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Prioritization of crew activities to apply autonomous technologies

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MASTER THESIS

17th May 2021

Abstract

The development of autonomous technologies has been increasing significantly in many different business areas. Although many industries have experienced a wide range of benefits of technology application, the maritime industry is still at the back of this deep transformation due to safety and security concerns, as well as a lack of maritime law and regulations. Although the design of oceangoing fully autonomous vessels doesn`t seem possible in terms of operation in the near future, some autonomous technologies can be applied to conventional vessels in order to support critical crew activities, increase operational efficiency, and ensure safer shipping.

The study is improved according to the 14 anonymous interviews with the marine professional people, who are both onshore and offshore employees from one small shipping company, which is located in Oslo. The target is to decide what are the critical crew activities in terms of safety and which activities can be supported by applicable autonomous technologies that are highly costly and do not exist on the current fleet to ensure a high level of safety and effective vessel operations according to their priorities.

Lastly, the results give the company analysis about the challenging critical crew activities and solutions about how to eliminate or reduce them by applying related autonomous technologies.

Key words

Autonomous technologies, challenges and heavy workload for vessel crew, criticality evaluations

Acknowledgments

I would like to express my feelings for my master's degree education and thesis process because it was a long way to come to this education level.

I thank the University of South-Eastern for my admission. It was the fact of changing my career life from offshore to onshore. I have experienced many new things in Norway and have met so many nice people.

I would like to say many thanks to my supervisor Dr, Hyungju Kim, who has been supporting me all time with his professional experiences, knowledge, and positive feedback.

I would like to express that having a collaboration with the company, which consists of marine professional people, was a great chance and advantage. I thank all of them for their support and information sharing during my master thesis process.

I want to give special thanks to my family for their support and respect for my decisions all time.

Lastly, I would like to say thank you to my two professors, Marius Stian Tannum and Marius Imset, for their knowledge sharing and valuable comments to me on my results that are related to the challenges and autonomous technologies.

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1.CHAPTER I–INTRODUCTION

1.1 Introduction to autonomous ships

The autonomous ship is a technologically advanced vessel, which is operated commercially without crew (IMO, n.d.). In 2017, the Maritime Safety Committee (MSC) as a part of IMO, took a decision to define Maritime Autonomous Surface Ships (MASS) in their own way so as to evaluate this new concept of unmanned vessels in terms of their safety, security as well as possible environmental effects (IMO, n.d.)

This new concept is also discussed and developed in different projects, such as Maritime Unmanned Navigation through Intelligence in Networks (MUNIN, n.d.), Yara Birkeland, ASKO, AutoShip, and concepts, such as ReVolt. All of these projects are explained in detail in the chapter two-literature review.

1.2 Advantages of autonomous ships

It includes different autonomous modes (IMO n.d.)**.** The main drivers of autonomous shipping are lower risk exposures for vessel crew, reduced emissions, the lower number of huge oil spills, reducing capital expenditures (CapEx), and operating expenses (OpEx) (Rødseth, 2017).

Safety advantage

When the topic comes to safety and crew activities, the most important concern should be an assessment of the marine accident reasons that are highly caused by human factors. According to the evidence, not less than 66% of the marine accidents and over 90% of the marine incidents occurred by vessel crew respectively (Coraddu et al., 2020). Reducing the number of crew or operating a vessel in unmanned mode will increase safety (Vos et al., 2021).

Emission advantage

The International Maritime Organization (IMO) has created the greenhouse gas strategy as the initial step with the aim of decreased emissions from vessels in 2018. With this strategy, the emission will be reduced significantly, especially the emission of carbon dioxide (CO2) by not less than 40% until the year 2030 when the emission quantity is compared with the year 2008 as well as about 70% until the year 2050 (IMO, n.d.). Environmentally friendly solutions and greener technology transitions will be necessary to achieve this important aim (Norwegian government, 2019). For instance, emission control technologies like ship performance monitoring systems will have an important effect on the controlling vessel`s energy efficiency as well as optimizing the fuel consumption (Norwegian control systems, n.d.). On the other hand, an autonomous vessel`s service speed is designed as lower than a manned vessel of similar size. For instance, Yara Birkeland`s service speed is designed as 6 knots (Kongsberg, n.d) and it is the same for the ReVolt with 6 knots speed (DNV, n.d.). Lower-speed vessels will consume lower fuel, so the emission level will be decreased or eliminated.

The advantage to reduce oil spill

Autonomous surface vehicles (ASV) and unmanned underwater vehicles (UUV) combination has the ability to monitor and map possible oil spills with a special monitoring device that consists of neuro-controllers. These developed technologies are created with special reasons to protect the environment (Gonzalez et al., 2016).

Reduced Capex

In fully autonomous ships, there will be no equipment, such as safety equipment or accommodation, air conditioning system, sanitary for the crew, so capital expenditures will be eliminated by the new design vessel (Massterly, n.d.)

Reduced Opex

Since a fully autonomous vessel is operated without crew and navigates at a slow speed, it can save from crew expenditures and contributes to fuel consumption positively (Massterly, n.d.)

1.3 Challenges of autonomous ships

Although there are different projects about fully autonomous vessels for inland or coastal waters, fully autonomous or unmanned oceangoing vessels are debatable regarding their operations in the international waters in the near future due to safety concerns, security issues as well as lack of maritime law and regulations. However, some developed autonomous technologies can be used for existing manned vessels to increase the safety and efficiency of vessels and also support crew activities.

1.4 Research problem

It is well known that autonomous technologies can support crew activities to improve both safety and efficiency, but the implementation of autonomous technologies is highly costly. Therefore, it is important to know what are the critical crew activities and which activities need to be in the first place to make a decision about the implementation of possible autonomous technologies to the existing fleet.

1.5 Research objectives

The main objective of this study is to understand how to maximize operational efficiency and safety by applying autonomous technologies, which are not existing on the current fleet. To understand the main objective of the study, it is crucial to analyze and prioritize current challenges and heavy workload of crew activities, which can result in operational deficiency, safety-related incidents, accidents, and even environmental disasters. After analyzing the challenges, possible solutions are given with the application of autonomous technologies in order to support the vessel crew activities as well as maximize operational efficiency and safety.

1.6 Research questions

This research study consists of three different research questions (RQ)s:

RQ1: What are the applicable autonomous technologies for oceangoing manned vessels?

RQ2: What kind of critical activities do we have onboard for both the deck and engine departments in terms of safety?

RQ3: Which crew activities can be supported by autonomous technologies by priority?

2. CHAPTER II – LITERATURE REVIEW

The new trend of a high degree of autonomous vessel projects can be seen as a revolution in the maritime industry with the concept of the ship without seafarers on board. Currently, the vast majority of the total vessel fleet in the world is operated by human decisions with controlling equipment both manually and remotely (Krzysztof et al., 2021). While there are many attractive and interesting sides of the application of this new type of vessels, such as reduced consumption of energy, cost, vessel size, increased flexibility, user adaptation, the new concept must be ready to be adopted by international regulations, classification societies as well as flag states. For this reason, it is crucial to understand specific definitions of the concept as well as what will differ from conventional vessels to autonomous ones (Rødseth &Vagia, 2020).

2.1 Autonomy concepts and levels

Autonomy originated from the Greek language with the "autonomia" word that expresses independence. This word is used in different fields of science. In engineering science, autonomy represents the system, which has the ability to make a decision without any operator or system support, while other tasks are performed.

The industrial autonomous mobile robot (IAMR) is a kind of autonomous mobile robot (AMR), which has been seen widely in commercial applications. The definition of IAMR consists of automated trucks for mining, automated vehicles as well as autonomous vessels with the MASS as a special one. Traditional ways of automation applications, such as automatic radar plotting aid (ARPA), have been used by operators with the aim of assistance without any changes in the rules and regulations. On the other hand, current ongoing projects like MASS, have the objective to give vessels full control in terms of critical tasks and complex situations execution. As a new case, it has been discussed by many different organizations, individuals, and companies, but still, there are many miles to go in reality. With the regulatory scoping exercise, IMO is aiming to answer for this new concept (Rødseth & Vagia, 2020).

It is aimed by IMO to define what is the most suitable way to use MASS, and analyze human factors, operational elements as well as technology (IMO n.d.).

The regulatory scoping exercise has an objective that specifies autonomy level. According to this assessment, the degree of autonomy is divided into four groups as shown in Figure 1.

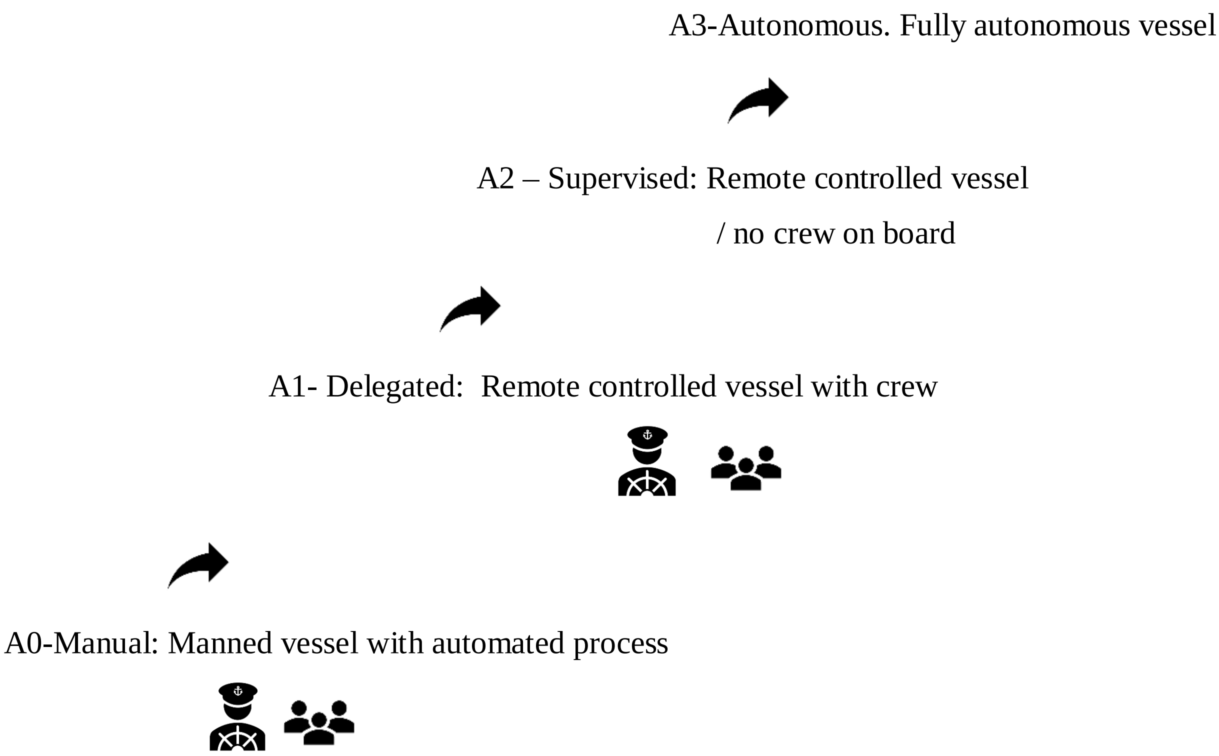


Figure 1: The four levels of autonomy / (IMO/MSC, 2018)

While a fully autonomous vessel (A3) has a system, which can take decisions itself and apply them, a remote-controlled vessel (A2) is operated by someone who takes decisions from different locations.

The degrees of A0 and A1 include seafarers. Remote-controlled vessels with the crew are also operated from different locations, but in case of any emergency situations, the crew is ready to take control. Manned vessels are operated by seafarers and to this degree, some vessel operations can be seen as automated (IMO/MSC, 2018).

The progression of MASS allows for reduced operational costs and advanced safety, usage of environmentally friendly technologies, such as clean fuels as well as cleaner propulsion systems. Although there are many safety challenges like cyber security, communication issues, information errors, physical risks for the MASS (Heffner & Rødseth, 2019), some positive improvements can be applied for conventional vessels (CV).

There are many papers, which give a description of autonomy level and task sharing information between humans and automation systems. These papers propose the level of independent operation degrees. Each degree has different aims and prioritization (Rødseth, 2019).

According to Lloyd's Register (LR), the level of autonomy is divided into six groups as illustrated in Figure 2.

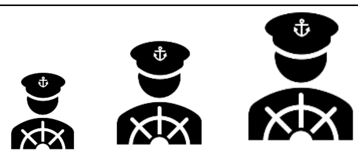
AL6 Fully autonomous / without supervision	
AL5 Fully autonomous / rarely supervision	
AL4 Human on the loop-operator /supervisory	
AL3 Active human in the loop	
AL2 On & Off vessel decision support	
AL1 Onboard decision support	
AL0 No autonomous function	

Figure 2: The levels of autonomy (Lloyd's Register, 2017)

AL1, in this level some decision support systems, such as dynamic positioning (DP) can be used by the crew in order to have support for their own decisions. AL1 and AL2 are not so different from each other, except AL2 has an option of provision of data, which can be given by either vessel or onshore systems. For the AL3 all onboard operations are carried by an onboard crew.

AL3 includes the provision of data too, but in case of any emergency situation, the vessel crew is responsible to make a decision. The supervision of humans is the main concept in the AL4 and in any risky situation, humans can interfere with the operation and invalidate the decisions, which have been taken autonomously. AL5, the vast majority of decisions are taken by the autonomous system and this level includes rare or non-supervision. AL6 has the highest level of autonomy, the fully autonomous vessel takes all decisions itself and there is no chance to access the vessel system in order to give any supervision. The system has full responsibility to detect, evaluate and take an action related to the existing environment (Komianos, 2018).

According to the Norwegian Forum for Autonomous Ships (NFAS), autonomous maritime vehicles are divided into two groups as unmanned underwater vehicles (UUV) and autonomous surface vehicles. While unmanned underwater vehicles are divided into two categories as remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV), autonomous surface vehicles are also divided into two categories as maritime autonomous surface ships (MASS) and unmanned surface vehicles (USV). It is well known that the term the vehicle is not used to express just vessels, so in this study, just vessel autonomy is discussed. NFAS improved the maritime autonomous surface ship (MASS) concept, which was developed by IMO as demonstrated in Figure 3. According to these improvements, MASS has four following sub-categories: autonomy assisted bridge (AAB), periodically unmanned bridge (PUB), periodically unmanned ship (PUS), continuously unmanned ship (CUS) (Rødseth & Nordahl, 2017).

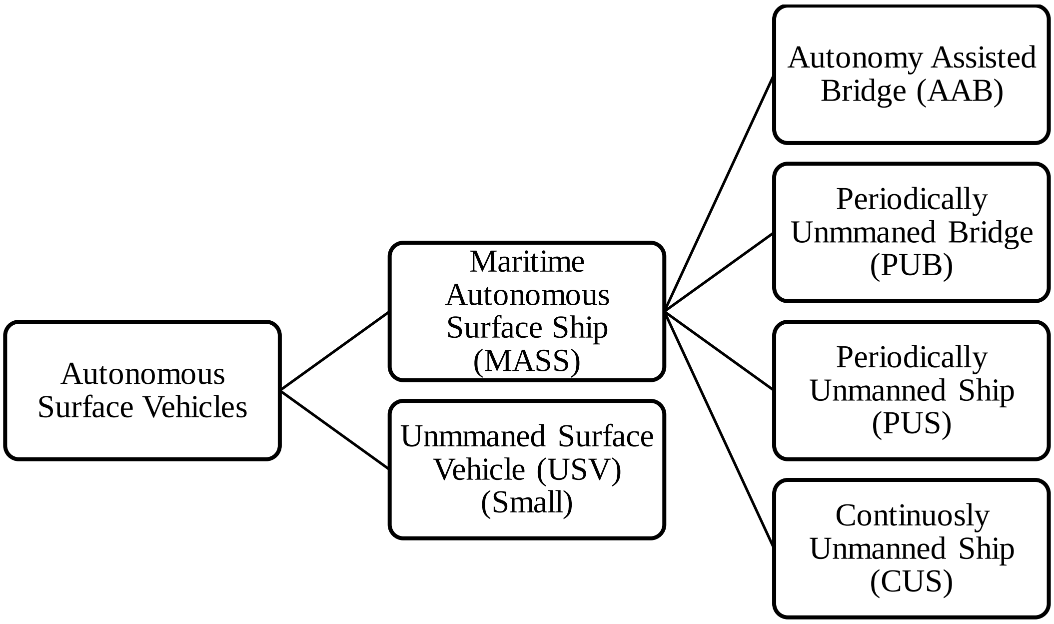


Figure 3: The sub-categories of the maritime autonomous surface ship (Rødseth & Nordahl, 2017).

Autonomy-assisted bridges always have a crew and they can intervene quickly for continuous functions. Periodically, unmanned bridges can be operated autonomously for some time when the weather condition is good and the vessel navigates in open seas. The crew is ready to take control in case of any emergency situation. Periodically, unmanned vessels can be operated without crew on the bridge for a prolonged time. For instance, deep-sea navigation. Crew can join the vessel when the vessel approaches a port. Continuously, unmanned ships operate without crew on the bridge at all times. For emergency situations, one person may be on board (Rødseth & Nordahl, 2017).

2.2 Major autonomous ship projects

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is a project with around 3.8 million Euro budgets in total. European Commission is the cofounder. The objective of the project is the development and verification of the autonomous vessel concept. (MUNIN, 2016). This concept gives the vessel the ability to make decisions primarily by the way of onboard decision-making systems and also holds a responsible remote operator from shore to control the vessel secondly.

This new concept consists of an advanced sensor module, an autonomous navigation system, an autonomous engine, and monitoring control system, a shore control center, a shore control center operator, a shore control center engineer, and a shore control center situation room. The dry bulk vessel, which is 75.000 DWT, has been investigated in order to understand whether this kind of big merchant vessel can be operated fully or moderately with the same or higher level of safety of today's vessels (MUNIN, 2016). The project started on the 1st of September 2012 and finished on the 31st of August 2015 (Cordis, 2019).

The ReVolt is a revolutionary vessel concept, which is developed by DNV-GL. This concept expresses the 60 meters unmanned and shortsea ship with zero emission. The vessel propulsion is 100% battery-powered. It gives a solution for the needs of growing transport capacity in the short-sea sector. The capacity of the vessel is 100 TEU containers. In August 2013, the ReVolt was started and one year later it was externally launched (DNV-GL, n.d.).

Yara Birkeland is the first fully autonomous and electric container vessel with the fame of zero-emission project in the world. The development and all fundamental technologies, such as systems integration, advanced sensors, the control systems as electric and battery propulsion are undertaken by Kongsberg. The capacity of the vessel is 120 twenty-foot-equivalent units (TEU). The ship is equipped with proximity sensors. For instance, Lidar, IR camera, radar, AIS, as well as normal cameras. The vessel`s operational area will be between 3 cities` ports "Brevik, Herøya, and Larvik" in Norway. The vessel will be controlled and operated by the designated centers, which are located in three different locations. One of them is located in Porsgrunn / YARA, one of them is in the Brevik / Kystverket vessel traffic center and the last one is in the Kongsberg Maritime location. The vessel design was finalized in 2017 and the ship will be operated fully autonomous by 2022 (Kongsberg, n.d.).

The autonomous shipping initiative for European Waters (AUTOSHIP) is the project of the EU with the objective of faster autonomous vessel transition in European Waters. This project includes two autonomous ships, which will operate in both inland waterways and short sea shipping to show their capabilities (AUTOSHIP, n.d.). The project partners are Kongsberg Maritime and SINTEF and the duration of the project is between the dates of 06/19 and 11/22. The cost of the project is 27.000.000 Euros in total (SAMS Norway, 2020).

ASKO is a Norwegian distributor company for grocery. The company has made a new building project contract with Massterly and Kongsberg Maritime in order to build two new ships, which will be equipped with autonomous technologies, and continue their business from waterways. These two ships will help to reduce CO_2 level (about 5000 tones yearly) because of shifting transport from roadway to waterway. In spring 2022, these vessels will be started for operation according to the plan. 2 years will be dedication years for the first vessel to understand its autonomy capabilities. It is expected that fully autonomous operations of vessels will be ready in 2024 (Kongsberg, 2020).

The autonomous vessel concept has been supported mainly by Japan and Scandinavian countries. Most parts of the concept have been executed by Rolls-Royce and Kongsberg companies. European Commission provided a total 27.6 million euros budget to the project of "Autoship" (Felski & Zwolak, 2020). Until the last months of 2023, two autonomous ship projects will be completed in order to show their capability both in the short seaway as well as inland waters (AUTOSHIP, n.d.). There is an expectation about these project experiments, in case of success, they will pioneer the conversion of existing vessels according to the implemented standards (Felski & Zwolak, 2020).

Autonomous Waterborne Application (AAWA), Safer Vessel with Autonomous Navigation (SVAN), Maritime Unmanned Navigation through Intelligence in Networks are other autonomous vessel research projects. Organizations like International Maritime Organization (IMO) and classification societies like Llyod's Register (LR), Bureau Veritas (BV), China Classification Society (CCS), DNV-GL have their own description and standards in terms of the construction of autonomous vessels (Felski & Zwolak, 2020).

As investigated above, autonomous ships are being recently considered seriously by innovative companies, organizations, classification societies, and countries with their remarkable investments to create more sustainable shipping.

2.3 Autonomy and human related marine accidents

Marine accidents are unwanted abnormal facts of a vessel that mostly end up with a human injury, different kinds of property harm, and even loss of human life. It has been seen as the biggest issue in the history of the shipping industry (Luo & Shin,2019).

It is estimated that the high percentage of marine accidents (between 75% and 96%) is caused by human failure (Allianz, 2017). Human failures can happen at any time due to fatigue, inadequate communications, insufficient general knowledge about either technical issues or vessel systems, poor automation design, decisions with insufficient information, weak judgment, defective practices & policies, poor maintenance, and risky environmental nature (Rothblum et al., 2002).

Between the years 2014-2019, the marine accidents and incidents occurred mainly within internal waters and the percentage was 50.9%. The second-highest occurrence risk of accidents was 27.4% within the territorial sea. The rest of the marine casualties happened within the open sea and other locations with percentages of 18.2% and 3.4% respectively. 43% of the total accidents happened when the vessels were on their route, 9% of them occurred on their departure, 16% of them occurred on their arrival, 21% of them happened at anchor / alongside and 11% happened within unknown places (European Maritime Safety Agency, 2020).

In detail, according to the European Marine Casualty Information Platform (EMCIP) report, between the years 2014 – 2019, 1801 accidents occurred in total and the action of humans as a root cause accounts for 969 of itself. The human factor is equal to 54% of total accidents, while 28% caused by the failure of equipment or system. On the other hand, the accident events include contributing factors, such as shore management, external environment, and shipboard operation and shipboard operation is the most common factor, which is related to accident occurrence as 65.2% (European Maritime Safety Agency, 2020).

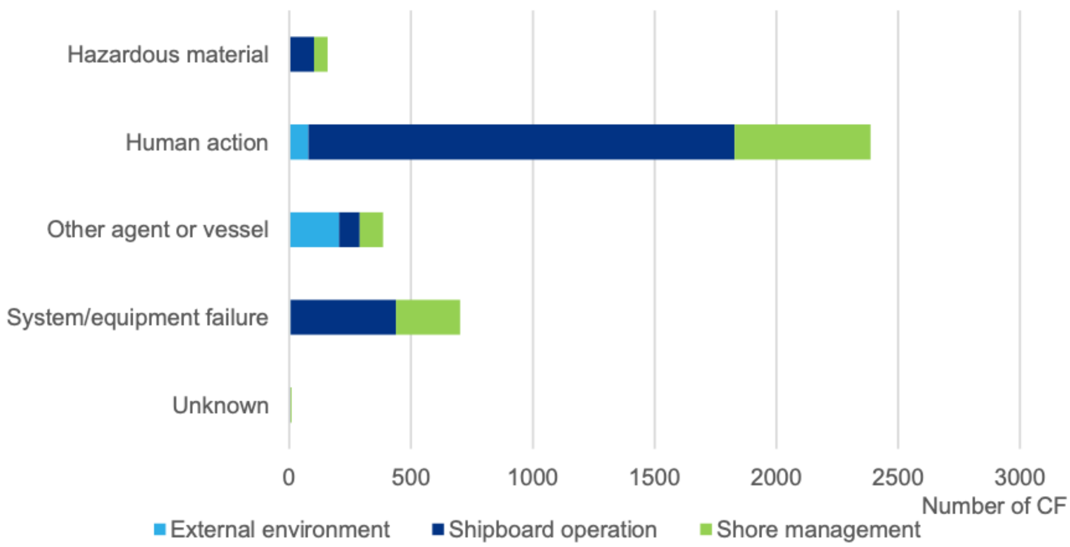


Figure 4: Relationship between accident events and the contributing factors for 2014-2019 (EMSA, 2020)

Human action is affected by the external environment, shipboard operation as well as shore management as demonstrated in Figure 4. The shipboard operation consists of personnel &

manning, crew resource management, social environment, workplace conditions, inadequate tools & equipment, emergency preparedness, maintenance, and physical stress. Shore management elements include operation management, safety & environment management, regulatory activities, design, emergency preparedness, organization & general management, personnel management, occupational health management, maintenance policy, business climate, and system acquisition. The external environment depends on both environmental impact and phenomenon (European Maritime Safety Agency, 2020). After human action, system and equipment failure is the most common problem factor that results in accidents/incidents. Hazardous material, other agents/vessels, and unknown factors have also affected marine casualties.

Organizations, such as IMO, an international association of classification societies (IACS), and international labor organization (ILO) have made efforts in order to eliminate the human element in marine casualties. For instance, the ISM Code is one of the strongest combat codes for human error (Hasanspahic et al., 2021). The code ensures safe management and vessel operations within the international standards as well as the marine environment protection (IMO, n.d.).

The autonomous vessel will be operated either with no vessel crew or a lower number of vessel crew and this new design of the ship will have a positive effect on the safety because there will be fewer people who will expose the risk at sea. Starting the operation of autonomous vessels will increase safety on board, even the accident numbers remain the same (Vos et al., 2021). On the other hand, the development of autonomy-related technology has a significant effect on maritime transportation with the aim of reduced accidental risk and increased operational efficiency. For instance, integrated bridge systems (IBS), ECDIS, central alert management human-machine interface (CAM- HMI), integrated navigation system (INS), electronic chart display integrated system are the product of these new technologies (Bielic et al., 2017).

In 2019, the total number of losses was 41. Loss numbers of all ships worldwide have declined 70% in just 10 years. Advanced technology, better vessel designs, management of risk and safety, specified mandatory regulations, procedures are important factors for this long-term progression (Allianz, 2020).

2.4 Autonomy and situational awareness

The total number of all ships lost was 951 for the past ten years (over 100 GT ships only). Five hundred and nineteen of them were either sunk or submerged due to bad weather, capsizing, flooding, an engine problem, ingress of water, 189 of them grounded and 97 of them fired & exploded. These are the most common reasons for all losses and their percentages were 85%. After these top causes, machinery damage or failure, collision, hull damage took part in the list as important reasons for the losses (Allianz, 2020). For collision at sea, the main reason is the lack of situational awareness among officers. A high level of situational awareness ensures safe navigation (Du et al., 2020).

Situational awareness should be one of the most fundamental abilities in bridge operations. It requires the right decision-making quickly. To know what is going on around the vessel and interpret this environment is the main objective of situational awareness (SA) (Sandhåland et al., 2015).

According to Endsley and Jones, situational awareness is divided into three levels as shown in Figure 5.

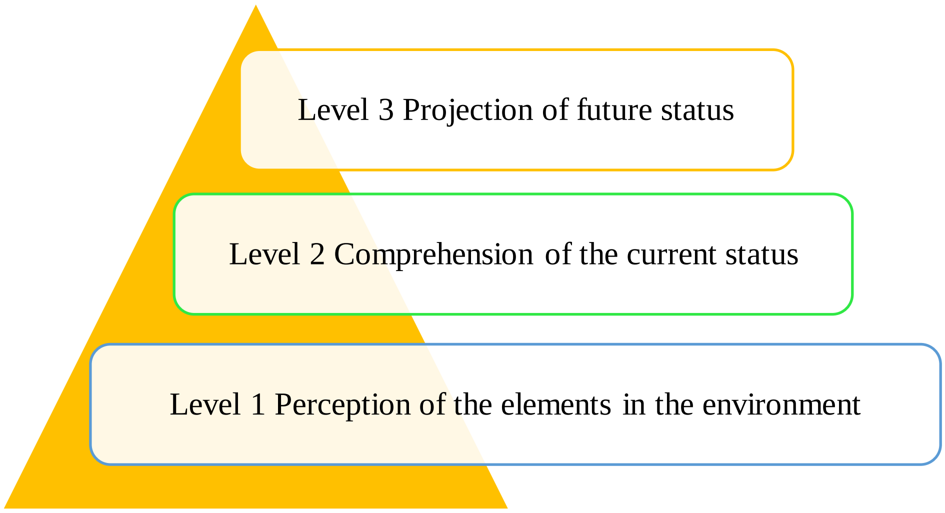


Figure 5: SA levels (Endsley & Jones, 2004)

The first level of the situational level is about detecting the environment individually. For instance, Look out for the sense of vibration. At this level, communication is also a tool of contribution to the level. Information confidence for level 1, mostly based on organization, sensor as well as the provided information by the individual. It can be detected by hearing, seeing, feeling as well as smelling and tasting. The second level is about understanding the data and also perceived cues, which are related to linked objectives. This importance level as well as meaning. This level is more than reading words and requires comprehension. The third level of situational awareness is a combination of level 1 and level 2. At this level, the person will have the ability to predict the obtained elements, which are about the element description and also its meaning (Endsley & Jones, 2004).

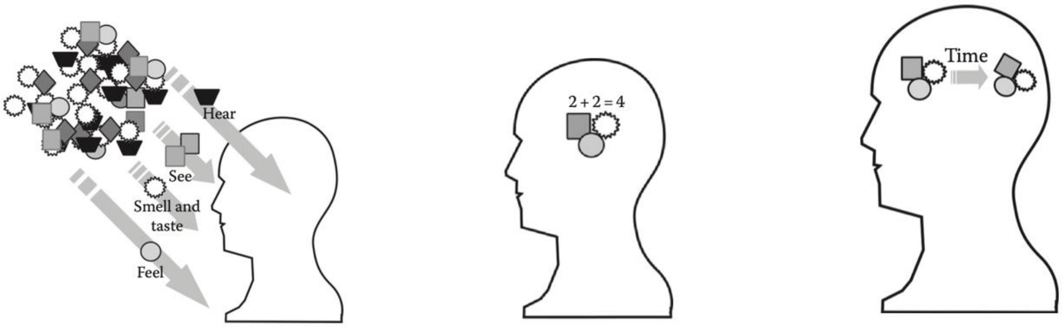


Figure 6: Level 1 SA, Level 2 SA, Level 3 SA (Endsley & Jones, 2004).

As illustrated in Figure 6, the officer on duty will detect the current status of the environment as well as dynamics in level 1. For level 2, duty officers will evaluate the existing information and integrate them. Any misinterpretation due to stress or heavy workload at this level can cause failure comprehension. For level 3, the officer on duty needs to use their own comprehension and perception to estimate the near future possible circumstances (Endsley, 1995b, 2012). For instance, there is an expectation from the duty officer, she or he has the ability to calculate existing internal and external factors, such as current, speed as well as wind in order to analyze the current situation and maneuver to avoid any possible collision (Sandhåland et al., 2015).

The international regulations for preventing collisions at sea (COLREGs) have many requirements related to full situation appraisal of circumstances as well as collision risk conditions. According to the COLREG, vessels are required to have proper monitoring with the radar in order to detect any kind of collision risk in advance. Current regulations based on seafarer senses and their interpretation of environment status, experiences as well as knowledge. This limited framework is bound with the vision of human equipment, such as radar, AIS, ECDIS, echosounder, ARPA, and global satellite navigation system (GNSS). Bridge technologies provide the bridge team advanced information that is related to situational awareness topics, because of this reason interactions of man – machines are very important on ships (Endsley, 2012).

On the other hand, only the usage of these technologies does not match with the concept of autonomous or remote-controlled ships. IMO 's regulatory scoping exercise has been trying to find answers for safer, environmentally friendly as well secure systems (Wright, 2019). These new technologies like advanced sensor systems can contribute to conventional vessels in terms of decision support, collision avoidance as well as creating a high level of situation awareness.

The main objective of sensor systems is vessel environment monitoring. The environment of maritime is divided into three categories in terms of the perspective of sensor systems. The first one is subsea sensor system, which consists of echo sounders, UUV, sonar with the type of navigation or side scan, the second is surface sensor systems, which includes, light detection and ranging (LIDAR), aid to navigation (ATON), mm RADAR, radar, ECDIS, audio, infrared, visual, unmanned aerial vehicles (UAV), Inertial Nav, and the third is space sensor systems that cover global satellite navigation system (GNSS), search and rescue (SAR), optical, long-range identification and tracking (LRIT), AIS, meteorology, and oceanography (METOC), vessel monitoring system (VMS). While the subsea and surface systems provide imagery as well as sightline data in real-time, space systems are mostly about accessing worldwide information and data from different external sources to ship (Wright, 2019).

2.5 Autonomous technologies

The usage of autonomous technologies has been increased for many years with the aim of a high level of safety, advanced capabilities, and fewer human laborers. Even though the concept of autonomy points to performing the tasks by itself regardless of capacity, human interaction is still indispensable for most existing autonomous operations as well as systems. Humans are still taking responsibility in providing directions, controlling the performances, and supervision (Endsley, 2016).

Hamburg School of Business Administration made a study for the International Chamber of Shipping (ICS) regarding the future of seafarers under the effect of autonomous vessels and they stated as follow:

"few vessels will be entirely autonomous in the next decade or two. With an overall increase of the world fleet, at least the number of officers on board will remain stable. At the same time,the number of crew onshore in supporting functions will increase, possibly significantly" (HSBA, 2018).

It is clearly seen that the high level of autonomy application is not possible in the near future according to the study, but some existing autonomous technologies can be used to help vessel crew in terms of increasing the level of safe operations and reduce the potential risks.

The nature of shipping has many different risks by virtue of the job environment. Application of automation systems can help to ensure higher safety on board for both seafarers and the environment (HSBA, 2018).

2.5.1 Bridge related new technologies

Surface Sensors

Sensor systems for the ship environment have been laid down as a condition of Maritime Autonomous Surface Ships by IMO in order to ensure a high level of situational awareness, monitorability of decision making as well as supervision (Wright, 2019)

Wright stated that "*Examples of shipboard surface sensing systems that can provide new, and redundant precision navigation, timing, vision and acoustic capabilities include:*

– *Inertial Navigation Systems (INS)*

– *Laser Imaging (LiDAR)*

– *Millimeter Radar (mmRADAR)*

– *Video and Infrared (IR) Cameras, and*

– *Microphones.* "(Wright, 2019)

Inertial navigation systems (INS)

The systems consist of measurement of accelerations, rate of rotations and calculation of positions, attitude as well as velocity. Inertial measurement units (IMUs), navigation computer(s), power supplies, interfaces of users are the subsystems of Inertial navigation systems (Grewal, 2013). Dead reckoning with the inertial navigation example and position fixing with the global navigation satellite system (GNSS) example are two major techniques for navigation. While position fixing is accomplished by the detection of accurate positions, dead reckoning depends on the comparison of initial values of moving platforms (Youssef & El-Sheimy, 2020).

Light detection and ranging (LIDAR)

Both light detection and ranging (LIDAR) and radio detection and ranging (RADAR) are examples of remote sensing applications, which can perform both day and night. Sending out signals to the surface of the ground face and receiving them back in the form of an image is the way of working. While the long wavelengths that enable the system to see in the different environmental conditions of some vegetation, clouds/smoke, are used by radar, laser scanning that ensures a high level of accuracy of the 3D surfaces of objects, is used by Lidar systems (Shih et al., 2016). The LIDAR system ensures the surface mapping, which is three-dimensional (3D) with a high degree of resolution properties in real-time (Kabel & Georgakis, 2019).

Intelligent Awareness (IA), is developed in order to reduce the risks, which navigators can be faced with at night or harsh environmental conditions, such as poor visibility, bad weather, high-density waters. It enables the surrounding vessel to be more understandable, especially by the captain, and officers. The system of intelligent awareness originates from the ship's 3D map. LIDAR is the infrastructure of this 3D mapping system onboard with the usage of the laser beam, which is pulsed in order to detect distances. The creation of a 3D environment makes it possible to see things that normally are not possible to see by the human eye. This 3D creation is linked with GPS data. Drawing a 3D map is performed with the usage of 300,000 light beams, which are fired by laser, and measurement of their back reflection time (Kongsberg Maritime Communication, 2018).

Intelligent Awareness (IA) can be used in any kind of vessel in order to increase situational awareness with the aim of advanced efficiency as well as safety (Hirvonen, 2018). (See Figure 7).

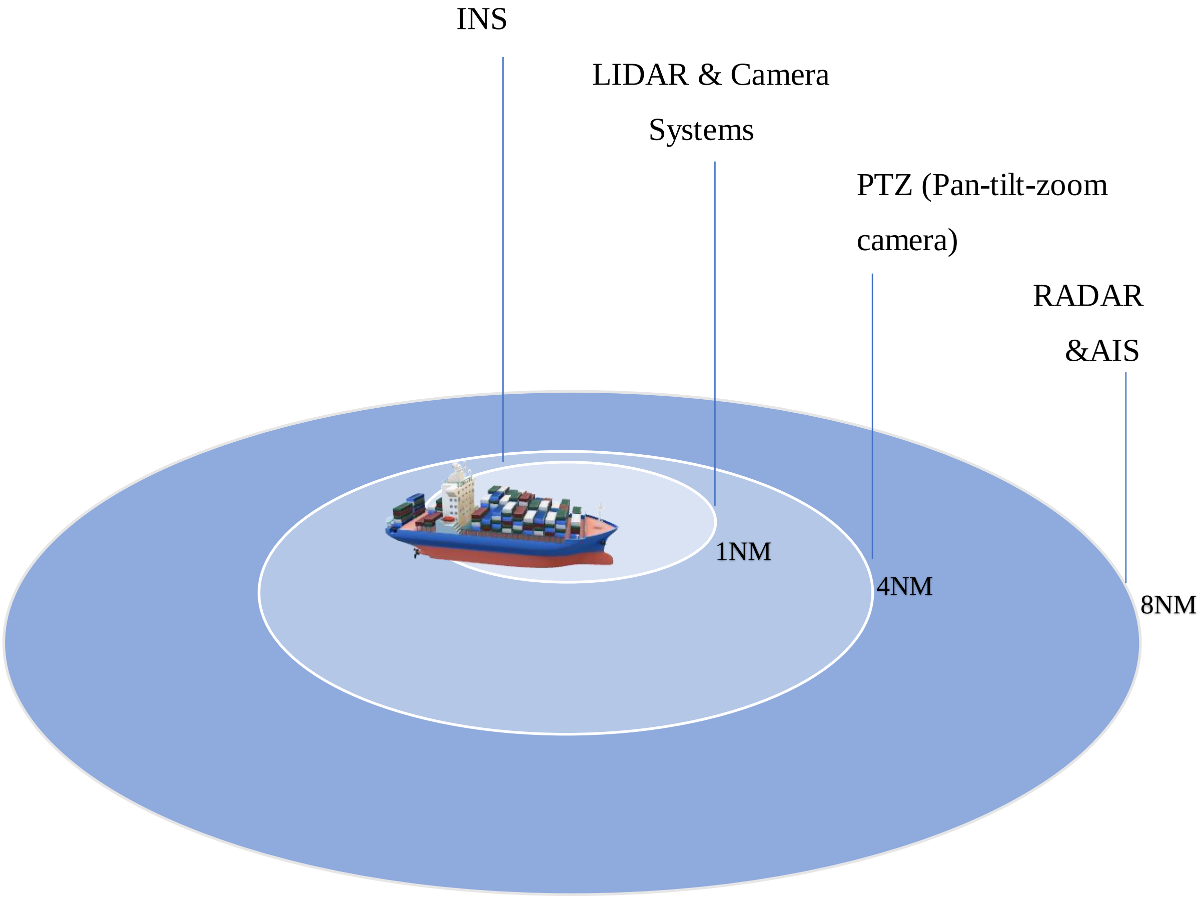


Figure 7: Cutting-edge camera and sensor technology (Rolls- Royce, 2018)

Pan-Tilt-Zoom camera (PTZ)

Pan-tilt-zoom cameras are the newest technology product, which can be used in commercial ships in order to detect objects in heavy weather and poor visibility conditions. It is intelligent imaging equipment and can be used with different options, such as visible single sensors and visible dual sensors.

This camera firstly, detects & recognizes any subject and later identifies it in a flexible way. Dual sensors can be fixed with thermal sensors as well as lens options and it ensures daily clear image surveillance without any defect due to darkness, smoke, fog, dust, or haze (IMENCO, n.d.) PTZ cameras are real-time suitable trackers and there is no need to make an assumption regarding either visual or marine environmental conditions because it is proven that they have high detection capability even in changeable visual situations (Makantasis et al., 2016).

InfraRed cameras (IRC) / Thermal imaging cameras (TIC)

Originally, infrared cameras were used by the military. Later on, they have been transferred to other areas, such as target detection, astronomy, mechanical engineering, pollution, monitoring of condition and process, R&D, search and rescue, etc. The thermography of IR is based on an image production technique that utilizes the emission of infrared light from objects, which have different thermal properties. Human eyes can`t perceive the IR lights. Typically, infrared cameras generate live videos. They have many advantages. For instance, prevention of equipment failures (corrective acts), real-time video movement, and creating visible pictures (enabling analysis of a wide-range area). On the other hand, measurement of real temperature, its interpretation, and proficiency in scanning can be both difficult and time-consuming. This infrared camera technology ensures reliability and safety in marine vehicles so that it can avoid equipment failure, which can result in ship or crew loss (Muzevic et al., 2008).

In the engine room, for instance, pipe rupture of fuel or oil is the main reason for the fire in the engine room according to statistics. Engine room fire is not common among the other space fires, but when it occurs, the consequences will be highly expensive and dangerous for both crew and ship. Although SOLAS put rules regarding insulation of cables and piping, there are many deficiencies about them on vessels. Every passing day, ship engines have been becoming more complicated and getting dependent on a large number of electrical parts. This makes the maintenance and inspection obligatory regularly. At this point, IR cameras are a very good solution to control and measure the temperature of any electrical equipment in the engine room without human contact and with visual proof. In cargo surveys, the usage of infrared cameras can help the experienced operator to understand any temperature differences on the surfaces. It can contribute to the detection of moisture in bulk carrier vessels because when moisture occurs on the cargo surfaces, it results in differences in terms of heat. Another advantage of infrared cameras is to understand the problem related to cargo temperature during the discharging operation as well as categorize the problem according to the root cause. It can be applied to both tanker and container vessels to locate problem sources. In navigation, thermo-visions can be used to see in the darkness, intense smoke as well as light fog to ensure a high level of security and safe navigation. In addition, search and rescue operations, water pollution protection can be ensured by infrared camera technology, which is cost-saving and time-efficient (Muzevic et al., 2008).

Video surveillance

Nowadays, there is an increasing trend of video sensors that can detect vessels visually in a short-range. This system`s usage is very beneficial for both inland waters and open seas (Heiselberg & Stateczny. 2020). System of video surveillance is mainly used under the traffic complexity or intensive traffic conditions in order to observe ship movement either on inland waters or coastal navigation. Although vessels have classic Automatic Identification System (AIS) and radars, video surveillance can be seen as a navigation support system for the existing onboard system of monitoring.

It gets data from both subsystems and different sensors so that it provides accurate information to the bridge team. Having the video surveillance back- up the systems. Within the monitoring zone, especially on narrow canals or rivers, all ships can be detected in terms of tracking status. Cameras can be positioned in different areas on the vessel, especially on the bridge location. Generally, it is not necessary to zoom in during the passage of a narrow waterway, but if the range of the waterway is big, it is important to put a group of cameras to recognize the other ships. Environmental effects, such as wind, sun, and waves create difficulties for the detection analysis for the system, because of this reason two solutions are improved. While the first one is related to the method of pixel-based analysis, which enables detection of background chances due to object movement, the other one is about to put objects in recognized classification if it is possible. The technical properties of video streams are based on different algorithms, such as algorithm of water detection, moving vessel detection (MVDA), and status update (SUA) (Wawrzyniak et al., 2019).

An on-board ship detection and real-time information system (AMARO)

Automatic identification system (AIS), which is based on satellite, only equipment that provides accurate data about the current position of a vessel in close real-time. It is mainly invented in order to avoid a collision. With the usage of this equipment, it can be known the following information; vessel name, IMO number, position, speed, type, position, and any other vessel traffic information by the other vessels or stations. At the present time, satellites are another option to possess information from AIS with the aim of real-time vessel tracking. Although AIS provides different information, it is not possible to gather information about non-legal activities. For instance, smuggling or pollution of water, etc. Earth observation (EO) is a kind of data from satellites, can be used to develop an awareness of the maritime field. This system consists of a platform and ground user, who wants to know vessel-based circumstances as soon as possible (Willburger et al., 2020).

Intelligent central alarm system (ICAS)

It is a software, which is designed and improved in the Flagship project for the free up crew in order to investigate a situation of emergency as well as enables continuing to ship routine operation without any confusion. Kongsberg Maritime AS was responsible for the project.

The main objective of ICAS on board is to avoid huge alarm cascades of the bridge and engine room. This system working principle is doing alarm grouping that is based on the criticality of alarms, their overviews, and temporary fake alarm shelving in order to reduce disturbance, and enable advanced focus vessel operations. It is well known that the high number of continuous alarms in a short time can result in blackouts thereby incidents (Kongsberg, 2011).

Integrated bridge system (IBS)

Integrated bridge systems express interconnected system combinations so that it makes it possible to have centralized access for information of sensors as well as command from workstations. The main aim of IBS is to ensure increased safety and efficient management of vessels by its qualified crew (IMO, n.d). The best way to increase a duty officer´s situational awareness in the high risky conditions is advanced developments in the integrated bridge system. Generally, IBS includes a navigation network and an automation system network. These separate networks contribute to the survivability of the system in case of different failure conditions. The system of automation can include a power management system, alarm &

monitoring, HVAC, control of bilge, and ballast (Perera & Guesdes 2015). The system of navigation can contain ECDIS, autopilot, Arpa radar conning, ICAS, control & monitoring sensors, different cameras, and make all of them available for usage on the working station, which gives duty officer flexibility as well as a high level of redundancy (Marine Technologies LLC, n.d).

Broadband radios

In other words, maritime broadband radio (MBR) technology, which is developed by Kongsberg Maritime. These radios are developed based on digital technology that makes reliable and high-speed communication possible. It is well known that both transfer data, so communications are very important for high safety and efficient vessel operations. MBR can be used for different aims as well. For example, transfer of echo sounder or sonar among the ships. It allows communication with other captains (Kongsberg, n.d.)

Electronic logbooks

It is software that logs needed information faster and easier on the electronic platform. Electronic logbooks reduce human error as well as remove the paper works permanently. They are designed to meet the authorization requirements because big and well-known flag states have requirements about sailing without paper. It is also accepted by IMO and improved according to the MARPOL and SOLAS. E- logbooks consist of deck logbook, engine logbook, radio logbook, operational logbook, garbage logbook (both part 1 and 2), DP logbook, oil record book (part 1) and etc. Electronic logbooks have a positive effect on-time efficiency.

The usage of e-logbooks can reduce the workload of the officers, so they can concentrate on their main operational duties, such as navigation, cargo operation, etc. These digital solutions can be applied to any type of vessel. The main advantage of the logbooks is to gather data within single storage of data so that it avoids any kind of confusion, mistakes and enables easy access to the desired documents during the inspections, flag state, or port state controls. Shipping companies also can follow up the electronic logbooks from shore (Kongsberg, n.d.)

Electronic checklists

A checklist of vessel operations is based on software that gives the responsible officer portable and time-saving solutions. Vessel arrival checklist, vessel departure checklist, and many other checklists can be filled up by this electronic solution. This software can be installed on Windows portable tablets. It is very easy to use and make any changes. It provides automatic commands like saving or printing out and shows checklists whether they are filled up or not (NAPA, n.d.)

Navigation assessment and routeing (NAR)

NAR is developed by Weathernews. Inc to avoid grounding in maritime transportation and it is expected to start to use this system in May 2021. It ensures supportive activities that can prevent the risk of grounding, which is one of the most common and serious types of accidents at sea. This serves as a first automatic service that detects any kind of grounding risk and sends notifications to the responsible people onshore, such as vessel managers, vessel operators, or other persons in the organization who are responsible for the vessel´s safety. When the ship proceeds to risky zones, such as shallow waters, high traffic density areas with fishing vessels, or deviates from the normal route, this system starts to transmit the alerts automatically.

It is also planned for the coming years, the risks of hull rocking and dragging of anchor due to heavy weather like tropical storms or cyclones will be covered by the service to notify the related people onshore. This service is the first supportive service in the world that provides notifications about the risk of grounding to shoreside. While the service secures the ship´s safety, it also assures the protection of the marine environment.

The system detects the risk of grounding with the usage of some data like route data, oceanographic data, and navigational data. For instance, passage plan of the ship, data of route, direction & speed & height of wind, wave, ocean current, tidal stream, risk of grounding area, every 2 minutes updated position data, navigational charts, hazards, and warnings (Weathernews, 2021).

Weather forecasting software

The bon voyage system (BVS) is developed by Storm Geo as combined software that provides both the reliable weather forecast and noon position of ship information. The system supports vessel captains in terms of understanding weather conditions, finding an optimal route, and decision-making on a navigational route with its easy usage. It ensures arriving at the next port in the shortest and safe way.

The latest data about oceans and weather is transferred to a vessel with the help of email or broadband as well as an information delivery platform, which is called KVH IP-Mobile. The system transfer uses the smallest format, so it contributes to communication expenses on board.

This system shows a seven days view of tropical storms in different colors, which have different possibility percentages on the screen. Different colors help the captain to detect danger in advance. This showing is based on 125 miles range distance from the selected port and every six hours, data about tropical cyclones is updated by the system. Large-scale forecasts for tides are also provided with a high level of accuracy by the system. Tide data calculation is carried out based on the model of velocity (Storm Geo, n.d.)

2.5.2 Engine related technologies

Power management system (PMS)

Today´s vessel fleet has a power system that is open for further improvement in order to optimize their consumption of fuels as well as reduce emissions. Any changes in the strategy of the power management system, configuration of system redesign, and the machinery can have a positive impact on the improvements. Advanced power management systems enable the sources of power to work at their optimal operating point. It ensures getting maximum benefits from the system (Jaurola et al., 2019).

Generation of power and its main distribution that includes governors, generator controls, synchronizer, switchboard breakers, on the ship are performed by the power management system. It has reliable logic, coherent functions as well as an easy user interface. It can be applied to different kinds of configurations of switchboards. It combines shaft generators, main ship engines as well as control of the clutch. PMS occupies a small space and it requires low power. Alarm & monitoring of events, control of diesel/gas, battery generator, load sharing, control of boil of gas, bus tie, clutch, thruster, and heavy consumers are the functions of the system. It is designed based on the redundancy concept so no single failure will lead to stop or change the system, so generators all time continue working and breakers will stay the same (close) in working condition. The system arranges the engine`s stop and start in different situations according to the power demand, load reduction, load sharing, switchboard configuration, gives pre-warning alarm in case of any detected situation that can result in the shutdowns, does disconnection of generator which is affected by the shutdown, repairs blackout that can be partial or total, with reconnection of crucial breakers (Høglund, n.d.)

Ship Performance Monitoring (SPM)

In 2011, IMO made the Energy Efficiency Design Index (EEDI) mandatory in order to keep the CO2 emission level under control for new vessels as well as the Ship Energy Efficiency Management Plan (SEEMP) to improve the vessel energy efficiency with cost-effective solutions for all vessels. These were the first agreements for the change of climate as legally binding.

EEDI, as the most critical measurement in terms of technical properties, encourages the usage of more efficient engines/equipment with fewer pollutant characteristics. It requires a different type of vessel minimum efficiency level of energy per mile of capacity. Two years initially (phase 0), it has been required from the new building vessel design to meet with the level of reference since 1st January 2013. Each of the 5 years, it is expected to compact the level step by step. Unsurprisingly, there is an expectation regarding stimulation of EEDI to continue innovative and advanced technological improvements so that it has a considerable effect on the component of fuel efficiency during the design phase. There is no standard index or prescription in the industry about the energy efficiency design, so marine technology solution providers and ship designers can freely choose and develop their own performance mechanism according to the regulations. The only requirement is to reach the required level of energy efficiency. This index as a specific figure shows CO2 in grams per vessel´s mile capacity. If the vessel has a smaller EEDI, it means this vessel has a more energy-efficient design (IMO, n.d.)

SEEMP is the unique approach for the companies in order to manage their fleet and monitor the energy efficiency performance of their fleet in the progress of time. The shipping companies can use energy efficiency operational indicators (EEOI) to monitor the progress. It ensures measurement of fuel efficiency, changes effect, cleaning of the propeller, technical measurement introduction that includes recovery systems of waste heat, and so on. It also motivates the vessel operators and owners to pay attention to newly developed technologies as well as their practices during the search of optimizing for ship performance (IMO, n.d.)

Ship performance monitoring (SPM) is an adaptable software that supports the both management and improvement of vessel/fleet efficiency. It gives support for the SEEMP implementation (Norwegian control systems, n.d.). It is based on computer systems, which monitor and control the complex types of vessel performance. For instance, liquefied natural gas carrier (LNGC) and roll-on roll-off vessels that have multi engines. It is developed at three different levels. Level 1 covers the performance data of hull & machinery and their monitoring, controlling, and reporting. The first configurations can be applied to all kinds of vessels. Level 2 consists of both the level 1 properties and improved savings with the help of advanced machinery and the arrangement of cargo model techniques. For instance, for bitumen or liquefied natural gas carriers. Level 3 includes voyage planning that is supported by automatic control of propulsion and it ensures optimum savings with the weather prediction and vessel modeling usage. Ship performance monitoring systems have many advantages. For example, running ship efficiency calculation, EEOI calculation, SEEMP, and key performance indicator (KPI) administration, reduced emissions, up to 3% cost of fuel reduction, increased ship efficiency, vessel crew awareness as well as wastage potential, the transmission of data between onshore and the vessel, efficiency analysis as well as troubleshooting, monthly rapid fast return investment (ROI) (Trelleborg, n.d.).

Heating Ventilation and Air Conditioning / HVAC Control System (HCS)

This system can be considered an ideal solution for retrofit. It can be installed both independently or dependently. Improved control tools of the HVAC system optimize comfort and also consumption of energy. Controlling the fan´s start-stop, interlocks start, easy settings of parameters, temperature & pressure & CO_2 level control, the interface of emergency shutdown (ESD) & frequency converter interface are the overview of the system functions. The system`s safety makes sure maintenance and protection of the crew/fan unit in case of any possible damage, such as limit extension in plant parameters (Høglund, n.d.)

Integrated automation system (IAS)

This system is an innovative technology, which provides distributed information regarding monitoring and process control at any time. It ensures a high level of safety and quality. It is applicable for different kinds of propulsions, such as dual-fuel diesel-electric propulsion, slow-speed diesel-electric propulsion, conventional steam propulsion, combined gas turbine, and steam turbine and electric propulsion. Machinery control, power management, thruster & propulsion control, HVAC, ESD, cargo, LNG, navigation, auxiliary equipment, and dynamic positioning are the specific applications of the integrated automation system. Integration covers the fundamental machinery system´s control and monitoring. Propulsion plants, power plants, auxiliary machinery, fuel plant and bunker systems, and bilge systems are part of the basic machinery systems. IAS interfaces to the integrated bridge systems, voyage data recorder (VDR), closed-circuit television (CCTV) system, ship performance system, ship administrative system. This system ensures dual redundancy & process, local operation & control, components hot-swap, quick recovery, local time option for alarms, arrangement, connection between ship & shore, historical database option, advanced online & offline commissioning tool (Wartsila, n.d.)

2.5.3 Summary of the autonomous technologies

It is clearly seen from table 1 that there are different kinds of autonomous technologies available as newly developed autonomous technologies. In this research, autonomous technologies are divided into the following two categories, bridge-related autonomous technologies, and engine-related autonomous technologies.

Bridge-related autonomous technologies support the vessel`s safe navigation/maneuvering with the help of monitoring environment and position with INS, LIDAR, PTZ camera, InfraRed camera, video surveillance, AMORO, IBS, broadband radios, NAR technologies, and weather forecast software.

Engine-related autonomous technologies support mostly the vessel`s efficiency with the help of PMS, SPM, HCS, and IAS.

Electronic logbooks, checklists, and ICAS are also common technologies that can be used both on the bridge and engine room.

Table 1: The list of the autonomous technologies

Bridge related autonomous technologies	**Engine related autonomous technologies**
- Inertial Navigation System (INS)	- Power Management System (PMS)
- Light Detection and Ranging (LIDAR)	- Ship Performance Monitoring (SPM)
- Pan- Tilt- Zoom Camera (PTZ)	- HVAC Control System (HCS)
- InfraRed Cameras (IRC)/Thermal Imaging Cameras (TIC)	- Integrated Automation System (IAS)
- Video Surveillance	
- An onboard ship detection and real time information system (AMARO)	
- Integrated bridge system (IBS)	
- Broadband radios	
- Navigation Assessment and Routeing (NAR)	
- Weather forecast software (BVS)	
- Electronic logbooks, checklists	
- Intelligent central alarm system (ICAS)	

3. CHAPTER III -METHODOLOGY

The methodology of the research includes the creation of own rules like public, explicit as well as accessible. It also provides a framework for both constructive criticism and replication. While replication is based on the investigation repetition by either the same scientists or others, constructive criticism is about asking different key questions about obtained knowledge regarding explanation, the accuracy of observations, methods of observation, the validity of the testing procedure, and interference of any factor (Nachmias &Nachmias, 2008).

3.1 Research strategy

Quantitative and qualitative research are two main concepts of research strategy. While the quantitative strategy is about highlighting quantification, the qualitative strategy is mainly about words in terms of data collection and analysis process. The qualitative research method is used for this study due to the nature of research that focuses on context description, participants of the study, process, concept & theory, the flexibility of study, and lack of structure (Bryman & Bell, 2011).

The study process started when the company presented the research problem and offered research collaboration to the university regarding prioritization of crew activities to apply autonomous technologies in order to understand demand and criticality.

The collection of data was carried out based on both literature review and online interviews & mail questionnaires due to the current Covid-19 and distance restrictions. Interviews have been used widely for qualitative research studies. Semi-structured interviews were carried out due to the structure of the questions, which are listed according to the specific questions about vessel crew activities with the right of leeway for the interviewees (Bryman & Bell, 2011).

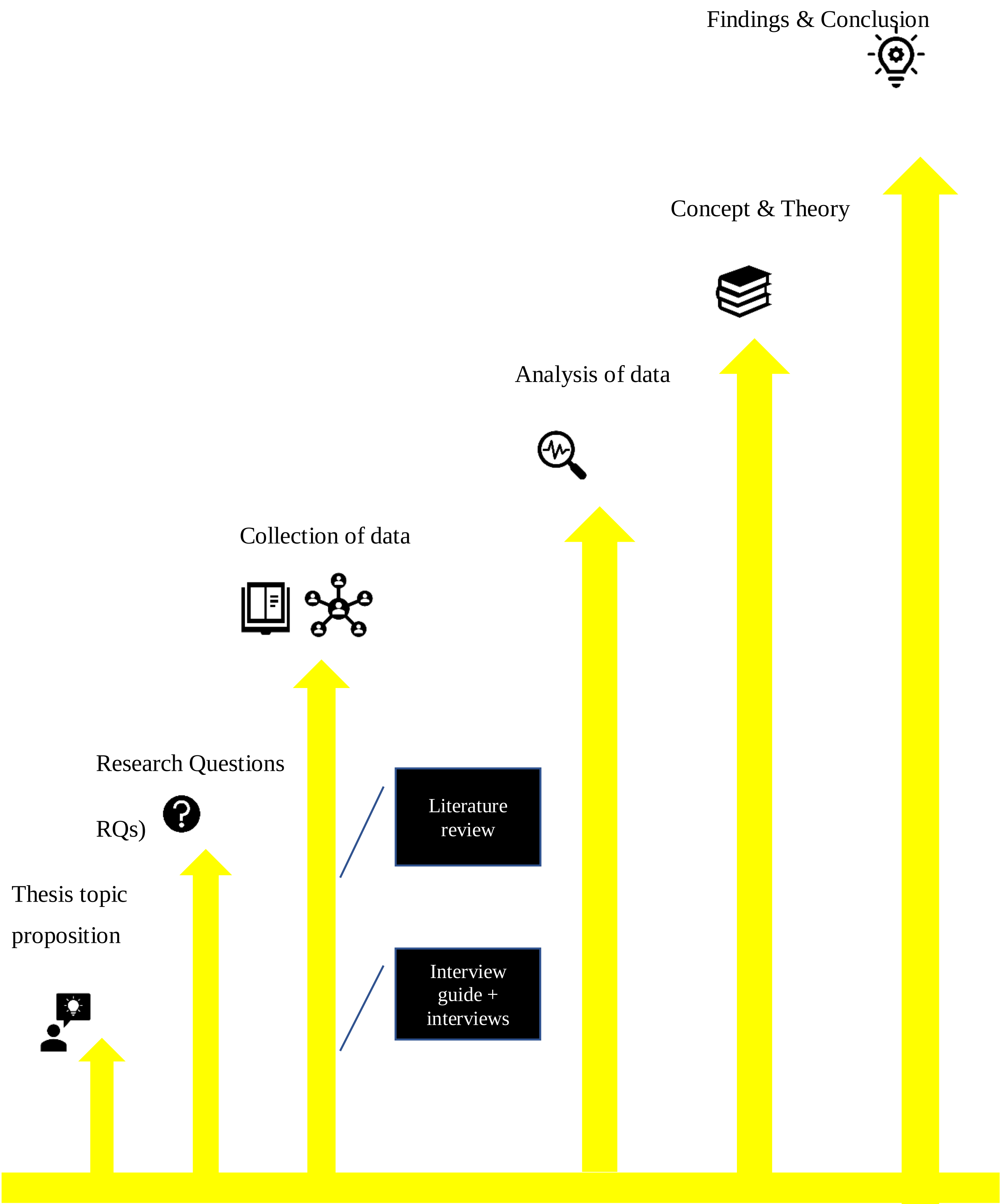


Figure 8: Process of the research study

3.2 Research design

Research design is a kind of logical model, which allows the investigator to give solutions for existing research problems as well as guides the researcher in the different levels of the research study (Nachmias & Nachmias., 2008).

This research has two different main focus sides. The first side is about to analyses of current challenges for vessel crew both under the extraordinary times, such as heavy weather condition, traffic complexity, inspection, and normal times, like satellite/radar or coastal navigation, anchoring or maneuverings according to collaboration with a Norwegian shipping company, which has VLCC and LNG vessels. The second side focuses on autonomous technologies, which can be applied to conventional vessels in order to support critical crew activities, increase vessel operational efficiency as well as ensure a high level of safety. The research topic is given by the company so that understanding of the crew activities demands and criticality to apply autonomous technologies with high costs.

Research topic selection is mostly shaped by the researcher's interests, job as well as concerns as the first step of field research (Nachmias & Nachmias, 2008).

3.3 Research methods

This research study was carried out according to the qualitative research method. The method consists of online interviews with maritime professionals from the shipping company and mail questionnaires with their offshore employees. All interviews were performed as per the Norwegian Centre (NSD) for Research Data rules and instructions.

Literature reviews and online interviews / mail questionnaires are the fundamental part of the study. To give an answer to research question 1, different literature sources have been researched. Interviews and mail questionnaires were used for the analysis of the research question 2. In the end, research question 1 and research question 2 were combined to find suitable solutions for research question 3.

For this research, non-probability sampling was used with the type of purposive sampling. Purposive sampling is related to the subjective judgment of the author regarding the units of the sample. For the researcher, marine professional people from both onshore and offshore are representative of the seafarers. (Nachmias &Nachmias, 2008). In addition, this study`s participants had the ability to make a contribution to the research regarding the subject understanding in terms of theory (Bryman & Bell, 2011).

3.4 Participants

This qualitative and non-randomized research was carried out with 14 participants in total, who were both onshore and offshore employees from a Norwegian shipping company. The interviews were performed between the 8th of March and the 24th of March depending on the suitable time schedule of both office employees and vessel crew.

All online interviews were performed by teams meeting with the onshore personnel. The other email interviews were carried out by transferring questionnaires using direct email of different vessels to connect with the vessel's crew. In case of any misunderstanding, the phone conversation was ensured.

For this study, only one shipping company was studied and the participants were chosen according to their profession in maritime strategically, so purposive sampling as a type of non-probability sample design was chosen. Purposive sampling is a kind of non-probability sampling. A sample of research is founded by researchers on a non-random basis. The objective of this sampling is to choose participants with the strategic approach because participant or sample cases are related to research questions (RQs) (Bryman & Bell, 2011).

The onshore participants of the research work in the technical department of the company. They have different positions, such as vessel manager, fleet manager, marine superintendent, and designated person ashore (DPA). The total number of interview participants from onshore was five, which accounted for 36% of the total population. The total number of interview participants from offshore was nine, which accounted for 64% of the total population and their positions were master, chief officer, second officer, safety officer, chief engineer, and second engineer. The involvement criteria for the interviewees from onshore was having a wide range of expertise on the vessel management as well as they were current employees of the shipping company and the criteria for offshore participants was the research question number 2, which is directly about the vessel crew activities. The participants from offshore have been working on two different vessels of the company. The company´s fleet consists of four vessels and two vessels with nine crew members who wanted to participate in the research voluntarily.

3.5 Ethical concern

Anonymity was the red line for the study. The author started to perform the interviews when the interview questions were approved by the Norwegian Center for Research Data (NSD).

Firstly, the interview questions were sent to Norwegian Center for Research Data (NSD) on the 28th of January 2021 in order to get approval, and NSD accepted the interview questions on the 8th of February 2021. The reference number of the approval was 539049.

After having the approval, potential participants were informed with the information letter and expected to find a suitable time to perform online interviews with onshore employees. For offshore participants, the interview questions were sent by the author via email. The information letter covered the objective of the research study, the way of participation & reasons, the option of volunteering, personal data & privacy, data anonymity, participants` rights, contact information related to researchers, and consent form. The consent form that was located on the last page of the information letter was signed up by the participants as a formal agreement.

It is generally agreed that by social scientists if the research involves the participation of humans, they should perform the study with the provided informed consent. Competence, voluntarism, full information, and comprehension are the reasons for informed consent (Nachmias & Nachmias,2008).

The participants of the research are considered anonymous due to there being no way to identify the person by the researcher or any other people (Nachmias & Nachmias,2008).

All interviews that include both online interviews (with the onshore employees) and mail questionnaires (with the offshore employees) were done and recorded according to the Norwegian Center for Research Data (NSD) instructions and information letter consent, which was designed based on NSD formal interview structure, between the last days of February 2021 and the beginning days of March.

3.6 Collection of data

The first meeting was held in the company`s quarterly meeting on the island, where the company owner`s house is located. The first meeting was carried out in a welcoming environment with 10 people from the company´s technical management department. The researcher found a chance to meet with all key employees, introduce herself, background, main motivations for thesis topic interest as well as observe the meeting. After the first contact with the company on the 10th of September 2020, the company ensured information sharing with the author. The second contact was carried out on the 18th of January 2021 due to the need for specific data from the company´s vessels. The company provided the username and password to the author in order to access their safety management system software, which is called Uni-Sea that includes much specific information about the vessels and company. The third meeting was performed on 28th January 2021 through the teams online meeting with the company´s employee who was responsible for the master thesis research. During the third meeting, the study´s current process, data collection ways, and the plan for the interviews were discussed. Online interviews and email interviews were ensured by the company one more time. Later on, potential participants were designated by the responsible person strategically in terms of their experiences and professional competencies. At the same time, the interview questions were sent to vessels. Finally, after contacting the participants the interviews were made during March 2021. (See Figure 9).

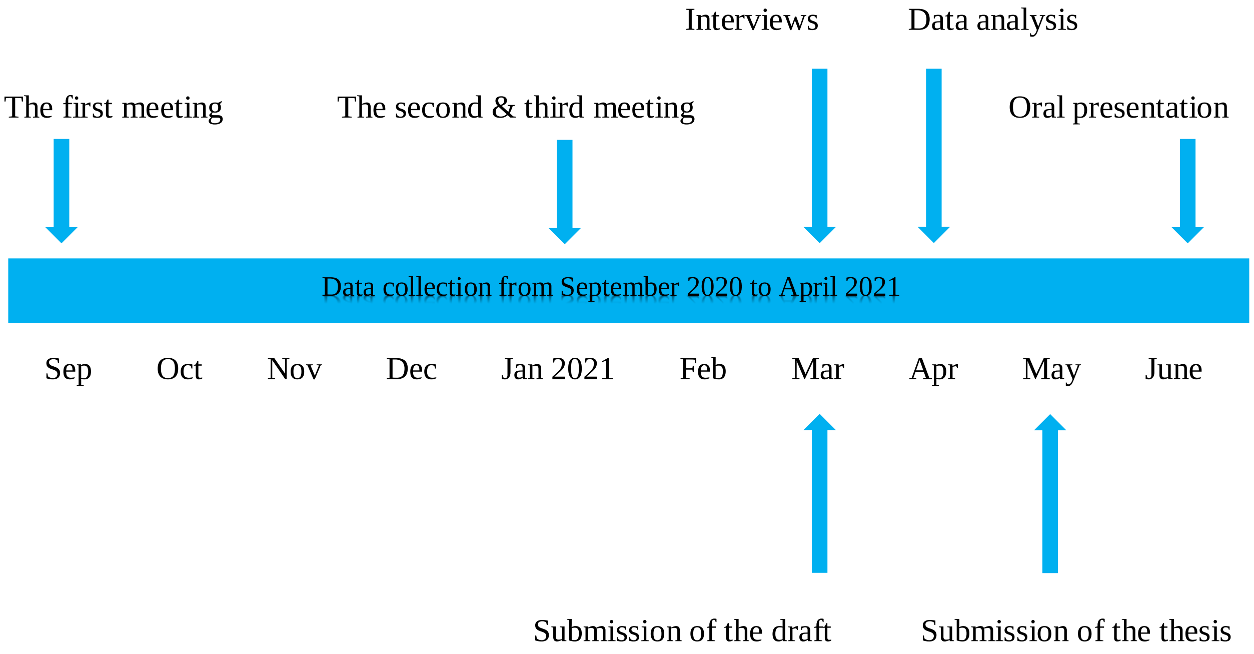


Figure 9: The timeline of the research study

For this study, literature reviews, online meeting interviews, and mail questionnaire/phone interview (in case of any clarification) were chosen as the suitable research methodologies in order to collect data for the study. (See Table 2).

Table 2: The data collection methods

The type of method	The aim of the method	Process
• Literature reviews	• State of the art / for the RQ1and RQ3 (What are the applicable autonomous technologies for oceangoing manned vessel?)	• Literature research
• Online meeting interviews (with onshore employees)	• Generation of grounded data from the experts / for the RQ2 and RQ3 (What kind of critical activities do we have onboard for both the engine and deck department in terms of safety?)	• Information letter and the guide of interview
• Mail questionnaire / phone interviews if it is needed (offshore employees)	• Impersonal survey to understand the research questions / for the RQ2 and RQ3 (What kind of critical activities do we have onboard for both the engine and deck department in terms of safety?)	• Obtained data via email

The reviews of the literature were mainly performed in order to understand what was already known and exists about the research problem that is about prioritization of crew activities to apply autonomous technologies. The company presented the problem of research in order to gather information about current applicable technologies that can have a positive effect on operational efficiency, safety, and crew support.

Doing literature review is just not only the theory or ideas reproducing, but it is more about having the interpretation ability to existing articles as well as using these opinions with the aim of supporting the argument. It also helps to refine the research questions, because after the interviews the research questions were enlarged and detailed (Bryman & Bell, 2011).

The main reason for the choice of the online meeting interviews as a data collection is to access the realistic and objective field-based information about the research question 2, which is about the vessel crew activities and their criticality in terms of safety. As the employees from the technical department of the company, they have a high level of experience with objective comments about their offshore personnel. Data collection was completed when the interviewees expressed their personal opinions, professional knowledge, and experiences.

The interviews were conducted one by one, online meeting conditions, and the semi-structured interview is chosen as the type of interview (Bryman & Bell, 2011). During the semi-structured interviews, the guide of the interview that covers the schedule is followed as illustrated in Table 3. It includes the research study introduction & its aim, question parts for both the deck department and engine department respectively, prompts & probes suggestions, open questions, and comments for closing. While the type of interview makes allowance for the systematic information gathering, it also allows for some more exploration, if the new issues show up due to its open-ended questions (Wilson, 2014). The interviewer also has a chance to ask further questions when the possible answers are considered significant and can have an important contribution to the study (Bryman & Bell, 2011).

The general outline of the interview guide was developed based on (Wilson, 2014) and it is summarized in Table 3 as below. The full interview questions are added to the Appendix II.

Table 3: The general outline of the interview guide for semi- structured interviews

Interview activity	**Question / Comment**	**Interview average time**
Introduction	-Interviewer introduction - Research study´s objective - Interviewee introduction - Interview methods, data usage, data protection, anonymity, confidentiality, privacy, interviewee´s rights	10 minutes
Structured titles (Written probes towards different ranks on board)	Title 1: Deck department questions in terms of crew challenges and heavy workloads Question 1 a Probe 1,2,3,4 Question 2 a	30 minutes

	Probe 1,2,3,4 Question 3 a Probe 1,2 Question 4 a Probe 1,2 Question 5 a Probe 1,2,3,4 Question 6 a Title 2: Engine department questions in terms of crew challenges and heavy workloads Question 1 b Probe 1,2,3,4 Question 2 b Probe 1,2 Question 3 b Probe 1 Question 4 b	
Open further question discussion with the interviewee	1 open question for deck department / 1 open question for engine department and general dialogue regarding the study	15 minutes
Closing notes and comments		5 minutes

(Wilson, 2014)

The interviews were scheduled with the designated participants methodically based on the participant availability. All interviews were performed in March. They started on March 8th and they were finished on March 18th. While two of the interviews were performed before lunch between 09.00 and 10.00 on 11.03.21 - 12.03.21, the other three of them were carried out after lunch between 14:00-15:00 and 13:00-14:00, on 08.03.21, 16.03.21, and 18.03.21 respectively. Microsoft Teams platform was chosen for the online interviews. (See Table 4).

Table 4: The online interview schedule

	Date	March 2021									
Time	08.03	09.03	10.03	11.03	12.03	13.03	14.03	15.03	16.03	17.03	18.03
09:00-10:00				Online room	Online room						
10:00-11:00											
11:00-12:00											
12:00-13:00											
13:00-14:00											Online room
14:00-15:00	Online room								Online room		

The duration of the online interviews with onshore participants was calculated as one hour. Although it was enough time to complete the interview, there was an opportunity to extend this time due to the nature of open questions.

Table 5: The mail questionnaire dates and participants

Vessel	The date of sending mail questionnaire	The date of getting responses	The number of participants
Vessel 1	08.03.21	19.03.21 (just revert from captain, no participation)	0
Vessel 2	08.03.21	22.03.21 (deck and engine crew participation)	6
Vessel 3	08.03.21	22.03.21(deck crew participation)	3
Vessel 4	08.03.21	never replied the email	0

For the offshore participants, the mail questionnaire and information letter that covers the consent form were sent to the vessel firstly by the responsible employee, who is in charge of HSEQ management and master thesis assistance, from the company on March 8th. A week after, he pushed a bit for an answer. On the 19th of March, he got an email from the first vessel regarding the concept of the interview questions being very huge with a lot of factors, so the master recommended to the researcher reading records of accidents, incidents, and few marine books after that he offered a phone call if it is still necessary. There was no participation from the first vessel. On the 22nd of March, vessel 2 and vessel 3 replied to the email and reverted their answers for the interview questions. While vessel 2 participated with six vessel crew who consisted of both deck department and engine department (master, chief officer, navigation, safety officer, chief engineer, second engineer), vessel 3 preferred to perform the interview questionnaire with three crew just from the deck department (master, chief officer, navigation officer). Vessel 4 never replied to the email that was sent by the company employees. (See Table 5).

The researcher wrote an email to vessel 4 on 24th March and got an answer from the captain for the help of participation, but later on, there was no email received by the researcher. Being busy with the current voyage, inspections, cargo operations could be the main reasons for no participation. The other reason could be forgotten email in the high tempo working environment due to the nature of mail questionnaires.

Gathering data from the offshore crew performed a mail questionnaire which is one of the main methods of data collection for the social science researchers. It is a method of impersonal survey (Nachmias & Nachmias, 2008). The mail questionnaire method is chosen by the researcher and the responsible employee from the company due to the restrictions in terms of distances, pandemic, and time. It was the most suitable way to conduct the research study with oceangoing vessels. While this method was being considered, phone conversation/interview also was ensured to further clarifications, but after obtaining the responses it was not needed to make phone calls with the offshore crew because all answers were understandable. The total number of participants from the vessel is nine. They participated in the study from two different vessels. Although the company´s fleet consists of four vessels, just two of them participated in the study.

To find out the current challenges and heavy workload of the vessel crew, the semi-structured interviews were completed with both onshore participants and offshore participants with the different two ways of data collection.

Interview questions are divided into two groups. The first one is for the deck department, the second one is for the engine department. While the first part includes seven questions in total, the second part covers five questions totally as shown in Table 6.

Table 6: The interview questions purposes

Part	**The descriptions of the question purpose**
Part 1: Deck department questions regarding the challenges and heavy workload under the both extraordinary and normal conditions (6 main question / 16 sub-questions + 1 open /and sub-question depending on the answers for the different ranks, such as captain, chief officer, second officer third officer, additional officer (if any)	-Find out the challenges and heavy workload of the deck crew in inspection / vetting preparation times, heavy weather condition, traffic complexity, maneuvering operations (berthing, unberthing, anchoring), geographical complexity / risk (high seas, tropical storms, piracy regions), that can affect the operational efficiency and vessel navigational safety and can result in the accident incidents. - Determination of the risk and criticality level of these challenges and workloads.

	- Determination of the high demand situations as to be reasons for fatigue or as consequences of the deck crew fatigue that can affect operation efficiency and vessel safety.
Part 2: Engine department questions regarding the challenges and heavy workload under the both extraordinary and normal conditions (4 main question / 7 sub-questions + 1 open /and sub-question depending on the answers for the different ranks, such as chief engineer, second engineer, third engineer and electric officer.)	- Find out the challenges and heavy workload of the engine crew in inspection / vetting preparation times, heavy weather condition, maneuvering operations (berthing, unberthing, anchoring), - Determination of the risk and criticality level of these challenges and workloads. - Determination of the common problems that can occur at any time in the engine room and can affect vessel efficiency and safety. - Determination of the high demand situations as to be reasons for fatigue or as consequences of the deck crew fatigue that can affect operation efficiency and vessel safety.

3.7 Analysis of data

The generation of data in qualitative research comes from mainly interviews, questionnaires, and literature reviews. This produces a large number of unstructured materials that are textual, so data analysis can`t be done directly. The main strategy of qualitative research is based on the grounded theory that covers coding as a key process, outcomes, and criticism (Bryman & Bell, 2011).

Data analysis was started when the researcher started recording the online interviews. Upon the completion of all online interviews, the transcriptions were done with the help of a software program that is based on the assistance of a computer. To make analysis the recorded online interview data as raw data, had to be processed with transcription like the common way (Miles et al., 2014). The accuracy level of transcription in the online interviews can be higher as there is no possibility of loss or inaccuracy (Roberts & Woods, 2000).

Mostly, transcription of the data that is collected from the interviews, is a kind of the norm in qualitative research. It is a useful way to exchange digital records into transcript documents. Transcription can also be seen as analysis as well as interpretation of the recorded digital data (Widodo, 2014).

For this research study, transcription is used in order to obtain the online interview overview in written format as well as highlights and keep the important findings in word documents.

On the other hand, the mail questionnaires had a majority percentage in the data analysis because most interviewees for this study were performed by the usage of email interviews. Right after getting an email from the vessel regarding interview questions, the written responses were ready to add for the analysis.

3.8 Reliability and validity

Reliability can be mentioned when the author tries to understand if a study`s findings are repeatable or not. Validity is about the conclusion integrality of research. Although they are mostly fundamental criteria for quantitative research in terms of both quality assessment and establishment, there is also an argument whether reliability and validity can be relevant to qualitative research or not (Bryman & Bell, 2011).

There has been a common and big reluctance about the acceptance of the trustworthiness for qualitative research studies by so many objectors for many years. In this situation, the qualitative researchers provide a wide range of detailed information of the selected fieldwork to potential readers to ensure transferability. Qualitative researchers need to try to make their studies as much as repeatable for any potential researcher, because of this reason they have to show data findings instead of their dispositions. The demonstration of data must be performed step by step to acquire confirmation (Shenton, 2004). In this study, all findings of data are shown with their details step by step so that the research study`s reliability satisfies any future researcher. For example, the data collection methods and dates, the general outline of the interview guide for semi-structured interviews, the online interview schedule, the mail questionnaires dates and participants, the interview questions` purposes are demonstrated.

To validate this study, interview and mail questionnaire questions were planned to understand vessel crew`s challenges / heavy workloads, and interviews were performed with both vessel crew and marine professional people from a company. These findings are combined with possible autonomous technology solutions which are found during the literature reviews and at the end, critical activities are expressed according to their criticality numbers that express prioritization.

4. CHAPTER IV- RESULTS

In this chapter, the interview and mail questionnaire findings, which are generated from 14 participants were analyzed. These findings will be important to understand the current challenges / heavy workload of the vessel crew on board and will be used for the decision of any possible autonomous technology application of existing oceangoing ships to support crew activities as well as operational efficiency.

This chapter is divided into the following parts: coding for the online interviews, researched population overview, the average time of online interviews, and environment, challenges/heavy workloads for the deck department, challenges/heavy workloads for the engine department, the evaluation of criticalities both for deck and engine departments, other challenges to be the reason for fatigue or as consequences of fatigue, and summary of the criticality of the challenges/heavy workloads.

Coding for the online interviews was carried out in table 7. Coding for the mail questionnaire was not added to this study because of the email questionnaire interview´s nature. The researcher got direct and clear short answers from the vessels for the interview questions, so there was no reason to do coding for this interview type.

Table 7: Coding for the online interviews

Part	Code	Sub-code	Criticality number	Extracted sentences from transcripts
Part 1 Deck	**Inspection preparations**	**Challenges for the master**	*5*	*"Yeah, it´s more to do with mental workload and rather than physical workload... All these SIRE inspections are very tough and they go into the details, so the master has to go through this questionnaire and make sure that if something is missing it has to be highlighted to the office and has to be rectified before the inspection takes place. "*
		Challenges for the chief officer	*4*	*"Cargo, deck part of course, so it´s more to do combination of paper workload as well as making sure that all physically also everything is perfect on the deck and one of the biggest challenges is coordinating the working hours with permits and the actual schedule"*
		Challenges for the navigation officer	*4*	*"passage planning and running through all the small details. the challenge is more to do with the people with the time onboard rest hours and everything, paper workload"*
		Challenges for the safety officer	*3*	*"to test everything which is quite difficult because we have big vessels".*
	Heavy weather	**Challenges for the master**	*5*	*"for master weather routing, challenge is how to interpret the software that we on board"*
		Challenges for the chief officer	*4*	*"securing everything of course, before departure in case of bad weather and their watch hours probably will be 6-6 with the master for the double watch"*

		Challenges for the navigation officer	*3*	*"Mainly to be aware of keeping the vessel safety against to weather"*
		Challenges for the safety officer	*2*	*"Keep the vessel safe in the watch"*
	Traffic complexity	**Challenges for the master**	*5*	*"We see challenges with the fishing vessels, they don't listen and they don't care about the traffic rules and all that, so the only way to cope with them effectively is look out and safe navigation with all these small fishing trawlers, increase the situational awareness."*
		Challenges for the navigation officer	*5*	

	Maneuvering	**Challenges for the bridge team**	*5*	*"Communication, when people are doing very important maneuvering, then the way of communication with local parts, it is very challenging, yeah."*
		Challenges for the deck team	*4*	*"Follow up the mooring lines and safety maneuvering".*
Part 1 **Deck**	**Geographical complexity**	**Challenges for the master**	*5*	*"A lot of documentation and procedures that has to be followed and safety measures create extra workload for the crew."* *"Additional safety and security precautions preparations on the deck"* *"Follow up the warnings and security messages"*
		Challenges for the chief officer	*4*	
		Challenges for the navigation officer	*3*	
		Challenges for the safety officer	*2*	
	Cargo operations	**Challenges for the chief officer**	*5*	*"Checklist workload and everyone asking him to do something."*
	High demand	**Reason for fatigue**	*5*	*"A lot of paper workload and it needs to be down may be with the help of good software."*
		Fatigue reason	*4*	*"Fatigue can lead to oil spills, collision, grounding, capsizing, communicational difficulties and many other problems.*

Part 2 **Engine**	**Inspection preparations**	**Challenges for the chief engineer**	*5*	*"Go through the vessel inspection questionnaire which is detailed and make sure everything is done according to the list, coordinate the engine team and carry out PMS jobs in detail instead of writing general." / Paper workload*
		Challenges for the second engineer	*4*	*"take care of engine condition" / Paper workload*
		Challenges for the third engineer	*3*	*"make sure everything is normal in engine room"*
		Challenges for the electric officer	*2*	*"can be paper works"*

Part 2 **Engine**	**Heavy weather**	**Challenges for the chief engineer**	*4*	**"***Make sure that engine conditions, lub-oils, fuels and everything is in order."*
		Challenges for the second engineer	*3*	*"extra safety barrier precautions against items fall down."*
	Maneuvering	**Challenges for the engine room team**	*3*	*"to have to the engine and thrusters are ready for the maneuvering."*
	Common problem **In the engine room in any time**		*3*	*"Leakages,"*
			5	*"Blackouts,"*
			4	*"Unexpected breakdowns and so on."*
	High demand	**Reason for fatigue**	*3*	*"The number of crew can be increased in order to avoid fatigue due to the lack of resting."*
		Fatigue reason	*3*	*"Wrong data interpretation"*

** Criticality number in terms of safety (1-5). (5 is the most critical, 1 is the least critical.)*

4.1 Researched population overview

The researched population consists of both onshore employees and offshore employees from a shipping company. While the high percentage of the population (64.3 %) is originated by nine offshore participants, the low percentage (35.7 %) is originated by five onshore employees as shown in Figure 10.

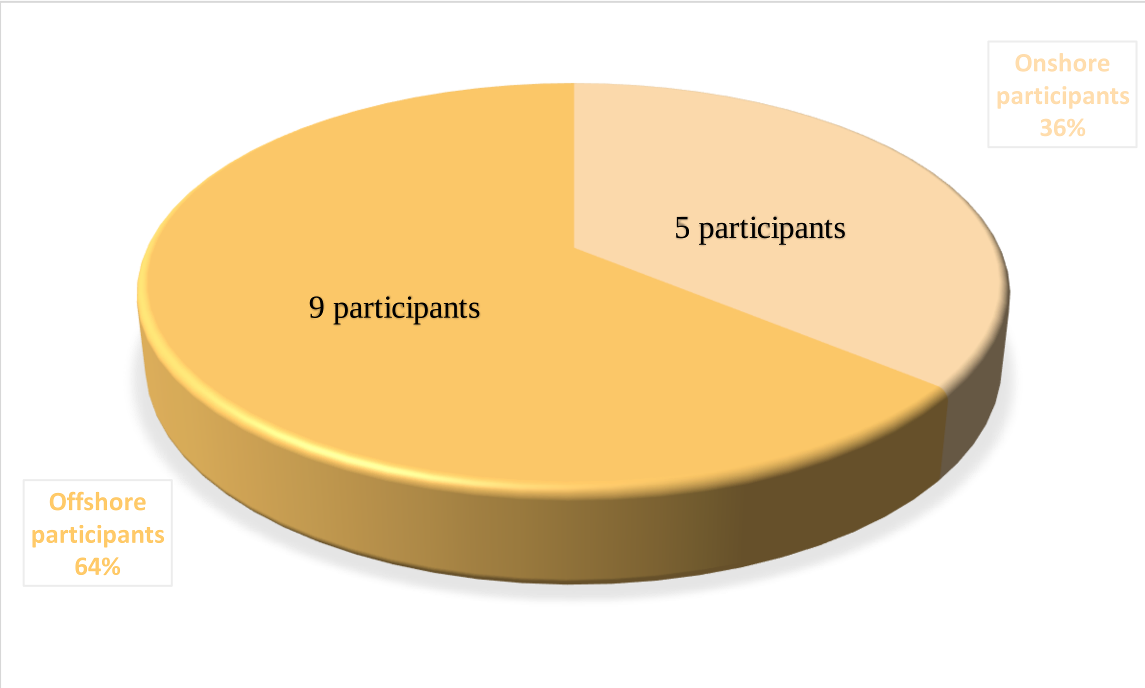


Figure 10: The total percentages of the researched population

35.7% of the total population is owned by the technical management office team and their percentages are 14.28% vessel manager, 7.14% DPA, 7.14% marine superintendent, 7.14% fleet manager.

64.3% of the total population consist of vessel crew with nine participants and their percentages are 14.28% master, 14.28% chief officer, 14.28% navigation officer, 7.14% third officer, 7.14% chief engineer and 7.14% second engineer.

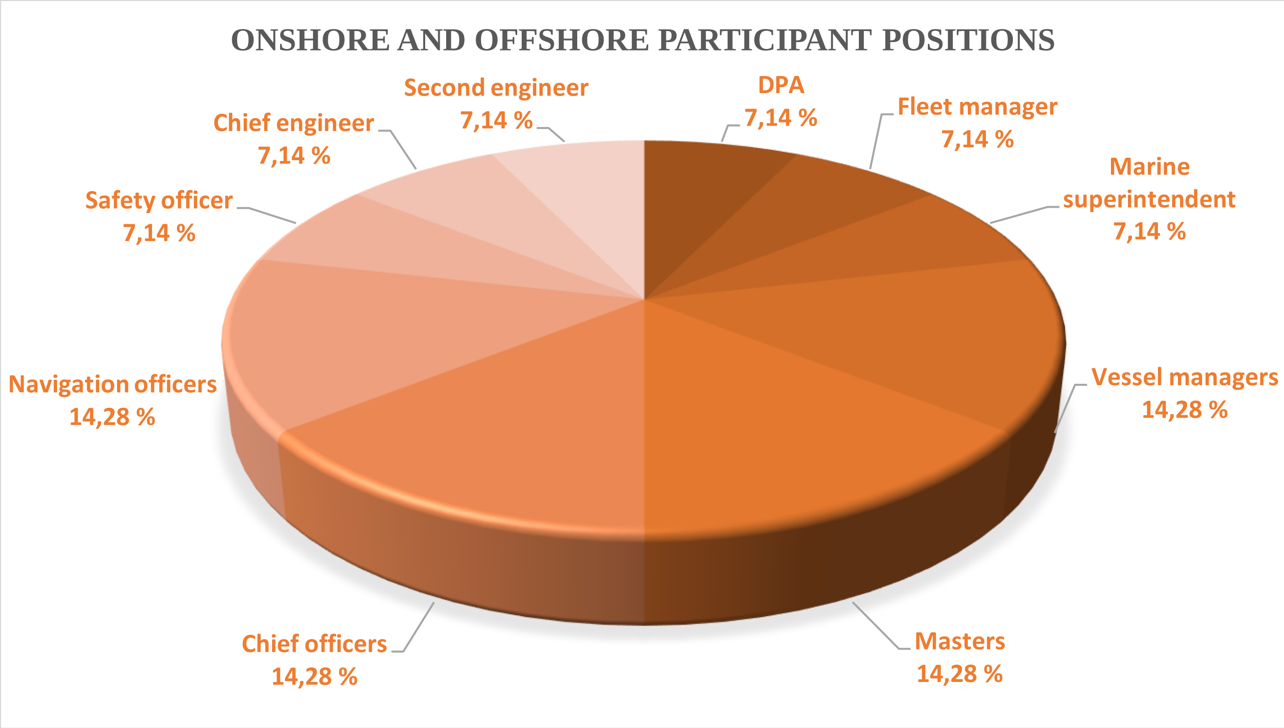


Figure 11: The positions of the researched onshore and offshore participants

Five participants from onshore have a high level of experience with vessel management and they work in the technical management department of the company. While two of the participants work as vessel managers, the other participants have fleet manager, designated person ashore (DPA), marine superintendent positions as illustrated in Figure 11.

It is requested by the researcher that the volunteer participants from the vessels should have different ranks to obtain more accurate current challenges of each position. Getting answers from different ranks is supposed to create an environment where the participants express their opinion freely. Masters, chief officers, navigation officers, safety officer, chief engineer, and second engineer are the participants´ ranks as shown in Figure 11.

4.2 The average time of the online interviews and environment

The average time of interviews with the five onshore participants was 48.4 minutes. While the shortest interview was performed in 39 minutes, the longest was carried out in 58 minutes as shown in Figure 12. The main difference in the interview duration is caused mainly by the different approaches of the participant´s views related to the asked questions. While some participants gave the general responses, the others gave more detailed answers about the seafarer workload on board. The other reason for the differences in the time of the interviews occurred due to the open questions for both the deck and engine department.

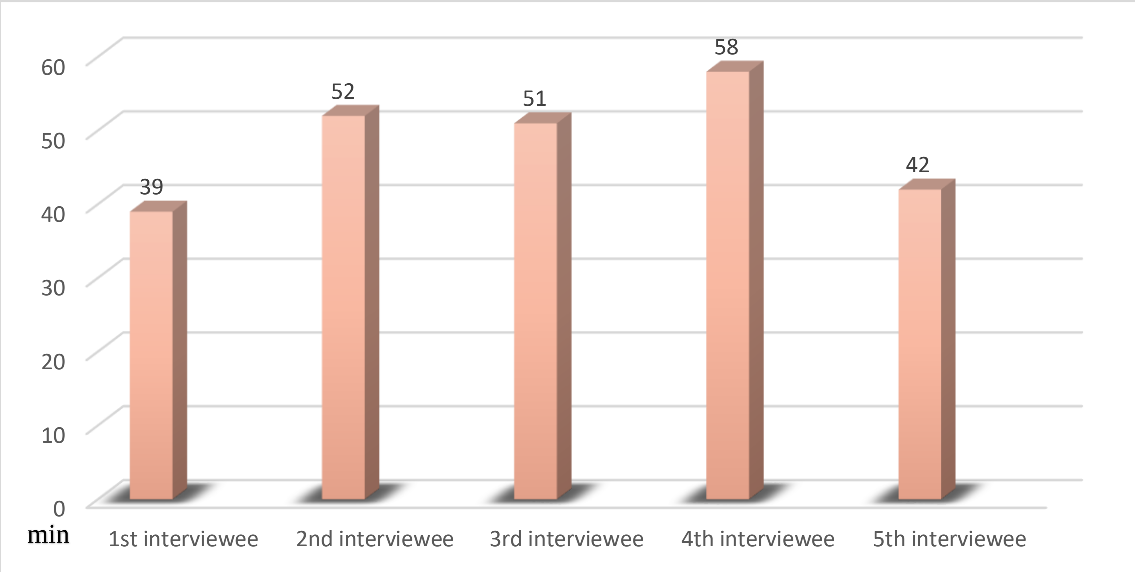


Figure 12: The real time of the online interviews

The environment of the online interviews was very comfortable and safe under the lockdown. Although there were a lot of restrictions due to the Covid-19, the online meetings were completed without any problem.

4.3 Challenges / heavy workloads for the deck department

4.3.1 For master

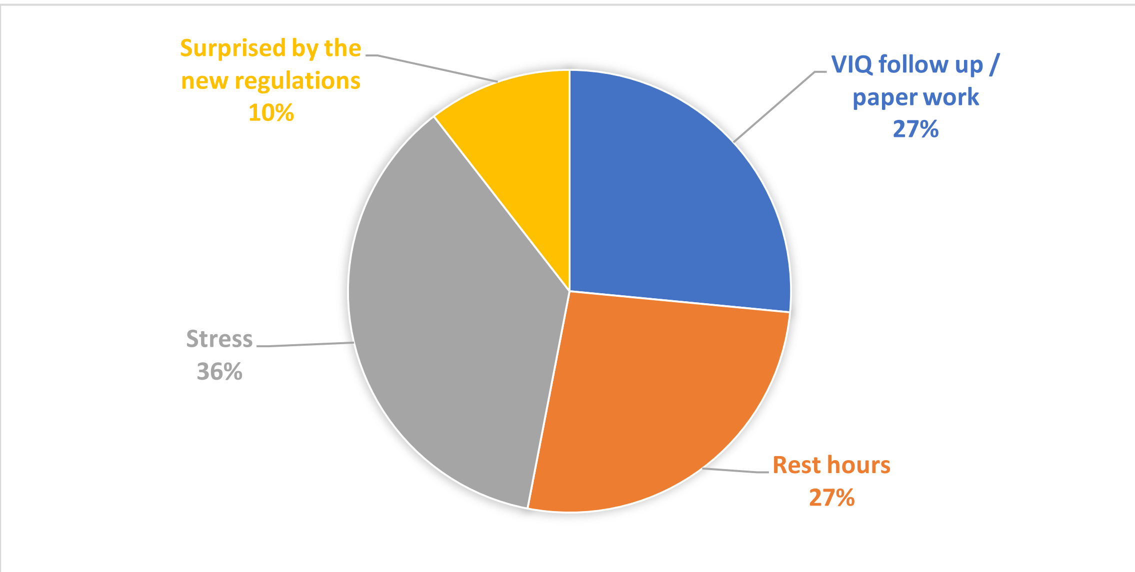


Figure 13: Challenges/heavy workloads during the inspection preparations for master

According to the participant answers, the biggest challenges are stress, resting hours, and going through the vessel inspection questionnaire (VIQ), which is quite detailed, and long, with the percentages of 36%, 27%, and 27% respectively for master. While the quick changes in the regulations surprise the masters, the time of preparations is not enough to prepare well.

Stress is the common and biggest challenge for all ranks on board. It can result in mistakes that can be either minor or serious and affect the vessel & crew safety as well as operations. Having a lack of resting hours is also another reason for lack of concentration, healthy follow up of the inspections, and organizing the vessel crew for the vetting because inspections are carried out in port and are supposed to perform multi-tasks during the inspection so it affects crew resting and working hours negatively. Vessel crew have different knowledge levels and experiences because of this reason the master needs to be sure that each crew is ready for their part in the vetting. To be sure, it is needed to go through VIQ by the master and it takes time. If there is any deficiency of equipment, the master has to inform the company. A lot of paperwork has to be carried out according to the VIQ.

On the other hand, the new regulations, which have come into force, surprise masters with their fast change nature, and the notice time of SIRE inspections are not enough to be ready properly. The percentage is 10%. (See Figure 13).

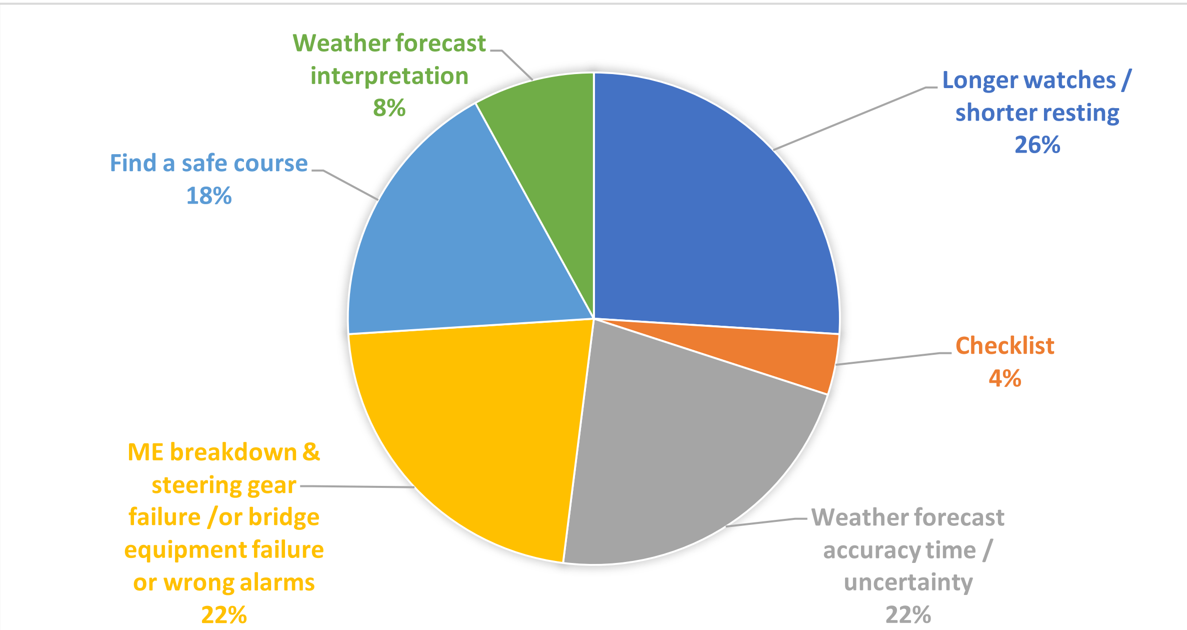


Figure 14: Challenges / heavy workloads in the extremely heavy weather conditions for master

The biggest challenge is the changes in work & resting hours for masters in heavy weather with 26 % in total. Being on the bridge for more hours due to the heavy weather is the main reason for the reduced situational awareness and decision-making and can affect vessel safety negatively.

Weather forecast accuracy time, main engine (ME) and/or steering gear failure, and wrong alarms are the two crucial challenges for the master with 22% equality. Many constant wrong alarms can result in blackouts. During heavy weather ME breakdown and or steering gear failure is the worst situation because without one or and two of these equipment means there is no control of the ship at all. Any failure in the bridge equipment, such as radar, ECDIS, or GPS can cause the wrong data interpretation and maybe an accident or incident. In addition, the weather forecast provides accuracy for a short period of time, which is generally between 24-48 hours, so master or other crew members can`t be sure about what kind of weather can be expected during the next few days.

Finding a safe course is the main responsibility of the master as always. It is not seen as a big challenge when compared with main challenges but according to the figure it has 18% among the challenges.

Weather forecast interpretation by the master and fill up the heavy weather checklist are the slight challenges with the 8% and 4% respectively. (See Figure 14).

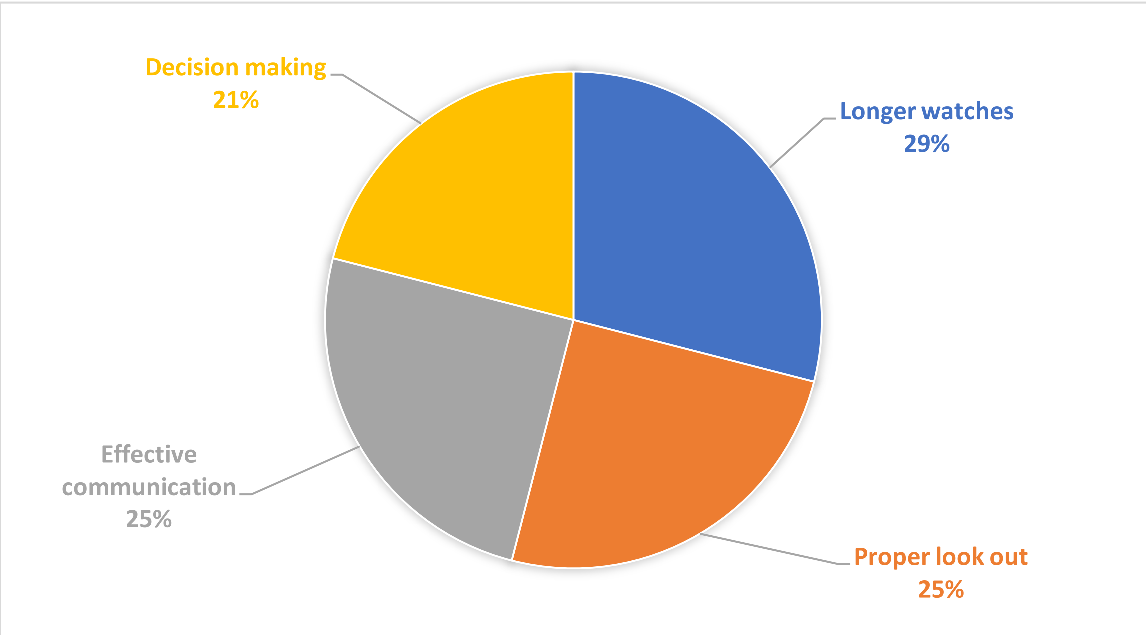


Figure 15: Challenges / heavy workloads in the traffic complexity for master

High-density traffic can cause stress and longer double watches on the bridge to ensure safe navigation for the master. The longer time on the bridge means the shorter time on resting for the master. It is well known that insufficient sleep is one of the main reasons for fatigue.

While long watches are seen as challenges on board with 29%, proper lookout and effective communication are also the other issues that are seen as a problem and their percentages are 25% equally. Traffic complexity is high in some regions, such as China, Singapore strait due to the high number of vessels and fishing vessels. Fishing vessels are the biggest problem when the topic comes to communication with them because they don't care about the COLREG and don't give responses to vessels that want to avoid a collision.

Decision-making is also another topic to consider in high-traffic regions. The decision about the safe route is also one of the important concerns in this condition and its percentage is 21%. (See Figure 15).

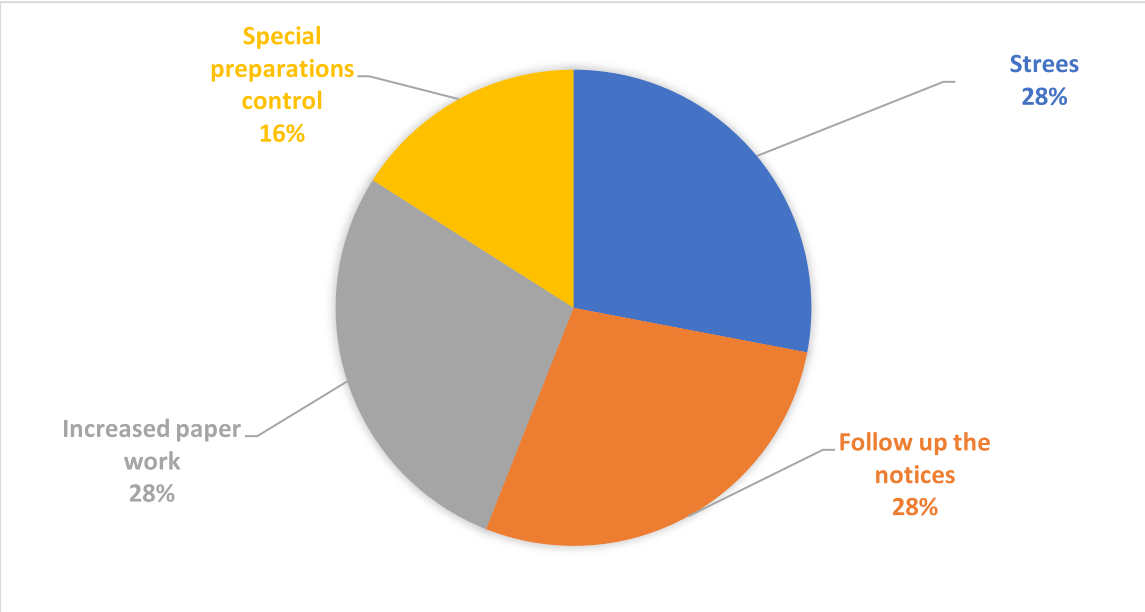


Figure 16: Challenges / heavy workloads in geographical complexity for master

It is asked to participants what are the issues in the geographical complexity, for instance, piracy regions, and got responses like in Figure 16 by priority. It is clearly seen from the figure that, following up the notice of piracy attacks, extra checklists & papers, and stress are the most challenges and workloads with 28%. Although the special preparation is carried out by the chief officer physically, the master has a mental workload and its percentage is 16%.

4.3.2 For chief officer

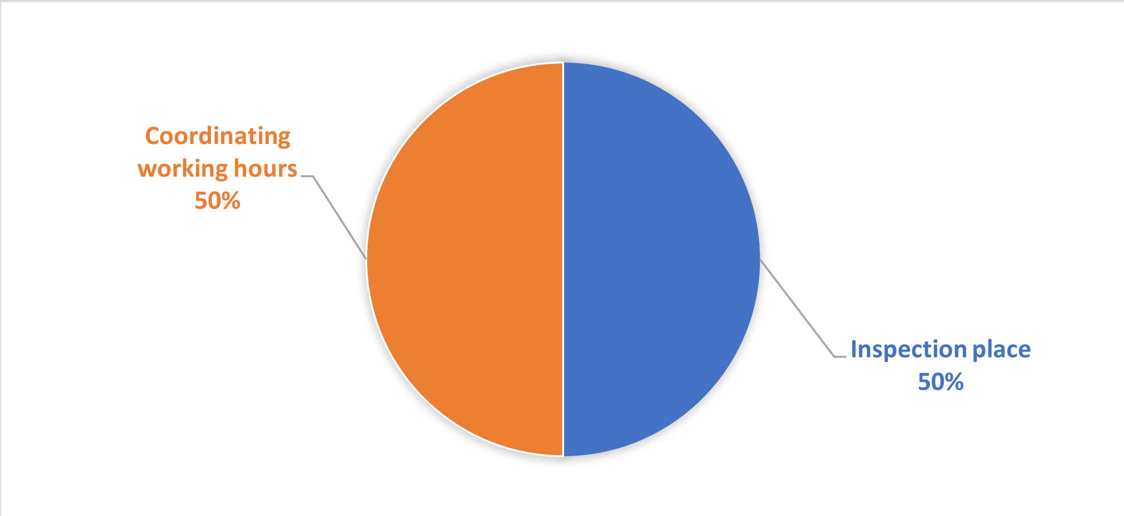


Figure 17: Challenges / heavy workloads during the inspection preparations for chief officer

Inspection place and coordination working & resting hours are the biggest problems for chief officers as demonstrated in Figure 17.

Usually, vetting inspections are performed in discharging ports. There are a lot of tests and preparations that must be done before arriving at the inspection port. At the port, the chief officer is very busy with cargo operations, crude oil washing (COW), documentation, and finding time for vetting at the same time is very difficult and heavy both physically and mentally.

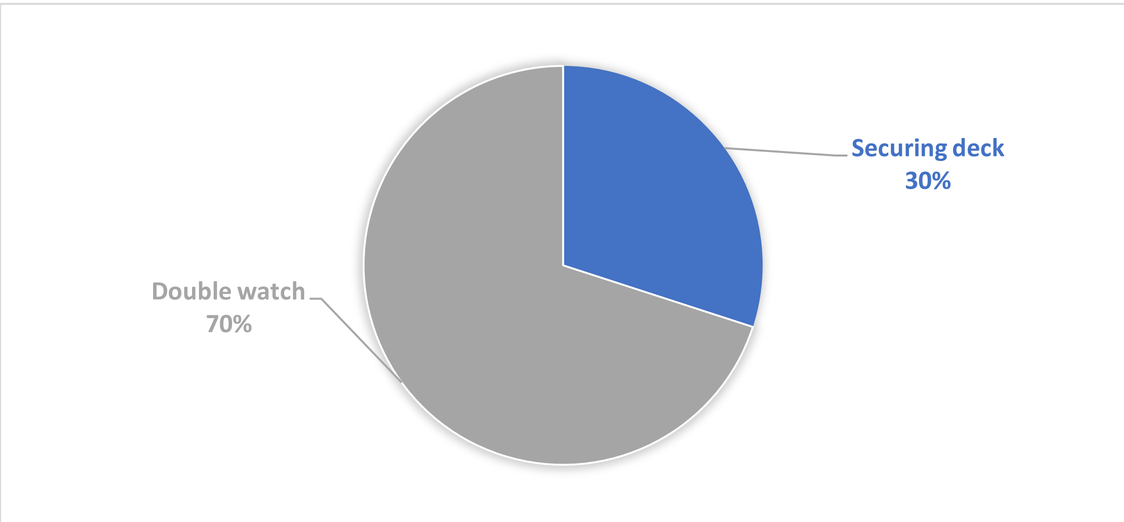


Figure 18: Challenges / heavy workloads in the extremely heavy weather conditions for chief officer

The biggest challenge for the chief officer is double watch during the extreme heavy weather condition. The percentage is 70%. The increased time for the watch can result in a lack of sleep, so in fatigue.

Securing the deck is one of the main responsibilities of the chief officer, but it doesn't seem like a big challenge (just 30%) for chief officers according to responses from the participants as demonstrated in Figure 18.

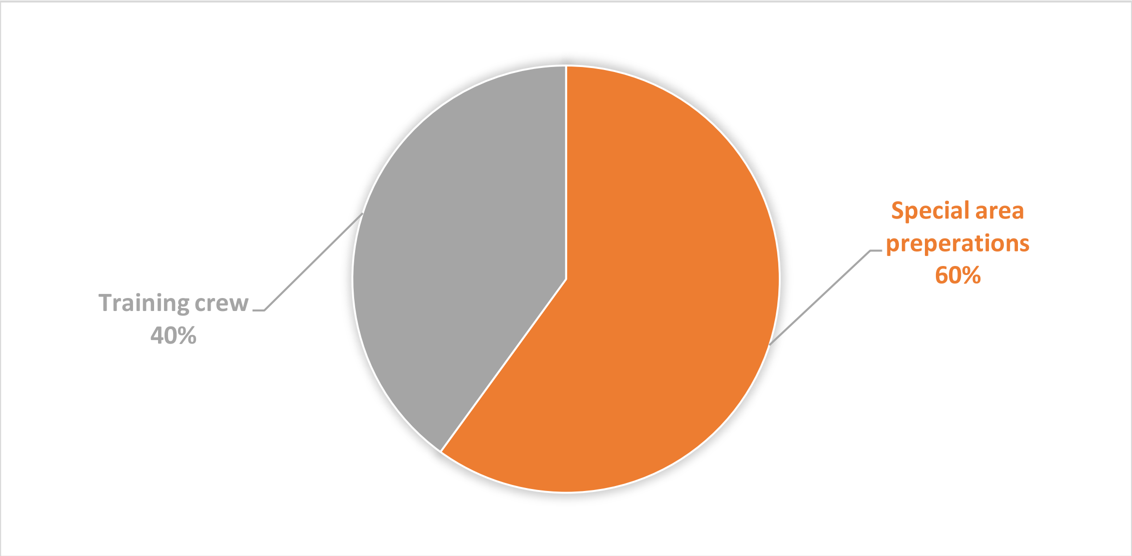


Figure 19: Challenges / heavy workloads in geographical complexity for chief officer

It can be seen from Figure 19 that the heavy workload for the chief officer is to prepare the vessel in terms of security before the piracy area and its percentage is 60%. During the preparations, the chief officer maybe needs to work more time than usual. Security equipment must be ready and all additional equipment needs to be fixed to the deck. For instance, fire hoses, razor wire barriers, and so on.

Additional training also needs to be given by the chief officer in case of emergency situations. Training as an extra work has 40%.

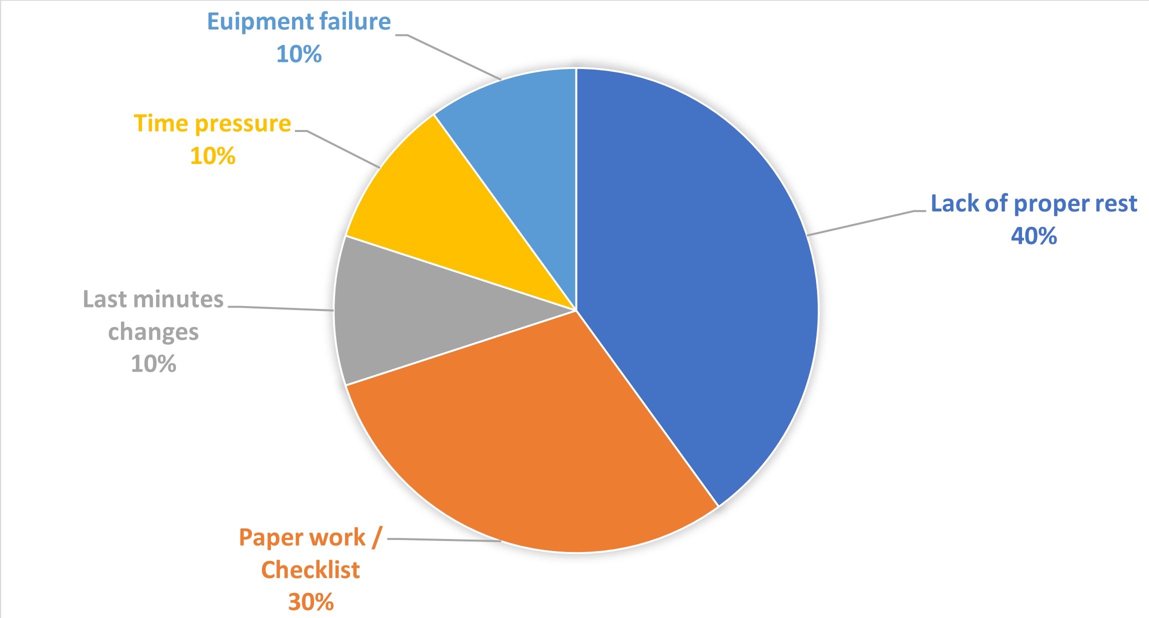


Figure 20: Challenges / heavy workloads of the cargo operations for chief officer

The biggest challenge for the chief is to be awake almost all the time during the operations. Lack of proper rest is one of the biggest challenges with 40%. When the vessel arrives at the port, everyone asks the chief officer to do another job at the same time. For example, related cargo operations, cargo calculations, questions from numerous visitors, cargo documentation, and so on.

The second biggest challenge is the paper workload. There are many checklists and paper workloads and the percentage of them is 30%.

Last-minute changes in loading / discharging plan, time pressure due to quick pilot arrangement upon the completion of cargo operation, and equipment failures, like ballast water treatment system are the other difficulties for chief officers with 10%. (See Figure 20).

4.3.3 For navigation officer

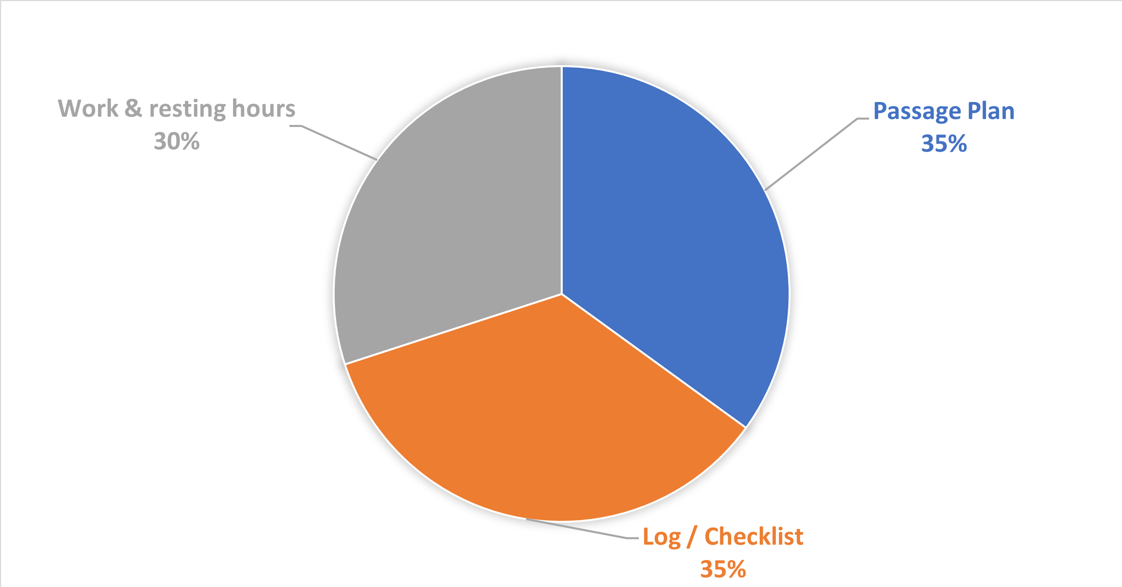


Figure 21: Challenges / heavy workloads during the inspection preparations for navigation officer

According to responses from participants, the navigation officer has the biggest pressure due to the passage plan and its small details. In addition, there are a lot of logs and checklists that need to be filled up. According to the vessel crew, the company helps the vessels with the review of passage plans and it helps a lot for navigation officers. The percentages of two biggest challenges for navigation officers are 35% equally.

On the other hand, an unbalance between working and resting hours and complying with the regulations is very challenging. In order to make everything ready, officers need to do their work overtime. It can result easily in lack of sleep, decision making, situational awareness. The percentage of working and resting hours is 30%. (See Figure 21).

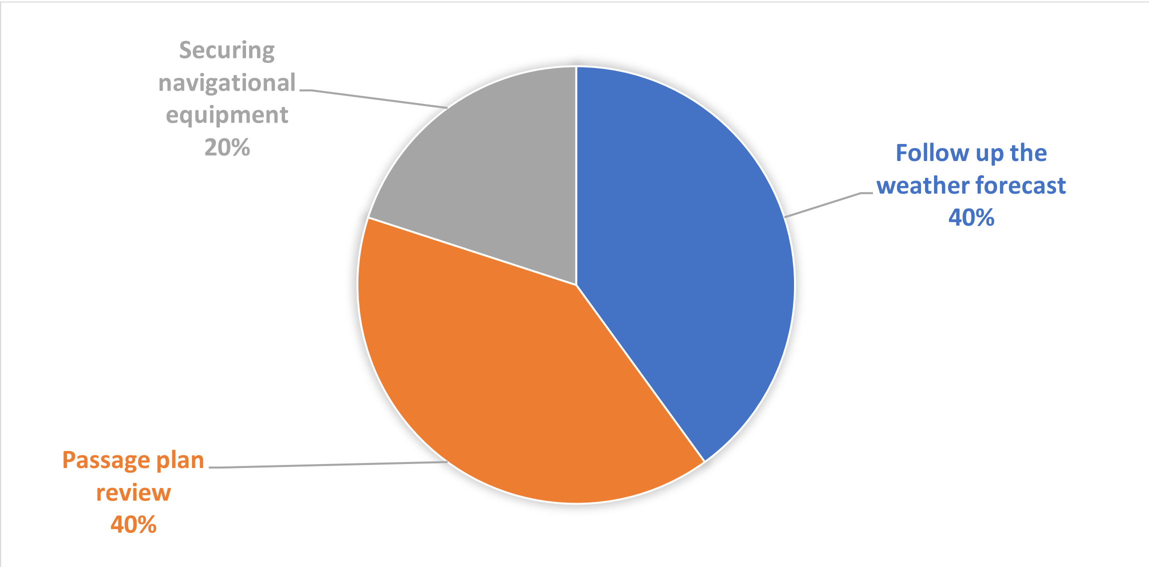


Figure 22: Challenges / heavy workloads in the extremely heavy weather conditions for navigation officer

It is found that acquiring the updated weather forecast for the existing voyage and the probable revision of the existing passage plan in order to avoid the effect of heavy weather are two workloads for the navigation officer. Their equal percentage is 40%. The other additional workload for the officer is to be sure that all navigation equipment in the weather deck is fully protected and also secured. The rest percentage is 20%. (See Figure 22).

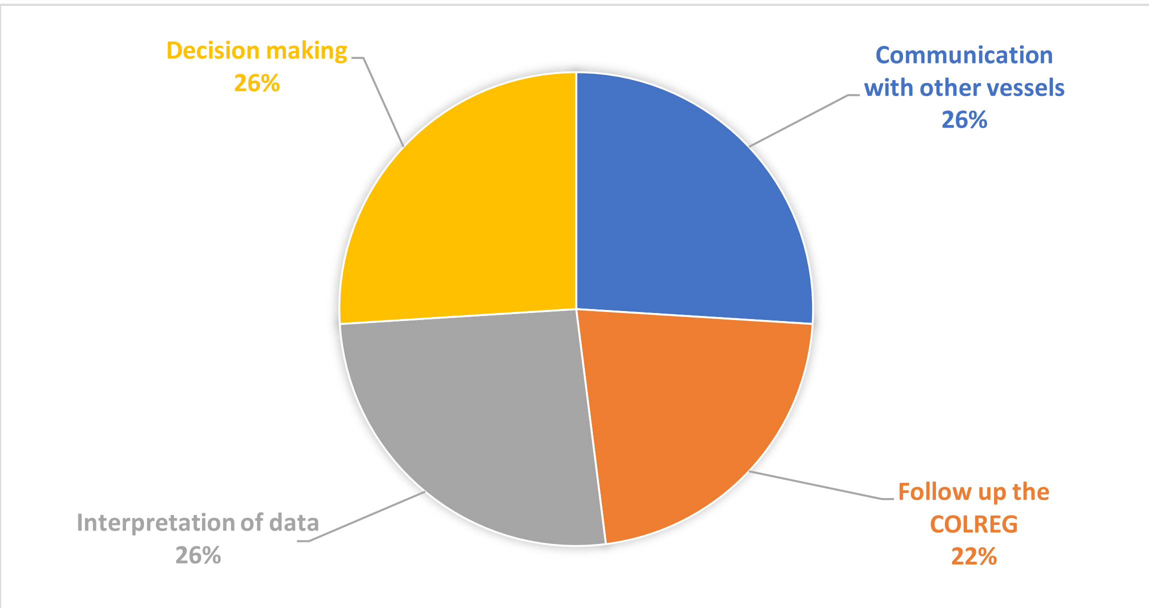


Figure 23: Challenges / heavy workloads in the traffic complexity for navigation officer

According to the figure, communication with other vessels, especially with fishing vessels, decision making, and interpretation of data are the main challenges in the high traffic areas for the navigation officer. It is clearly seen that these three challenges have equal percentages, which are 26%, and 22% is following up the COLREG rules as illustrated in Figure 23.

Navigation in the high traffic areas is very challenging. Navigation officer has to cope with different vessel crews in terms of communication when the vessel encounters other ships. According to common ideas, more and more officers are not aware of or disregarding the rules of the road that causes more accidents at sea.

Interpretation of data that is obtained from ECDIS, radar, and GPS, is also another challenge. Equipment failure and bad weather conditions can affect communication negatively in high-traffic areas. Both following another vessel, rules, and trying to contact them can be not easy and can result in doubt in decision making.

Decision-making can be not always easy due to the lack of communication, interpretation of information, and at the same time trying to act according to COLREG.

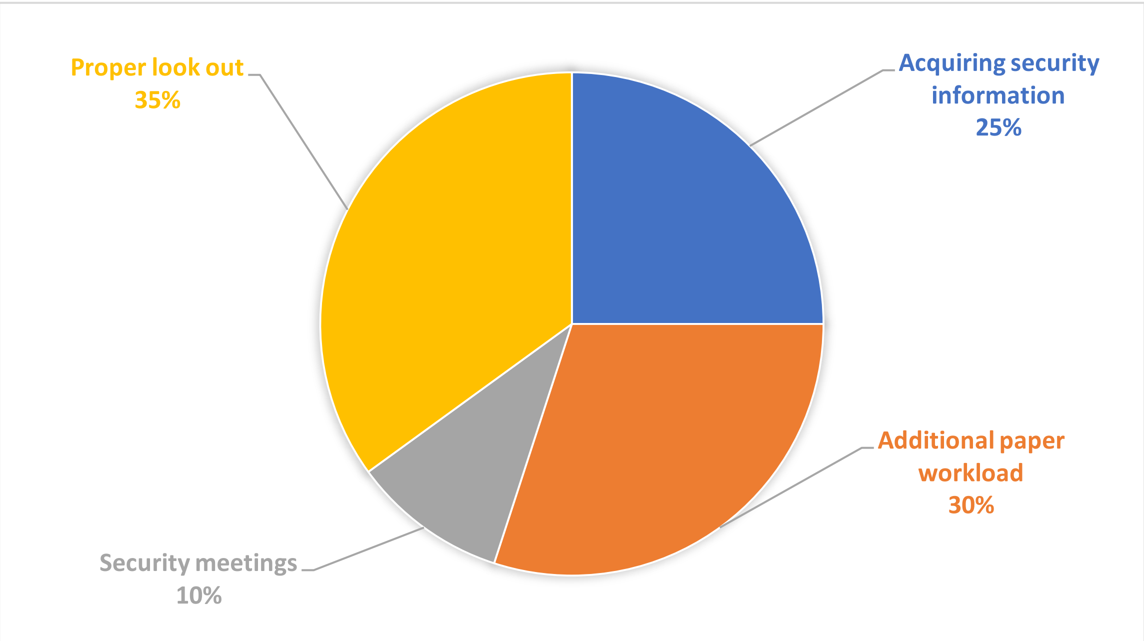


Figure 24: Challenges / heavy workloads in geographical complexity for navigation officer

According to Figure 24, proper lookout, additional paper workload, acquiring security information, and security meetings are the critical situations in geographical complexity like piracy region with the percentages of 35%, 30%, 25%, 10% respectively.

Proper lookout is one of the most critical tasks for the navigation officer during the piracy region passage. It is well known that pirates use fishing vessels and they look like fishermen so it is important to follow up with them both with lookout and radar are additional workload.

Additional papers, checklists are needed to be filled up and sent to the company. It creates an additional paper workload. Gathering security information, informing the master and crew is also very critical. Extra security meetings that are caused by the nature of high danger areas are also seen as additional time and maybe a navigation officer needs to spend from the resting time.

4.3.4 For safety officer

After evaluation of criticality of the activities, there are no crucial critical tasks found for the safety officer. The only challenge for this position is found during inspection preparations due to the need to test all safety equipment. The company has big ships, so going through each safety equipment and testing them takes time.

The other challenges like over time watches, vessels maneuvering, heavy weather and so on also affect safety officers´ both mental and physical routine. Working more hours means resting less hours and results in reduced situational awareness and reduced ability of decision making and lastly in fatigue.

4.3.5 For bridge team

The challenges like, coordinating the maneuvering with both vessel crew and onshore local people or pilot, commands, communication with tugs, crews on deck, pilot, shore, monitoring the environment, and looking out are the main challenges for the master and the officer who is on the bridge. These challenges are creating pressure on the team. The bridge team needs to be aware of what is going on near the vessel and detect each object that is close to the vessel in order to avoid any kind of collision, incident, accident and hit. The most important critical activity is proper look out and monitoring the vessel.

Finding a safe anchorage area and drop the anchor is another challenge for the bridge team.

4.3.6 For deck team

For the deck team, it is very critical to do safe maneuvering during berthing and unberthing. It is well known that the false movement during the operation with mooring lines can result in undesired cases and even in the loss of life. Berthing, unberthing, and anchoring operations are dangerous operations for the deck crew, so the crew needs to be so careful and the responsible person has to give clear order to the team. Some crew have a lack of maneuvering experience, especially deck cadets and engine department crew like motormen, so this is a potential risk for their safety.

4.3.7 Other challenges to be the reason for fatigue or as consequences of fatigue

It is commonly found that the increasing number of paper workloads causes fatigue and frustration on board. Trying to complete each paperwork takes so much time and the crew has to work overtime mostly during the high tempo days.

Time differences are also other challenges for the vessel crew. For instance, when the ship personnel end their working day, the office just starts their own working hours and starts to send requests or questions to be answered as soon as possible which results in changes in the vessel crew`s resting hours.

Dealing with crew needs and crew changes are also very challenging, especially during this Covid-19 pandemic. Extension on the changes has a great negative effect on the mariners.

The conflict between crew members on board is the other common challenge that can be caused by cultural differences, personal attitudes, mental conditions, and so on.

4.3.8 Summary of the challenges/heavy workloads for the deck department

Figure 25 shows the relationship between the reason for challenges and heavy works and their possible autonomous technology solutions. Arrows express both challenges and reasons. While the arrowhead highlights the reason, the starting point of the arrow shows the challenge.

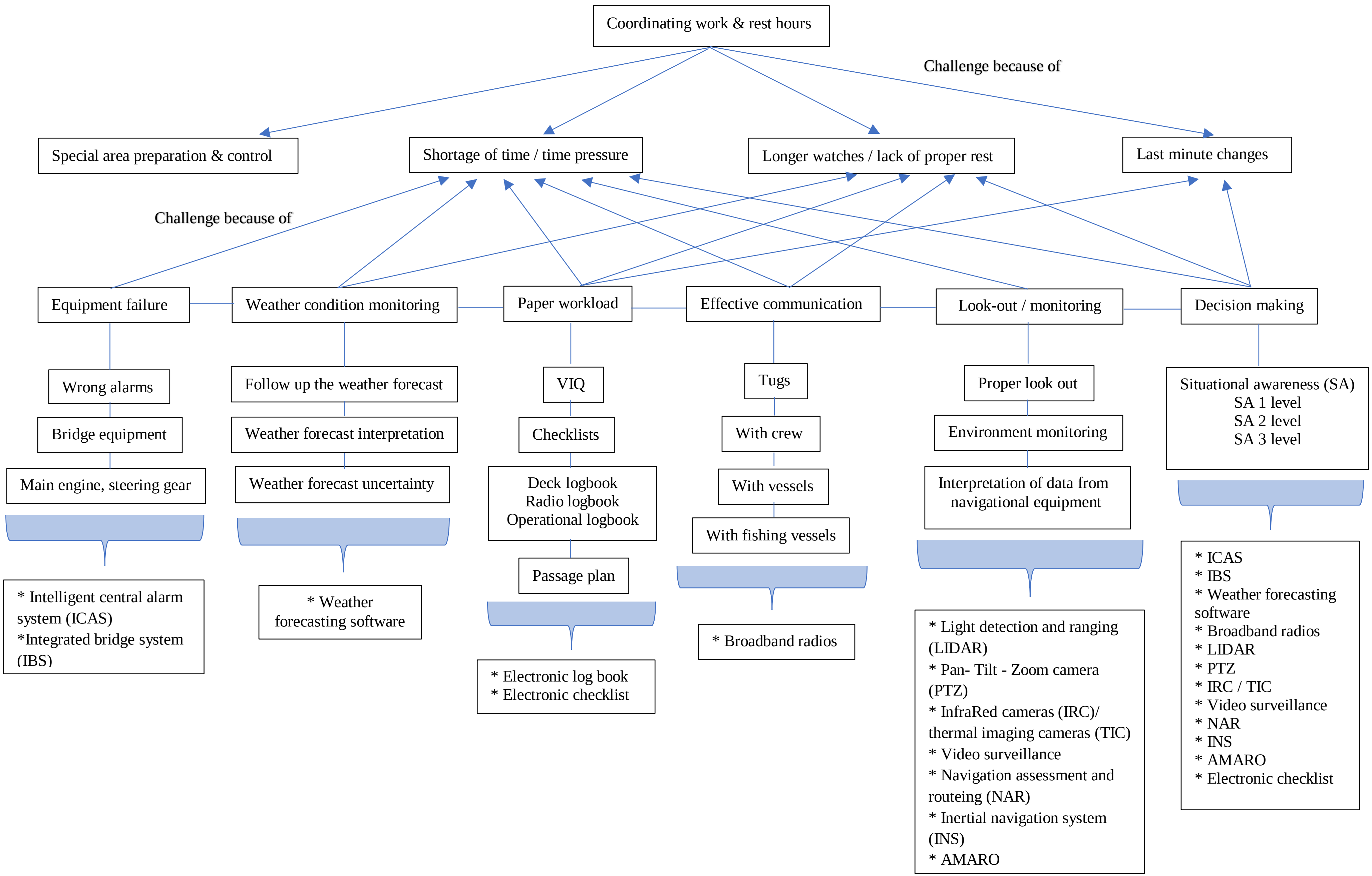


Figure 25: Challenges / heavy workloads for the deck department and autonomous technologies as possible solutions

Under the nonroutine and extraordinary conditions, such as inspection preparations, heavy weather, traffic complexity, berthing/unberthing/anchoring operations, geographical complexity it is found that coordinating work and rest hours of the crew is the biggest common challenge. Coordinating work and rest hours is a challenge because of additional workload like special areas / heavy weather preparations & control, time pressure/shortage of time, longer watches/lack of proper rest, and last-minute changes.

Equipment failure, weather condition monitoring, paper workload, effective communication, look-out /monitoring, and decision-making are the challenges / heavy workloads for the bridge crew because of shortage of time in other say, time pressure.

Weather condition monitoring, paper workload, effective communication, look-out/monitoring, and decision making are also challenges/heavy workload for the bridge crew because of the bridge crew who already keep longer watches, and lack proper rest. Officers or masters who are tired due to longer watches experience the challenge or heavy workload when they want to keep effective communication, proper lookout, monitoring, and so on.

According to the findings, the paper workload is also a challenge especially when there are some last-minute changes. For instance, last-minute changes on the cargo plan.

Equipment failure challenge consists of wrong alarms, bridge equipment faults, main engine steering gear failures. Intelligent central alarm systems (ICAS), and integrated bridge systems (IBS) can be possible solutions for equipment failure. While the ICAS ensures routine operations like navigation without any confusion due to the huge number of false alarms, IBS increases the survivability of the equipment with the help of redundancy design. These two technologies support the duty officer or master in terms of increased safety and flexibility.

Weather condition monitoring challenge covers weather forecast follow-up, interpretation as well as uncertainty. Advanced weather forecasting software can eliminate the doubtfulness of the forecast. It gives reliable and longer validity than the existing weather forecast program on board. It is also very easy to use.

Paper workload as a heavy workload includes VIQ, checklists, logbooks (deck log book, radio logbook, operational logbook), and passage plan. It is found that the passage plan is already planned by the usage of electronic software and after that, the company supports the passage plan in terms of review if it is needed. Checklists and logbooks can be supported by electronic software ones in order to reduce errors and workload as well as increase operational efficiency.

Under the non-routine condition, effective communication with crew, tug, especially with vessels & fishing vessels is challenging. Broadband radio can support effective communication with vessels.

Look-out and monitoring are other challenges in terms of proper look-out, environment monitoring, and navigational data interpretation in extremely heavy weather conditions, traffic complexity, and geographical complexity as well as during inspection preparations. For instance, during the vetting preparations, all crew try to fill up the high number paper workload even in their navigational watch. To avoid marine accidents and increase situational awareness, some autonomous technologies, such as LIDAR, PTZ camera, infrared cameras, video surveillance, NAR, INS, and AMARO can be used. Maneuvering operations and navigation require a high level of monitoring, perfect lookout, and ability of data reading. LIDAR technology supports the officer or master with real-time 3D surface mapping in restricted visibility, traffic complexity, as well as heavy weather. PTZ and Infrared cameras can also be used to ensure safe navigation. Video surveillance can be used for the detection of vessel movement in real-time. While AMARO provides real-time vessel position, NAR and INS provide position information.

Decision making is a challenge because of lack of time, insufficient rest, and last-minute changes onboard for the bridge crew. All of them have a negative effect on the duty officer`s decision making ability. As mentioned during the literature review, one of the most important capabilities of the duty officer on the bridge should be having situational awareness, and having a high level of situational awareness enables making the right decision in a short time. It is clearly seen that from Figure 25, equipment failure, weather condition monitoring, paper workload, effective communication, lookout/monitoring are the challenges that have an effect on decision making. For example, when the radar fails onboard, it will either give wrong or no information about the vessel course to the duty officer. This wrong or lack of information will affect the officer`s situational awareness in level 1 because there will be no right information on the radar to see and percept. While all challenges affect the decision making, all suggested solutions can contribute to increasing situational awareness and decision support at different levels as shown in Figure 26.

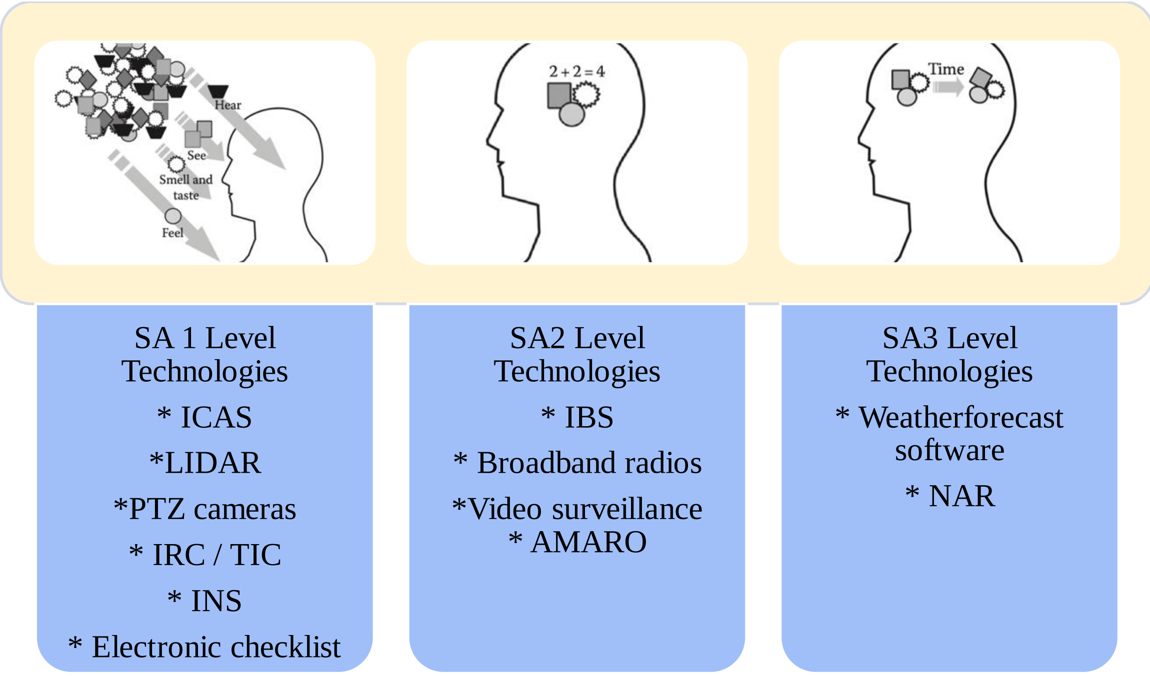


Figure 26: The relationships between SA levels (Endsley & Jones, 2004) and autonomous technologies

ICAS as the grouping of failure alarms software can support the officer with providing accurate and prioritized information about the alarms. The duty officer can see directly evaluated information from the system. LIDAR, PTZ cameras, and IRC as object detector systems in heavy weather conditions can support the duty officer with highly reliable data of an object that is not possible to detect with human vision. They can increase the officer`s situational awareness by providing additional data to the existing radar, ECDIS and AIS. INS as a kind of position calculation system can support the duty officer with providing reliable data. Electronic checklists in terms of emergency situations checklists can support the duty officer or master about the way, which should be followed up in emergency or extraordinary environmental conditions.

IBS as combined system information can support the officer with providing all necessary data in the same working station with its redundancy concept that will eliminate the equipment failure affect. Including all bridge equipment data enables comprehension of data from the same working station. Broadband radios as fast communication equipment can support the duty officers with the right and fast data to evaluate the risky and safe operations. Video surveillance as a video-based sensor can support the duty officer and master during the passage of narrow canals or high traffic density areas in terms of safe navigation. Officers or masters can compare their vessels with the other detected vessels. AMARO is a real-time data provider system that can support the duty officer with existing position information as well as the other vessels` information. It can help in terms of comparison of the existing vessel`s positions and activities.

Weather forecasting software as reliable and seven days in advance weather condition provider can support the master with the coming days` safe routes. Navigation assessment and routeing as risk notification software can support anyone who is responsible for the vessel`s safety by providing warning signals in dangerous areas.

4.4 Challenges / heavy workloads for the engine department

4.4.1 For chief engineer

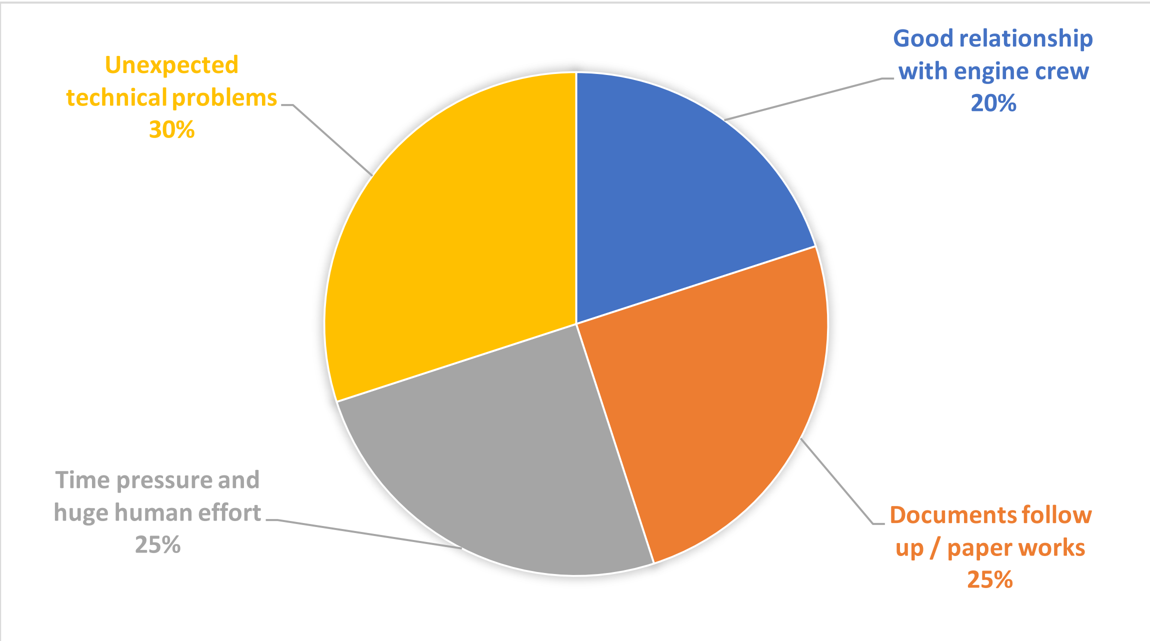


Figure 27: Challenges / heavy workloads during the inspection preparations for chief engineer

According to the participant answers, the challenges are unexpected technical problems, time pressure & huge human effort, documents follow up / paper works, and good relationship with the engine crew with the percentages of 30%, 25%, 25%, and 20% respectively for the chief engineer as demonstrated in Figure 27.

Unexpected technical problems always occur in the engine room and they need to be handled directly.

Documentations and paper works are highly time-consuming. Usually, the engine room is ready for vetting all time. The chief engineer, who is in charge of the engine department, has to check all documents twice. For instance, the validity of all certificates, exhaust gas cleaning system (EGCS) record book, oil record book (ORB), bunker logbook, garbage record book, sewage disposal record book, marine Sulphur record book. In the planned maintenance system (PMS), all planned jobs should be checked and have to be updated (no overdue jobs) by the chief engineer.

Time pressure and huge human effort are also other issues. According to the findings from the chief engineer that there is a huge human effort in case of any unexpected failures/damages or jobs. Unexpected technical damages, failures, or jobs may occur at any time as well as before the vetting. These last-minute occurrences always create stress on the engine team.

Creating a good environment in the engine room is the other challenge for the chief engineer. Preparing the engine room for vetting requires time, attention, and human power in order to avoid high-risk observations as found in the inspection report. High-risk observations mean high risk on safety, security as well as pollution. To perform the tasks, it is very important to have good communication between the crew and trustful relationships.

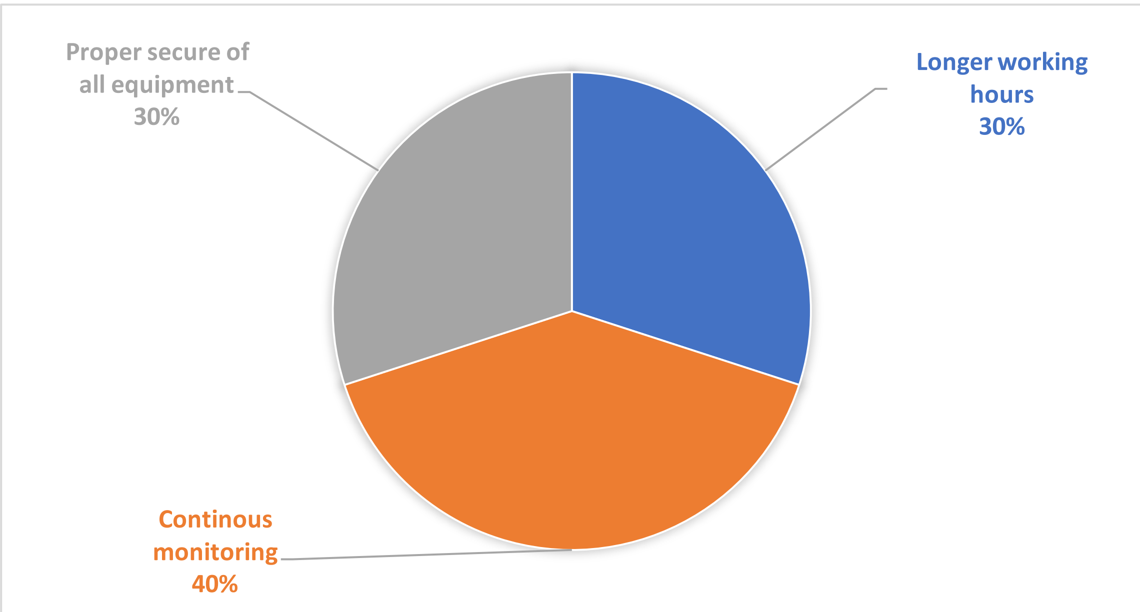


Figure 28: Challenges / heavy workloads in the extremely heavy weather conditions for chief engineer

It is clearly seen in Figure 28 that continuous monitoring is the biggest challenge for the chief engineer with its 40%. Longer working hours and proper securing of all equipment in the engine room have equal percentages, which is accounted for 30%.

The continuous monitoring of the main engine performance is very important to reduce the risk of the main engine breakdown, so it is the most critical challenge for the chief engineer. It is also found that two auxiliary engines should be in service and monitoring them properly will reduce the risk of blackout. Lube oil, fuels, and bunkers need to be monitored.

The balance between working and resting hours is not easy to catch up. The common and safe practice is keeping the engine room on manned mode during heavy weather in case of any emergency situation. It causes changes in the crew´s working and resting hours, especially for the chief engineer as a fully responsible person of the engine room.

Proper lashing of all equipment and heavy parts are also other issues. The chief engineer needs to ensure that all objects and equipment are secured. Although the tasks can be performed by other crew, the chief engineer has to be sure about the lashing.

4.4.2 For second engineer

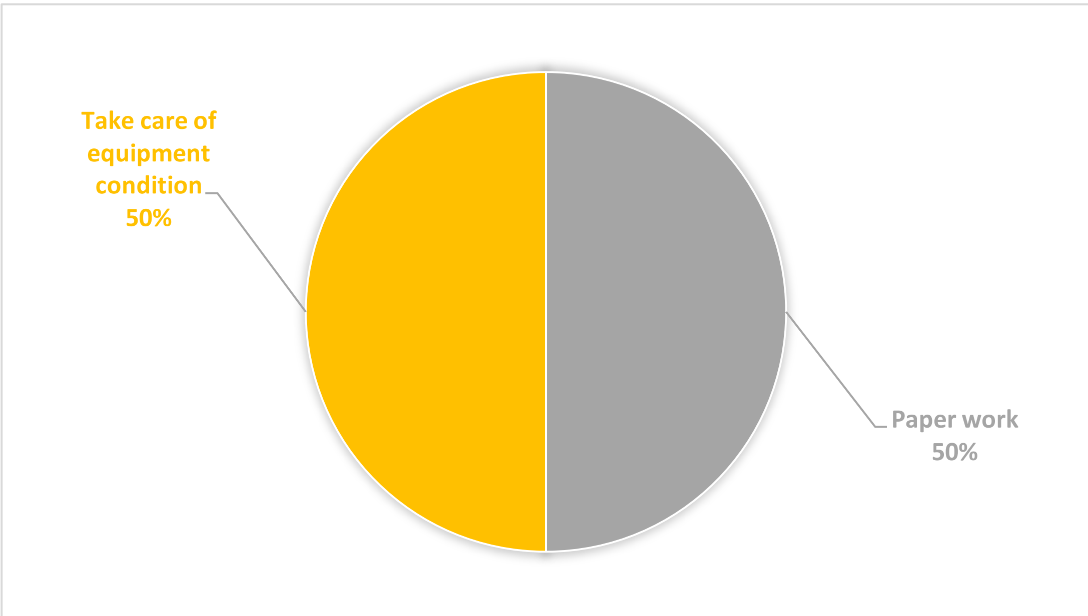


Figure 29: Challenges / heavy workloads during the inspection preparations for second engineer

The challenges for the second engineer are found like taking care of equipment condition and paperwork with equal percentage, which is 50% as illustrated in Figure 29. In addition, engine room housekeeping, safe practice, and routine records are also performed by the second engineer but the findings were more regular work than heavy workload for this rank.

During heavy weather, sudden breakdown of the main engine or any fundamental components can result in risky work, especially for the second engineer. In addition to this, it can lead to unbalanced working & resting hours and stress.

4.4.3 For third engineer

Right after the evaluation of the critical activities, it is found that there are no high critical challenges or heavy workload for third engineers. The only challenge for a third engineer can be stressful, which is common for each rank in the extraordinary environment.

The internal environment can affect the third engineers` both mental and physical routine. Any breakdown in the fundamental equipment in the engine room can result in additional working hours and can lead to fatigue.

4.4.4 For engine room team

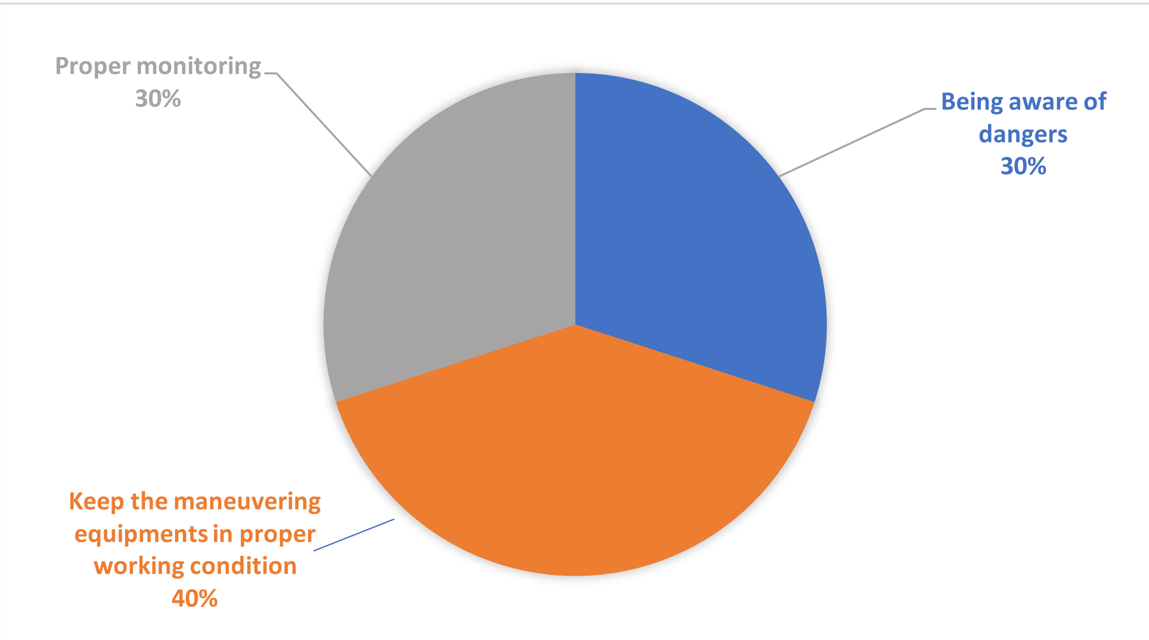


Figure 30: Challenges / workloads during berthing, unberthing, anchoring operations for engine room team

According to the findings, the biggest challenge is to keep the maneuvering equipment in proper working condition and its percentage is 40%. The other two challenges are proper monitoring and being aware of maneuvering dangers with 30% equally as shown in Figure 30.

During the berthing, unberthing, and anchoring operations it is very important to have equipment in proper working condition. Emergency and standby equipment need to be tested according to the checklists that are established by the company before the operations.

Keeping proper monitoring for engine & auxiliary machines` parameters, maintaining the right parameters, and log for changing load of the engine is very critical. Another critical topic is to have awareness of potential dangers during the expressed operations. Mooring machinery, air starting compressor, main, and auxiliary engines, and steering gear units have to be kept in good condition.

4.4.5 Common problems in the engine room

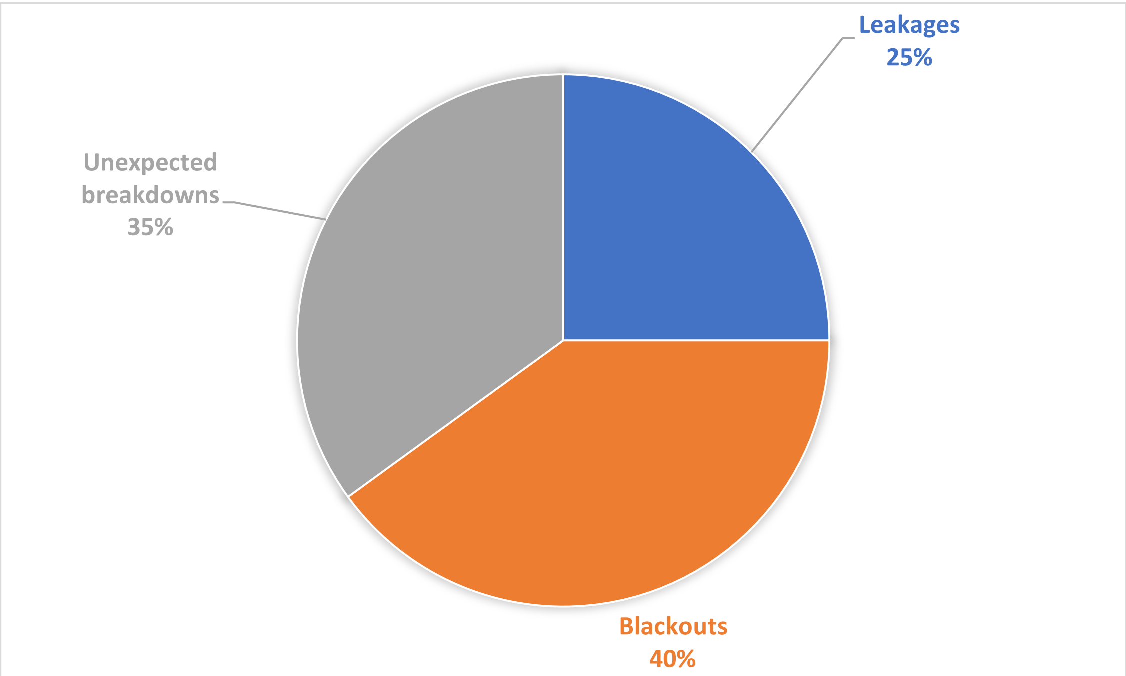


Figure 31: Common problems in the engine room

Although blackouts are not common in the engine room the percentage that is accounted for 40% more than leakages and unexpected breakdowns that are accounted for 35% and 25% respectively as demonstrated in Figure 31.

Blackouts are more emergency situations. When a vessel experiences a blackout situation, it means this vessel loses the ability of propulsion and its operation is stopped. Therefore, blackouts can cause marine disasters under extraordinary conditions.

Unexpected breakdowns or shutdowns can occur due to the problem with fuel, cooling, and lube oil systems. Leakages are also another common problem that can occur at any time in the engine room. It can happen in the cooling, fuel, and oil systems.

4.4.6 Other challenges to be the reason for fatigue or as consequences of fatigue

High noise in the engine room can lead to misunderstanding among the engine team during the repairing of unexpected failures or damages. This is a big risk as a consequence of a noisy environment.

Port operations, bunkering operations, unplanned maintenance like critical machinery components, port activities, spare parts supply leads to extra work hours for the engine crew when all of them need to be carried out at the same time, so they result in stress and fatigue.

4.4.7 Summary of the challenges/heavy workloads for the engine department

Figure 32 shows the relationship between the reason for challenges and heavy works and their possible autonomous technology solutions.

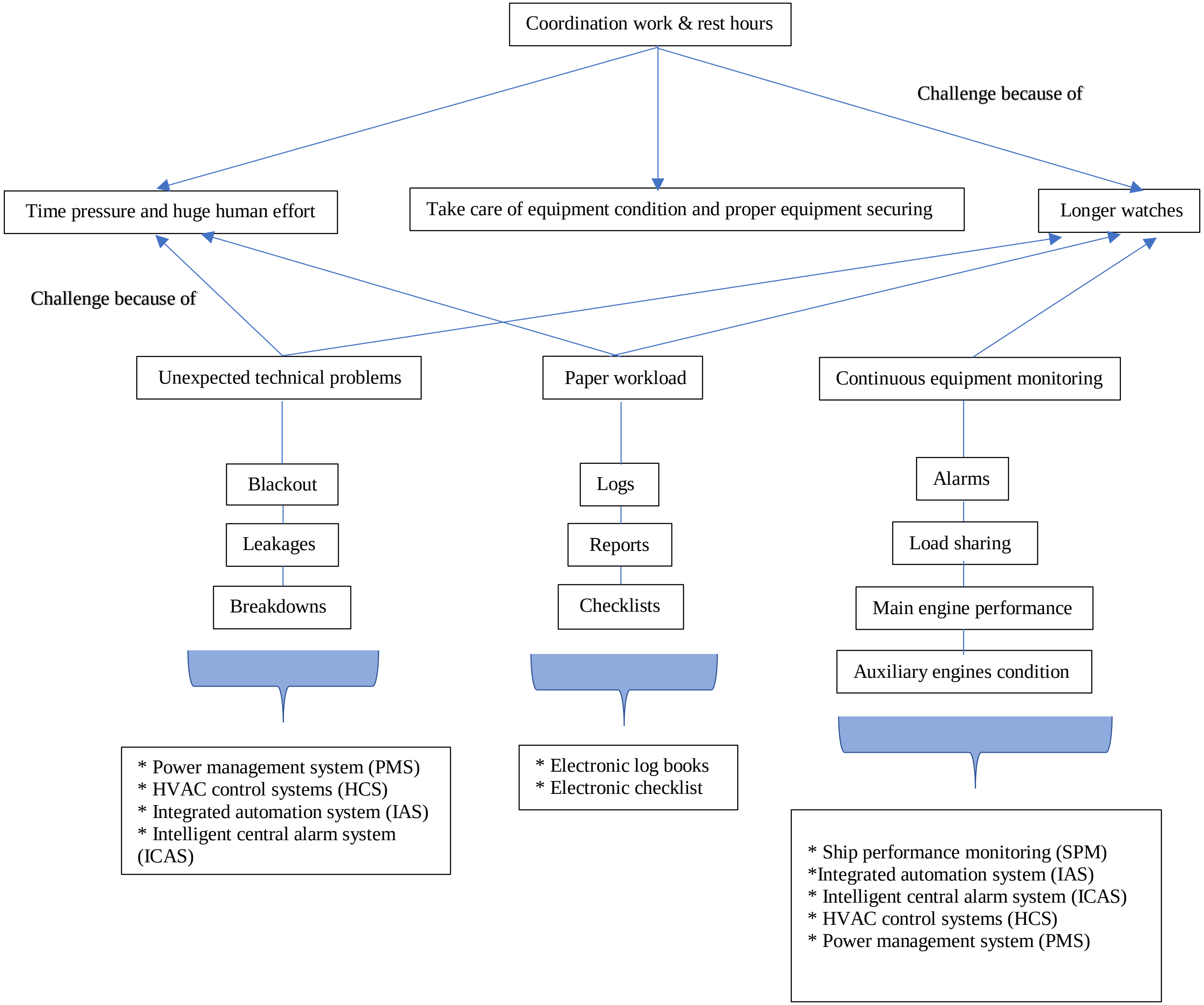


Figure 32 Challenges / heavy workloads for the engine department and autonomous technologies as possible solutions

It is clearly seen that within the non-routine conditions, coordination work and rest hours is a common challenge due to the following reasons, time pressure & human effort, taking care of equipment condition & proper equipment securing, and necessity of longer watches.

Unexpected technical problems, such as blackouts, leakages, breakdowns are challenges because of shortage of time, engine crew`s great effort as well as longer watches. The paper workload is the other challenge because of restricted time and also the need for longer watches to handle paper works. Continuous equipment monitoring is also a challenge because of long watch hours. When the vessel is under nonroutine or extraordinary conditions, the engine crew needs to stay in the engine room for more hours.

Sudden technical failures consist of blackouts, leakages, and breakdowns. PMS, HVAC control systems, IAS, and ICAS can be supportive autonomous technologies regarding protection from these problems. PMS is developed according to the redundant design, so any single error will not affect the whole propulsion system or vessel`s operations negatively. The HVAC control system ensures maintenance in case of any problem with the HVAC components. IAS as one of the newest innovative solutions can also provide a redundant concept that secures vessels` continuous effective operation. ICAS will prevent confusion due to the huge alarm complexity and it will help the duty engineer make both prioritizations of alarms as well as eliminate wrong alarms.

Paper workload includes engine logbooks, checklists, and reports. The common finding of paper workload is the most time-consuming workload for the crew. The usage of electronic logbooks, checklists surely will help the engine crew in terms of time-saving.

Continuous equipment monitoring covers alarms, load sharing, main engine performance, and auxiliary engines condition. Advanced systems like SPM, IAS, ICAS, HCS, and PMS can help with continuous equipment monitoring. SPM will ensure performance and efficiency monitoring.

4.5 The evaluation of the criticalities

4.5.1 For the deck department

The deck department`s challenges / heavy workloads were scored by both shore and ship participants as illustrated in Table 8. The total number of shore participants was five and they were fleet manager, DPA, marine superintendent, and two vessel managers. The total number of ship participants was seven and they were two masters, two chief officers, two navigation officers, and one safety officer from vessel 2 and vessel 3.

Table 8: Criticality average for the deck department`s challenges / heavy workloads

	Criticality numbers					
	Equipment failure	Weather condition & monitoring	Paper workload	Effective communication	Look-out / monitoring	Decision making
1st interviewee	5	3	4	5	5	5
2nd interviewee	5	3	3	4	5	5
3rd interviewee	5	3	4	4	5	5
4th interviewee	5	3	4	5	5	5
5th interviewee	5	4	4	4	5	5
6thinterviewee	5	2	3	4	5	5
7th interviewee	4	2	4	4	5	5
8th interviewee	4	3	4	4	5	5
9th interviewee	5	3	4	5	5	5
10th interviewee	5	3	5	5	5	5
11th interviewee	5	2	3	5	4	5
12th interviewee	5	3	4	5	5	5
Sum	58	34	46	54	59	60
Average	4,8	2,8	3,8	4,5	4,9	5

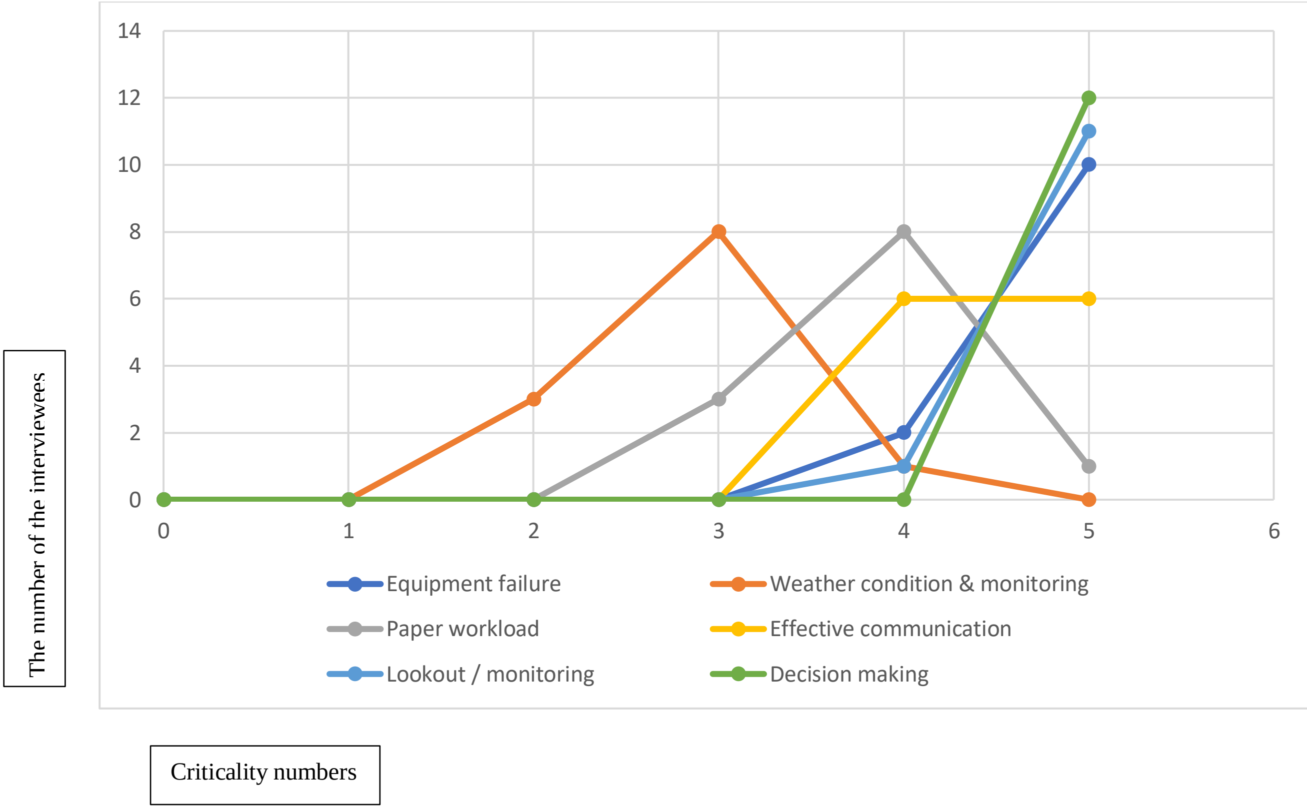


Figure 33: Criticality numbers for the deck department`s challenges / heavy workloads

Criticality numbers are determined between one to five. While the number five indicates the most criticality, one indicates the least criticality in terms of safety.

Figure 33 includes the analysis of criticality numbers from the 12 interviewees.

It is clearly seen that decision-making is one of the most challenging activities. It is located in band five. All of the interviewees gave the criticality number five for decision making.

Lookout/monitoring is the second critical activity on board and its criticality average is 4,9. While the 11 interviewees gave the critical number five for this activity, one of them gave the number four.

Equipment failure is the third most critical challenge with its 4,8 averages. 10 interviewees gave for this failure the number five and two of them gave the number four.

Effective communication is also another critical challenge, and the average is 4,5. Half of the interviewees gave the criticality number five, the other half gave the number four.

The paper workload is also a challenging and heavy workload for the crew. The average is 3,8. While one interviewee gave the number five, eight of them gave the number four and three of them gave the number three.

Weather condition & monitoring is the least critical challenge when compared to the others. The criticality average is 2.8. One interviewee gave the number four, eight interviewees gave the number three, and three interviewees gave the number two.

4.5.2 For the engine department

The engine department`s challenges / heavy workloads were scored by both shore and ship participants as shown in Table 9. While the total number of shore participants was five, the total number of ship participants was two and they were a chief engineer and a second engineer from vessel 2.

Table 9: Criticality average for the engine department`s challenges / heavy workloads

	Criticality numbers		
	Unexpected technical problems	Paper workload	Continous equipment monitoring
1st interviewee	5	3	5
2nd interviewee	5	2	5
3rd interviewee	4	3	5
4th interviewee	5	2	5
5th interviewee	5	2	5
6thinterviewee	5	2	5
7th interviewee	5	3	5
Sum	34	17	35
Average	4,9	2,4	5

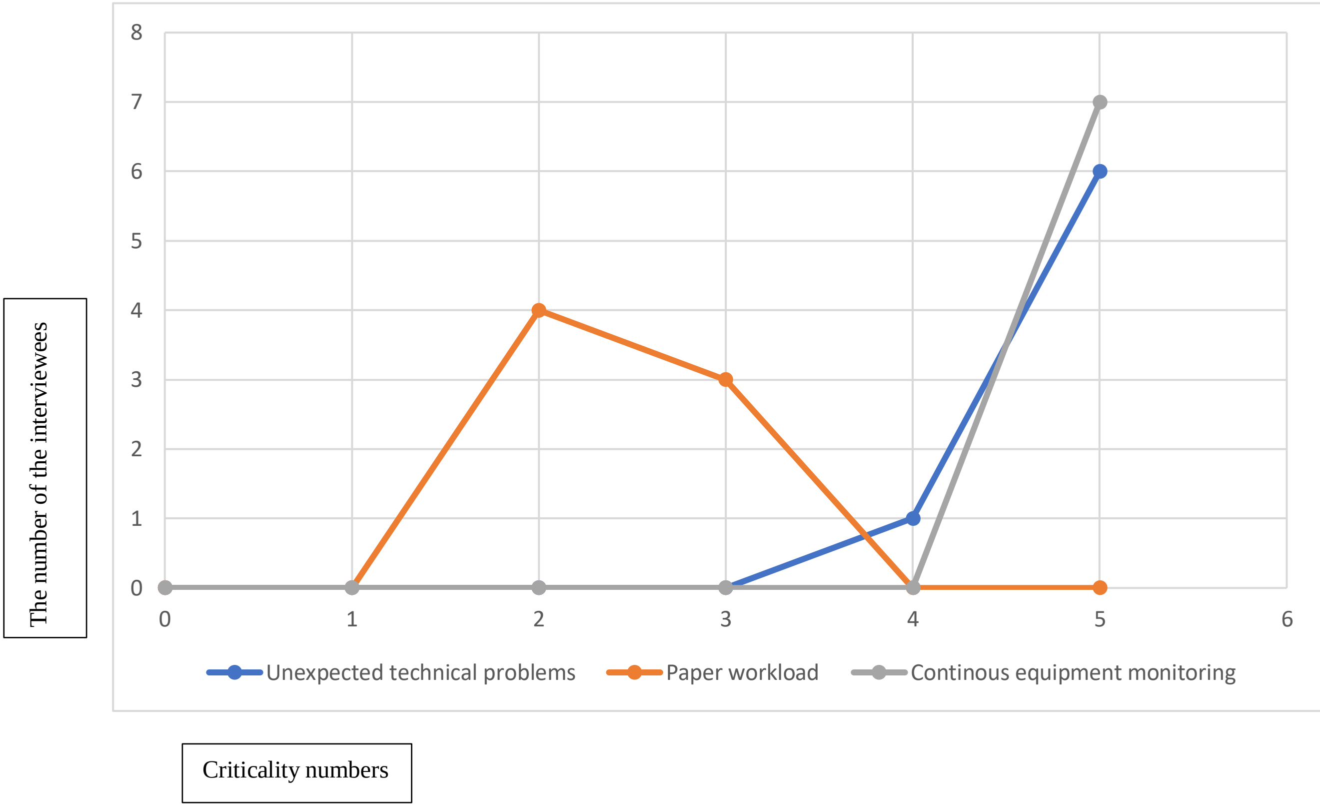


Figure 34: Criticality numbers for the engine department`s challenges / heavy workloads

Figure 34 includes the analysis of criticality numbers from the seven interviewees.

It is clearly expressed that continuous equipment monitoring is one of the most critical activities for the engine crew. All interviewees gave criticality number five, so the average criticality number is five.

Unexpected technical problems are the second critical situation in the engine room. While six interviewees gave the number five, one interviewee gave the number four for this challenge. The average of this challenge is 4,9.

The paper workload seems the least critical workload for the engine room with its 2,4 the criticality average. While three interviewees gave the number three, the four interviewees gave the criticality number two.

Table 10: Criticality average for both the deck and engine departments

	Suggested Technologies	Equipment failure	Weather condition monitoring	Paper workload	Effective communication	Look-out/ monitoring	Decision making SA1	Decision making SA2	Decision making SA3	Decision making	Unexpected technical problems	Paper workload	Continous equipment monitoring	Sum
Bridge / 12 *	ICAS	4,8					X							9,8
	IBS							X						9,8
	Weather forecasting software		2,8						X					7,8
	Electronic log book & checklist			3,8			X							8,8
	Broadband radios				4,5			X						9,5
	LIDAR						X			5				9,9
	PTZ						X							9,9
	IRC/TIC						X							9,9
	Video surveillance					4,9		X						9,9
	NAR								X					9,9
	INS						X							9,9
	AMARO							X						9,9
Engine / 7 *	PMS													9,9
	HCS										4,9		5	9,9
	IAS													9,9
	ICAS													9,9
	Electronic log book & checklist											2,4		2,4
	SPM												5	5
	Sum	4,8	2,8	3,8	4,5	4,9		5			4,9	2,4	5	162

*** Number of participants who scored the challenges / heavy workloads**

Table 10 shows the criticality averages of both deck & engine departments for each challenge / heavy workload and the autonomous technologies as possible solutions.

4.5.3 Summary of the criticality of the challenges/heavy workloads and autonomous technologies as solutions

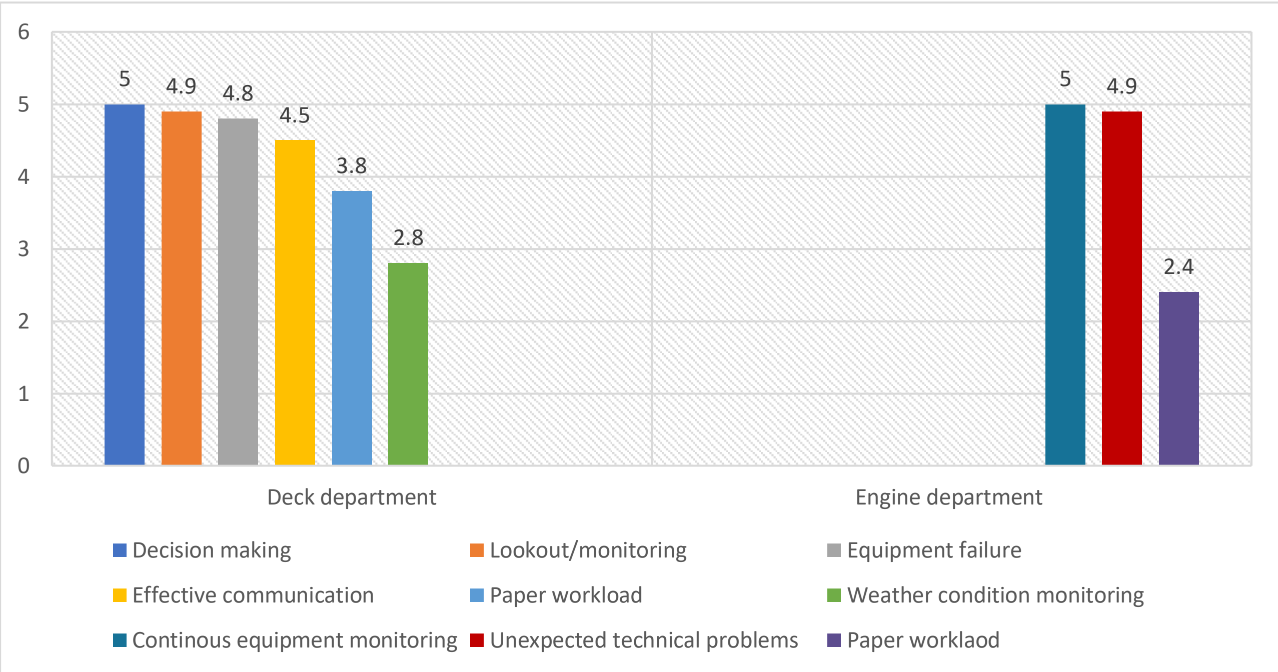


Figure 35: Summary table of the critical challenges / heavy workloads

Figure 35 clearly shows which challenge/heavy workloads are the most critical and which are the least critical in the two departments.

For the deck department, decision making is the most critical challenge under extraordinary conditions. Decision making depends on the duty officer`s situational awareness and it can be affected by all of the mentioned challenges. The second highest critical challenge is lookout/monitoring in non-routine conditions. The third critical heavy workload is related to equipment failure in different challenging conditions. Effective communication is the fourth critical challenge. As it is seen in the figure the first four challenges/heavy workloads take place in the critical bands 4 and 5. While the paper workload is the fifth critical heavy workload onboard, weather condition monitoring is sixth critical challenge, so the least critical challenge. Their bands take part in 3 and 2 respectively.

For the engine department, continuous equipment monitoring is the most critical challenging activity. The second highest critical heavy workload is related to unexpected technical problems. It is obviously seen that the first two activities are located in the 5 and 4 criticality bands. The least critical challenge is the paper workload for the engine department.

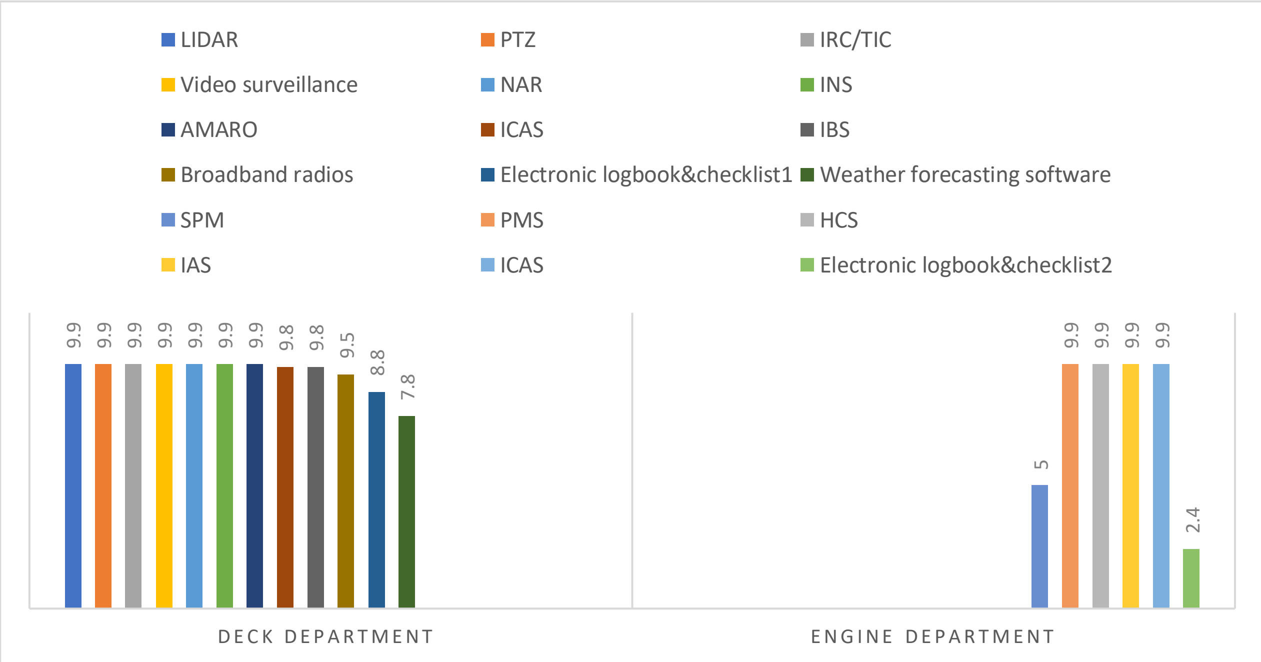


Figure 36: Summary table of the autonomous technologies as solutions

Figure 36 demonstrates some of the autonomous technologies that can be used as solutions for the described challenges/heavy workloads.

For the deck department, LIDAR, PTZ camera, IRC/TIC, video surveillance, NAR, INS, and AMARO are the most important technologies for lookout/monitoring and decision-making challenges. ICAS and IBS are also highly critical technologies, especially for the challenge/ heavy workload in case of equipment failure. Broadband radios can be used as a solution in order to ensure effective communication. Electronic logbooks & checklists can be also good solutions for the paper workload. According to the figure, the least critical technology is weather forecast software when compared with the others. The comparison is performed between the highest critical challenges/heavy workloads, but it doesn't mean that the least critical number technology is not important. All of the technologies, which are selected, can be a very good solution to reduce or eliminate the challenge or workload.

For the engine department, PMS, HCS, IAS, and ICAS are the most important autonomous technologies that can be used for the elimination of unexpected technical problems as well as helping continuous equipment monitoring. SPM is also an important technology for continuous equipment monitoring independently. Electronic logbooks & checklists seem the least critical technologies for the paper workload in the engine department. As it is said before, the least critical technologies are not expressing the worthless. All of the technologies, which are chosen, can be useful in some way for the mentioned challenges/heavy workloads.

5. CHAPTER V – DISCUSSION

The discussion chapter represents the main findings from the research study with the consideration of three research questions.

All autonomous technologies are researched and found in the literature review chapter II, so research question 1 answer is found during this process. Many technologies are found in the marine technology company`s websites because there was not enough technology description in the journals or other academic research papers. Lack of academic paper sources regarding new autonomous technology applications was one of the limitations of the study.

The results show the vessel crew`s challenging environment. Many different challenges were expressed during the interviews by both onshore and offshore crew. Research question 2 answer is found during the execution of the online interview and mail questionnaires findings. For each rank, each condition is evaluated separately to find the most suitable autonomous technologies as solutions. Challenges are shown in the result chapter IV in the pie figures with their percentages.

After detecting the existing challenges / heavy workload for the crew from both deck department and engine department, Figure 25 and Figure 32 are created to show the current challenges and heavy workloads and their suggested autonomous technologies. These figures also show that the relationship between challenges and technologies. For the deck department (Figure 25), decision making and situational awareness levels were analyzed in detail to reflect the study`s findings and the literature review are combined. Situational awareness theory is applied to the decision-making process and autonomous technologies in order to make clear in terms of which autonomous technologies can be useful in which level of situational awareness.

Later on, the result part continued with the evaluation of the criticality of each challenge and heavy workload. During the interviews, the participants were asked by the researcher to give some criticality numbers for their expressed challenges / heavy workload. The criticality averages were calculated for both deck and engine departments separately. The numbers of participants and sum of criticality numbers division gave the criticality average for each challenge / heavy workload. The criticality average table shows which challenges or heavy workloads have a high level of risk in terms of safety as well as highly possible autonomous technology solutions. In addition to the tables of criticality averages, two figures (Figure 33,

Figure 34) are also added to express the criticality numbers. The research question 3 answer is found upon completion of these criticality tables and figures.

5.1 *RQ1: What are the applicable autonomous technologies?*

The first research question answers were found during the literature review in chapter 2. Autonomous technologies are divided into two groups as the bridge-related and engine-related technologies in this study to optimize and find the most suitable solutions for the current sailor`s challenges.

5.2 RQ2: *What kind of critical activities do we have onboard for both the deck and engine department in terms of safety?*

To find answers to research question 2, the semi-structured interview questions & mail questionnaires were designed and performed with the target group that consists of both marine professional people onshore and vessel crew from two different ships from the same company. In chapter 4, all interview results were discussed and showed. The interview method was the most fundamental way to conduct this study due to the need for reliable data from the vessel crew.

5.3 *Which crew activities can be supported by autonomous technologies by priority?*

After obtaining the literature review & interview findings and the criticality evaluations, some related existing autonomous technologies were given to the current challenge / heavy workload as solutions to increase the vessel and crew safety, efficiency as well as decrease the workload.

The results give an opinion to the company on what are the most critical challenges or heavy workload in their vessels and some autonomous technologies as solutions.

While the LIDAR, PTZ, IRC/TIC, video surveillance, NAR, INS, and AMARO should be the first prioritized technologies for the deck department, PMS, HCS, IAS, and ICAS the technologies that looks like having the highest criticality average for the current challenge for the engine department. For the deck department, it is clearly understandable from the findings that additional sensor technologies, cameras, and videos will make the navigation and maneuvering more-safer. They are the lookout and monitoring supportive technologies. For the engine department, to be aware of the equipment performance and conditions is one of the critical activities. On the other hand, SPM is s good solution to be aware of vessel performance as well as emission control reply for the coming regulations from IMO. It is well known that for the coming years the strict regulations about emission control will be in operation, so retrofit will be a good start to move.

Although some technologies are found as solutions, these technologies don't cover all challenges/heavy workloads. For instance, broadband technology can be used for effective communication between the vessels, but this technology doesn't ensure effective communication with the crew during maneuvering. This is also a limitation of the study. When the process of autonomous shipping is improved, additional technologies can be created. For instance, maneuvering with one crew and robots on the forward or aft of the vessels.

At the beginning of the study, the paper workload was looking like the biggest time-consuming and challenging activities, but at the end of the study, the findings give the other results. According to my experience as a navigation and safety officer from the different kinds of vessels, I was thinking the paper workload is the most demanding workload to shift with the electronic software as soon as possible, but my interview results give me another evidence. This can be because paper workload can be time consuming or annoying, but that it is not so critical in terms of safety as much as the other challenges.

The company has a fleet of LNG carriers and VLCC. In this study, the findings are created by both onshore and offshore crew who have a tanker vessel culture. Tanker vessels are much more different than passenger vessels or bulk carrier vessels. This is also one limitation of the study.

In this study, stress is found also as the most common and important challenge for each crew who works onboard. For stress, there were no technologies that can reduce stress, so this topic wasn`t evaluated in detail. This is another limitation of the study. Stress can cause any kind of accident, incident, or physical injury onboard. Although we put additional technologies onboard to support the vessel crew, if the crew has a high level of stress, these technologies will not help to ensure a vessel`s safety or efficiency.

For future studies, there are three recommendations.

The first one is the following the newest technologies in the near future can develop this research study questions more further.

The second one is to collect various data from additional interviews with different companies, which have different types of vessels in their fleet and different crew from different countries. It will provide a wide range of opinions about the different challenges and heavy workloads.

The third one is to increase vessel safety by reducing the workload on the crew shoulders and operational efficiency, stress and its effect should be investigated. Because vessel crew is still the key point in the shipping industry and their concerns, working conditions, demands need to be listened to, evaluated, and try to find the most supportive solutions for their physical and mental life onboard too.

6. CHAPTER VI- CONCLUSION

This research study is conducted based on three research questions and executed by the collaboration of the shipping company. During the research, it was possible to define autonomous technologies that can be possible solutions for the challenges that ship crew faces every minute during their time onboard.

While the literature review was the method to access autonomous technologies, online interviews and mail questionnaires were the main ways to reach reliable data from vessel crew regarding the activity challenges / heavy workloads and their opinions about the criticality evaluations of each mentioned problem.

The answer to research question 1, the newest autonomous technologies were investigated and all of them were found in different marine technology companies` pages. Literature review in chapter 2 performed according to both the academic information and newest technology trends. Responses for research question 2 were gathered with the help of online interviews and mail questionnaires. The vessels` crew were analyzed to learn what are the current challenges/heavy workloads that affect the vessel`s safety, efficiency as well as criticality evaluations of each challenge/heavy workload. The participants were asked to describe these challenges/heavy workloads in different extraordinary conditions. Later on, a combination of both the autonomous technologies and interview/questionnaire findings helped the research study move into the answer for research question 3 regarding the description of these challenges/heavy workloads and their possible solutions with the aim of increasing safety, efficiency as well as reducing workload in some way. Possible autonomous technology solutions were suggested based on their evaluations under the situational awareness levels to contribute decision making.

The main aim is achieved with the suggestions of the possible autonomous technology solutions that can be utilized in order to get maximum efficiency from both vessel and crew. While some autonomous technologies, such as integrated automation systems, integrated bridge systems directly optimize the vessel efficiency, the others like sensor technology systems can support the crew to increase situational awareness with their functions and help decision making.

The results from the study give the company an idea about how they can have a way to apply costly autonomous technologies according to the research study findings` criticality prioritization.

In conclusion, this study clearly defines many different challenges and heavy workloads of vessel crew in different conditions and expects to motivate other researchers to improve crew working environment with utilization from autonomous technologies in the near future just before the shipping industry shifts from manned vessels to fully autonomous vessels.

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Appendix I

Abbreviations

IMO : International Maritime Organization
MSC : Maritime Safety Committee
MAAS : Maritime Autonomous Surface Ships
RSE : Regulatory Scoping Exercise
RQ(s) : Research Questions
NSD : Norwegian Centre for Research Data
IAMR : Industrial Autonomous Mobile Robot
AMR : Autonomous Mobile Robot
ARPA : Automatic Radar Plotting Aid
LR : Llyod's Register
AL : Autonomy Level
DP : Dynamic Positioning
ICS : International Chamber of Shipping
HSBA : Hamburg School of Business Administration
SA : Situational Awareness
VLCC : Very Large Crude Carrier
LNG : Liquified Natural Gas
CV : Conventional Vessel
SVAN : Safer vessel with autonomous navigation
BV : Bureau Veritas
CCS : China Classification Society
DNV-GL : Det Norske Veritas-Germanischer Lloyd
AAWA : Autonomous Waterborne Application
MUNIN : Maritime Unmanned Navigation through Intelligence in Networks
SAR : Synthetic Aperture Radar
AIS : Automatic Identification System.
MVDA : Moving Vessel Detection Algorithm
SUA : Status Update Algorithm
AMARO : An On-Board Ship Detection and Real- Time Information System
EO : Earth Observation

DPA : Designated Person Ashore
CAPEX : Capital Expenditures
OPEX : Operating Expenses
COLAV : Collision Avoidance
COLREG : The international Regulations for Preventing Collisions at Sea
ECDIS : Electronic Chart Display Information System
GNSS : Global Satellite Navigation System
UUV : Unmanned Underwater Vehicles
UAV : Unmanned Aerial Vehicle
ATON : Aid to Navigation
LIDAR : Light Detection and Ranging
SAR : Search and Rescue
LRIT : Long Range Identification and Tracking
METOC : Meteorology and Oceanography
VMS : Vessel Monitoring System
IBS : Integrated Bridge System
CAM- HMI : Central Alert Human-Machine Interface
INS : Inertial Navigation System
EMCIP : European Marine Casualty Information Platform
IMU : Inertial Measurement Units
RADAR : Radio Detection and Ranging
3D : Three Dimensional
IA : Intelligent Awareness
GPS : Global Positioning System
PTZ : Pan-Tilt-Zoom Camera
TEU : Twenty- Foot- Equivalent Units
AUTOSHIP : Autonomous Shipping Initiative for European Waters
NFAS : Norwegian Forum for Autonomous Ships
IASCS : International Association of Ship Classification Societies
ILO : International Labor Organization
ISM : International Safety Management
IR : Infrared
ICAS : Intelligent Central Alarm System
HVAC : Heating, Ventilation, and Air Conditioning

IAS : Integrated Automation System
SPM : Ship Performance Monitoring
EEDI : Energy Efficiency Design Index
SEEMP : Ship Energy Efficiency Management Plan
EEOI : Energy Efficiency Operator Indicator
LNGC : Liquefied Natural Gas Carrier
KPI : Key Performance Indicator
ROI : Return On Investment
VDR : Voyage Data Recorder
CCTV : Closed Circuit Television
ESD : Emergency Shutdown
NAR : Navigation Assessment and Routeing
VIQ : Vessel Inspection Questionnaire
M/E : Main Engine
COW : Crude Oil Washing
PMS : Planned Maintenance System
ORB : Oil Record Book
CO2 : Carbon dioxide
COW : Crude Oil Washing
IRC : Infrared camera
TIC : Thermal imaging cameras

Appendix II

Interview questions

Introduction

- What is your job definition in the company?

a) Deck department questions

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1) **What are the challenges and/or heavy workloads during inspection/vetting preparations;**
   a) for master?
   b) for chief officer?
   c) for navigation officer?
   d) for safety officer?

1.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

2) **What are the challenges and /or heavy workloads in extremely heavy weather conditions;**
   a) for master?
   b) for chief officer?
   c) for navigation officer?
   d) for safety officer?

2.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

3) **What are the challenges and/or heavy workloads in the condition of traffic complexity;**
   a) for master?
   b) for navigation officer?

3.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

4) **What are the challenges and / or heavy workloads during berthing/unberthing/ anchoring operations;**
   a) for bridge team (command)?
   b) for deck team (maneuvering)?

4.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

5) **What are the challenges and/or heavy workloads in the condition of geographical complexity; (For instance, tropical storms, piracy regions, etc.)**
   a) for master?
   b) for chief officer?
   c) for navigation officer?
   d) for safety officer?

5.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

6) **What are the challenges and/or heavy workloads of the cargo operations for chief officer?**

6.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

7) **Are there any high demand situations; such as to be the reason for fatigue or as a consequence of fatigue in addition to given questions?**

7.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

b) Engine department questions

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1) **What are the challenges and/or heavy workloads during inspection/vetting preparations;**

a) for chief engineer?
b) for second engineer?
c) for third engineer?
d) for electric officer?

1.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

2) What are the challenges and/or heavy workloads in extremely heavy weather conditions;

a) for chief engineer?
b) for second engineer?

2.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

3) What are the challenges and/or heavy workloads during berthing/unberthing/ anchoring operations;

a) for engine room team?

3.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

4) What are the common problems that can occur at any time in the engine room? (For instance, blackout during the normal voyage and so on.)

4.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)

5) Are there any other high demand situations; such as to be the reason for fatigue or as a consequence of fatigue in addition to given questions?

5.1 What are the criticality numbers of each challenge in terms of safety? Please give a number for each challenge from 1 to 5. (5 is the most critical, 1 is the least critical.)