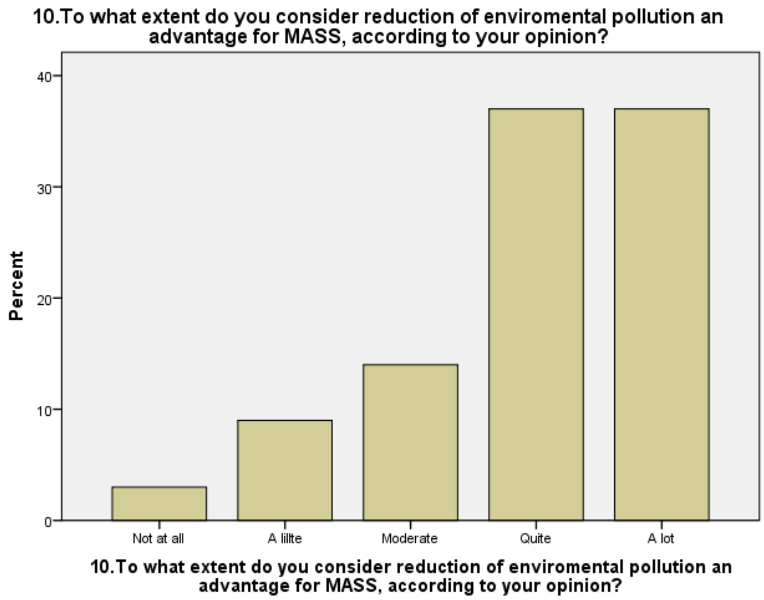


Question 10

The 37% of the participants consider the reduction of environmental pollution quite an advantage for MASS and the same percent consider it a big advantage and the 14% a moderate advantage.

10.To what extent do you consider reduction of environmental pollution an advantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	3	3,0	3,0	3,0
	A lillte	9	9,0	9,0	12,0
	Moderate	14	14,0	14,0	26,0
	Quite	37	37,0	37,0	63,0
	A lot	37	37,0	37,0	100,0
	Total	100	100,0	100,0	

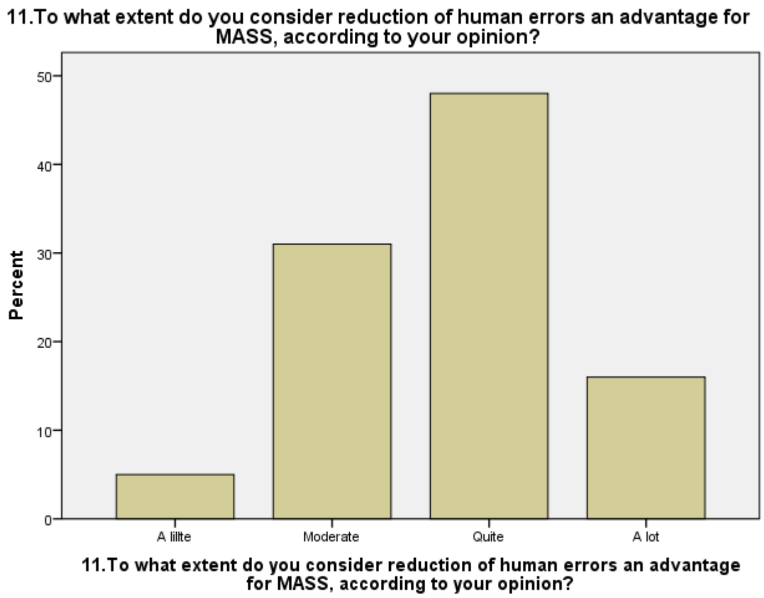


Question 11

The 48% of the participants consider the reduction of human errors quite an advantage for MASS, the 31% consider it a moderate advantage and the 16% a big advantage.

11.To what extent do you consider reduction of human errors an advantage for MASS, according to your opinion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A lillte	5	5,0	5,0	5,0
	Moderate	31	31,0	31,0	36,0
	Quite	48	48,0	48,0	84,0
	A lot	16	16,0	16,0	100,0
	Total	100	100,0	100,0	

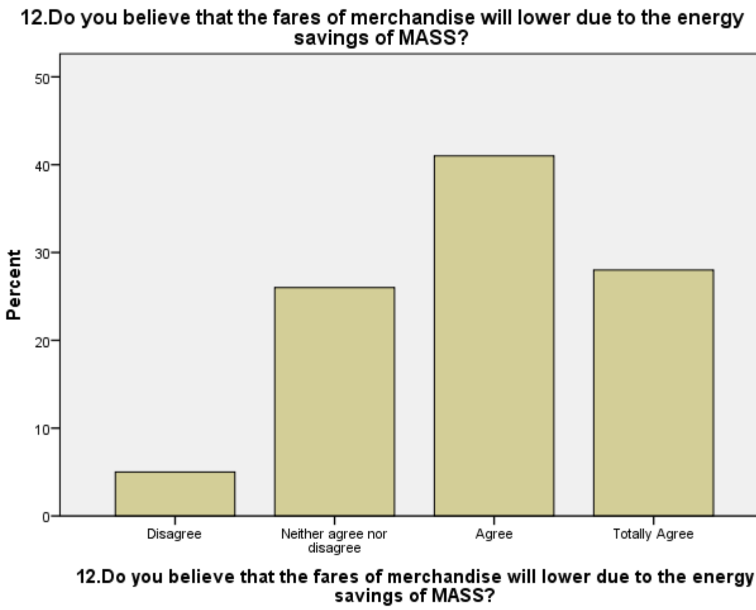


Question 12

The 41% of the participants agreed with the fact that the fares of merchandise will lower due to the energy savings of MASS, the 28% totally agreed and the 26% neither agreed nor disagreed.

12.Do you believe that the fares of merchandise will lower due to the energy savings of MASS?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Disagree	5	5,0	5,0	5,0
	Neither agree nor disagree	26	26,0	26,0	31,0
	Agree	41	41,0	41,0	72,0
	Totally Agree	28	28,0	28,0	100,0
	Total	100	100,0	100,0	

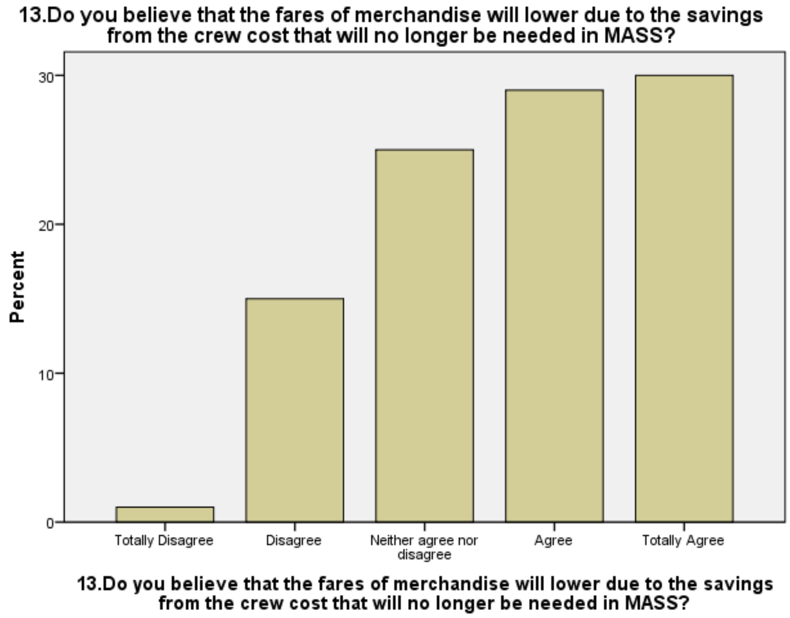


Question 13

The 30% of the participants totally agreed with the fact that the fares of merchandise will lower due to the savings from the crew cost that will no longer be needed in MASS, the 29% agreed as well and the 25% neither agreed nor disagreed.

13.Do you believe that the fares of merchandise will lower due to the savings from the crew cost that will no longer be needed in MASS?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Disagree	1	1,0	1,0	1,0
	Disagree	15	15,0	15,0	16,0
	Neither agree nor disagree	25	25,0	25,0	41,0
	Agree	29	29,0	29,0	70,0
	Totally Agree	30	30,0	30,0	100,0
	Total	100	100,0	100,0	



4.3 Synopsis of the Results

According what was mentioned above with the questionnaires' results, it should be said that the 39% of the participants consider piracy quite a disadvantage for MASS, the 27% consider it a moderate disadvantage and the 23% piracy a small disadvantage for MASS, the 38% of the participants consider cyber-attacks quite a disadvantage for MASS, the 32% consider it a big disadvantage and the 22% piracy a small disadvantage for MASS and the 61% of the participants consider legal issues a moderate disadvantage for MASS and the 25% consider it quite a disadvantage.

In advance, the 36% of the participants consider marine aid and rescue quite a disadvantage for MASS, the 26% consider it a moderate disadvantage, the 17% consider it a small disadvantage and the same percent consider it a big disadvantage, the 34% of the participants consider Marine insurances a moderate challenge for MASS, the 32% consider it quite a challenge and the 18% consider it a small challenge and the 45% of the participants consider the attribution of responsibility in case of collision a big challenge for MASS, the 28% consider it a moderate challenge, the 16% quite a challenge and the rest 11% consider it a small challenge.

Moreover, the 33% of the participants consider environmental compliances a moderate challenge for MASS, the 31% consider it a big challenge and the 24% consider it quite a challenge, the 38% of the participants consider specialized staff a small challenge for MASS, the 32% consider it a moderate challenge, the 15% consider it quite a challenge and the 13% a big challenge, the 38% of the participants consider specialized staff a small challenge for MASS, the 32% consider it a moderate challenge, the 15% consider it quite a challenge and the 13% a big challenge and the 37% of the participants consider the reduction of environmental pollution quite an advantage for MASS and the same percent consider it a big advantage and the 14% a moderate advantage.

Finally, the 48% of the participants consider the reduction of human errors quite an advantage for MASS, the 31% consider it a moderate advantage and the 16% a big advantage, the 41% of the participants agreed with the fact that the fares of merchandise will lower due to the energy savings of MASS, the 28% totally agreed and the 26% neither agreed nor disagreed and the 30% of the participants totally agreed with the fact that the fares of merchandise will lower due to the savings from the crew cost that will no longer be needed in MASS, the 29% agreed as well and the 25% neither agreed nor disagreed.

5. Conclusion

The purpose of this thesis, it was to present the shipping challenges regarding autonomous ships. Through searching and analyzing the existing literature we tried to identify what these challenges are and to answer some research questions. To answer these questions, the specific theoretical research focused around the following areas: Technology, Security, Legal and Institutional Framework, Sustainability.

First in terms of technology, someone can found that the means are available to achieve even fully autonomous ships that will rely minimally on humans. The great challenge of technology, however, is to properly combine all these available means with the aim of a safer and more economical solution for shipping. The areas of most research interest are the creation of autonomous navigation systems that will not rely on a crew on board, the integration of collision avoidance systems that will even achieve the complete elimination of accidents at sea, the efficient processing of data from sensor systems and the operation of remote control centers. So far, although the technology is available it needs time to be tested and matured to be able to be adopted and scaled to create fleets of autonomous ships.

After technology ensures safe navigation and operation, a big challenge of autonomous ships is cyber security, a concept that has preoccupied shipping in recent years. As many functions of autonomous shipping rely on cyberspace data, strict protection systems against possible attacks are required. To deal with this challenge, which has also attracted a lot of research interest, a key factor is the analysis of all possible cases of cyber-attack risks, but also ensuring how to protect or deal with such attacks.

An equally important challenge is the creation of an appropriate Legal and Institutional framework for autonomous shipping. Many of the existing laws and conventions will need simple revisions. But there are many regulations that will be needed some radical change but also regulations that will have to be created from scratch to govern the new reality of autonomous ships. This requires a collective effort from all shipping regulatory bodies and all states. This challenge is quite difficult, as most existing regulations have been "born" from accidents or from incidents over the years, while there is still no sample of such events from autonomous ships.

The shipping industry's bet should be to effectively define tasks and responsibilities in an autonomous shipping where humans will be largely replaced by machines and algorithms.

From the study of the ventures in autonomous shipping so far, we conclude that there is a lot of interest from both private companies and young researchers as well as governments. The most important project so far can be said to be the YARA – Birkenland ship, not only because it is at a stage before its consolidation, but because it indicates that autonomous shipping could start from short distance shipping. Replacing traditional manned ships used for short-haul routes by autonomous ships may be easier not only because of the scale but also because of remote control from control centers at close distances.

Finally, an important challenge is the sustainability of autonomous ships. The social acceptance of the project of autonomous ships may even determine its evolution. It is not easy for people to trust such a new and revolutionary technology. Just as it is not easy to drastically change such a traditional and culturally important profession as that of the navy. However, it will not be the first time that a profession is in danger of "disappearing", in this case it will probably be reshaped rather than disappear.

Furthermore, regarding the economic viability of autonomous ships this is only based on assumptions and we cannot have definite conclusions. But there is considerable business interest, as it is expected that an autonomous ship will be more economical and more profitable than a traditionally manned ship. Regarding the environment, the shipping industry is increasingly pressured by international conventions to reduce its environmental footprint. Autonomous ships are quite promising in this direction, as they promise fewer accidents, less leakages of harmful substances and emissions and reduced energy requirements. It remains to be seen if they can pull it off yes in practice.

Therefore, someone could come to the conclusion that autonomous ships are a challenge that will greatly concern shipping in the near future. The integration and adoption of autonomous unmanned ships will be done gradually and with collective efforts. None of the challenges we've listed are impossible, they just take time and testing. With the first ventures already matured and approaching their final stages, autonomous shipping is getting closer and closer to becoming a reality.

As a basic conclusion, the present work has been based exclusively on the existing literature and the theoretical approach to the topic of autonomous ships. However, further research is needed to delve into all the important aspects and understand the topic better. In the current phase of the autonomous ship venture, there are many issues related to the design, construction, operation and safety of autonomous ships that need study, analysis and best practices to make autonomous shipping a reality.

As autonomous technology and related legislation will continue to develop, it is important for the shipping community to stay abreast of changes to stay informed and ready for the shift to autonomous shipping. All the while, opportunities can arise at any time for both shipowners and managers, as well as IT and communications companies, taxonomists, surveyors and shipyards. In addition, the practical approach to the project of autonomous ships is also decisive. It was mentioned in the dissertation that many traditional shipping countries have already shown interest with research and development centers for autonomous ships. Greece and its Universities have the resources to participate in such ventures. It would be very interesting to create autonomous ship research centers in Greek Universities but also in collaboration with private companies in the field of technology and computers.

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