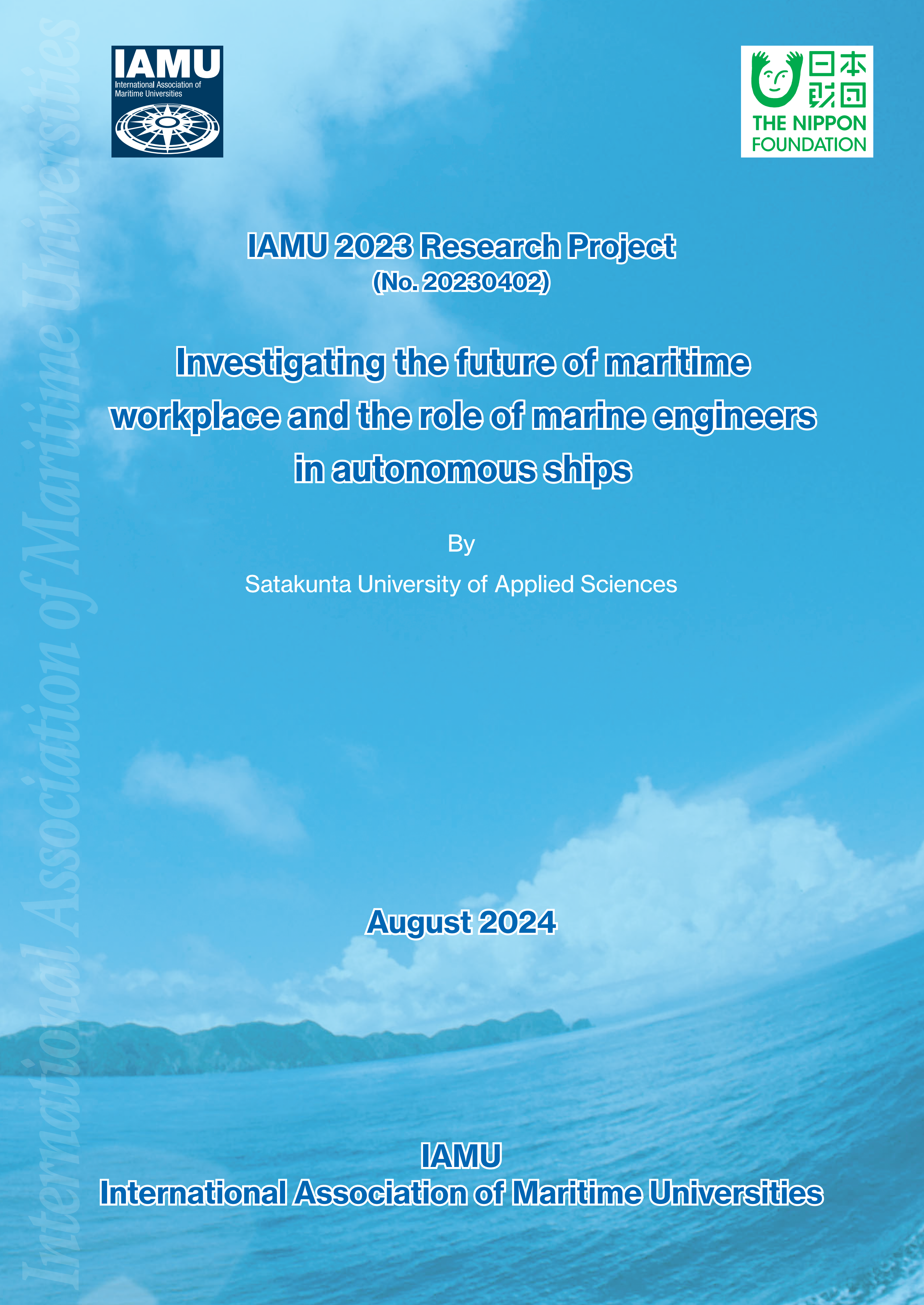

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IAMU 2023 Research Project
(No. 20230402)

Investigating the future of maritime workplace and the role of marine engineers in autonomous ships

By

Satakunta University of Applied Sciences

August 2024

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Abstract: The shipping industry is experiencing profound changes and challenges by adopting Industry 4.0 technologies. Todays' advanced technology and digitalization allow connecting different elements of a ship to the onshore remote operation centers (ROCs). The newly built ships have the capacity for their navigational systems to be operated and their main and auxiliary engines to be constantly monitored from distance. These technologies are fundamentally changing ships and the jobs that seafarers conventionally performed onboard ships. Consequently, the seafarers required competencies to operate, monitor, and control the new ships are being redefined. There is a gap between the STCW's current skills and competency and the requirements for operating, monitoring, controlling, troubleshooting, and maintaining the current smart and future ship. To address these concerns, the IMO is developing the Maritime Autonomous Surface Ships (MASS) Code. However, the proposed MASS Code does not clearly address these issues, and it is still need further development. Although there were numerous projects that investigated the competency requirement of future ship officers, the complexity of ship machinery and auxiliary systems prevented the future workplace and required competency of marine engineers to be studied. The ROME project was designed to fill this gap by investigating the current advancement in marine engineering technology onboard ships and its trajectory to the future. The research data was collected through a qualitative research interviews with stakeholders. The research also collected ethnographical data of newly built ships and ROCs. The research participants included ship owners, seafarers, classification societies, technology providers, and shipbuilders with different levels of expertise. Our research data shows that the progress of the shipping industry's transition to different degrees and modes of operation of MASS is gradual but not consistent across its different sectors. The analysis shows that in commercial shipping, the adaptation of MASS 3, where marine engineers will be relocated to the ROCs, is feasible for the short-sea and near-coastal shipping. This is because the short range and the limited engine power output required allow these ships to be powered by battery-operated electric engines. In these ships, the role of engineers will be limited to the electro-technical officers' role where they can monitor and operate the electric propulsion system from a distance. However, the roadmap to MASS 3 for the SOLAS class oceangoing ships has not been drawn yet. The marine engine manufacturers are facing many challenges associated with the complexity of massive engines and their auxiliary support systems. However, there is immense pressure from national and international bodies on shipping for the decarbonization and reduction of greenhouse gases emitted by ships. While the industry is shifting toward smart shipping in terms of the realization of MASS and decarbonization, marine engineers require new training and certifications system under the MASS regulatory framework. While marine engine manufacturers and technology providers are developing the new generation of ships there is a need for the MET institutes to take the initiative and make plans for training the future marine engineers. Our research shows that the speed of integration of technology onboard ships does not match the progression of marine engineers' competency and knowledge development at MET institutes, posing safety and security risks. Our research identified gaps and made recommendations that the IMO, MET, and other stakeholders could use to benefit from and be able to train marine engineers during the transition period. These insights will assist in equipping marine engineers with the new competencies and skills required when transitioning to work at Remote Operation Centers (ROCs). This research also recommend areas for further research in the field.

Keyword: *Marine Engineer, Safe Return to Port, Unattended engine room, Seafarer, MASS, Autonomous Ship, Remote Operation Centre*

Executive Summary

IAMU research Project (20230402 _SAMK _AMC)

Industry 4.0 advanced technologies are driving the shift toward remotely operated and Maritime Autonomous Surface Ships (MASS), revolutionizing ships and their workforce roles and responsibilities. While considerable ongoing research focuses on the navigational operations of MASS, there is a scarcity of research investigating the progression of technology in marine engines and their effect on marine engineers' roles and responsibilities. However, recently the engine department has moved under the spotlight not only due to MASS technological transformations but also due to the request for decarbonization and the shift toward greener operations. Our research shows that marine engineers will soon experience a workplace that requires a mix of traditional (hands-on experience), digital, and robotics skills. Currently, the training in Maritime Education and Training (MET) institutes under the International Maritime Organization (IMO) framework does not align with the integration of technological advancements in the engine department, particularly in areas such as remote sensing, engine health and condition monitoring, and integrated artificial intelligence (AI) systems. In most cases, the training provided by manufacturers is the only resource for engineers to maintain and operate the newly introduced advanced engine components. IMO, as the leading regulatory body, is not keeping pace with updating existing regulations and standards related to MASS seafarers' training and competency development. This gap poses safety and security challenges for the industry as their seafarers may not be ready for the transition to MASS and green shipping.

This research was designed to collect data from different stakeholders, including shipowners, seafarers, classification societies, technology providers, shipbuilders, and marine engineers, to closely examine the advancements in marine engine technology and investigate the skills and competencies that future marine engineers need. Moreover, the research team members also visited newly built or under-construction ships with recently developed class notations such as Safe Return to Port (SRtP) and interviewed the designers, naval architects, and project managers. These included M/S AURORA BOTNIA, M/S MySTAR, and M/S SPIRIT OF TASMANIA IV (under construction). Ethnographical data were also gathered at shipboard engine remote monitoring centers including Wärtsilä and Kongsberg, and the ROC Massterly. Data analysis shows that the roles of marine engineers and other professionals in the maritime industry will dramatically change due to growing digitalization and the implementation of MASS technologies, as well as the shift toward decarbonization through the introduction of alternative energy sources and dual-fuel engines. Manufacturers are implementing highly advanced monitoring systems to observe the behaviour of the main engines, auxiliary engines, and other components to predict the required maintenance and understand how they can extend the lifecycle of the systems. These advanced systems require marine engineers to monitor trends and identify and rectify faults independently or through online consultation with manufacturers.

After the analysis of the collected data, the following themes emerged:

- Workplace Evolution
- Role Expansion of Marine Engineers
- Training Gaps
- Certification Gaps
- Regulatory Gaps

Although the newly introduced advanced technology-oriented workplace requires fewer human operators onboard ships, it simultaneously needs skilled marine engineers who are able to perform the emerging roles. These roles require skills and competencies which include strategic monitoring, decision-making in collaboration with intelligent systems, ROC operation, MASS seafaring, and working with third-party service providers. The research data highlighted the importance of introducing seafarers to new concepts such as 'Safe Return to Ports' (SRtP). Operating these systems not only requires seafarers to be familiar with the procedures for the successful operation of MASS but also enables seafarers and remote operators to develop the concept

of system redundancy, integral to MASS technology. Our analysis shows that it is critical for MET institutes to balance practical and theoretical knowledge by focusing on skills such as cybersecurity, data analysis, software management, alternative fuels, simulation, and remote monitoring, in addition to many of the traditional skills. Moreover, the data indicate that monitoring skills and the SRtP concept are becoming increasingly critical for autonomous systems and require marine engineers to learn to collaborate with remote operation centers for identifying and diagnosing issues as well as predicting required maintenance. While the research data highlighted the required skills for the transition period to different modes of MASS, it is crucial for seafarers to adopt a mindset of continuous and lifelong learning while new technologies are being introduced. More importantly, the research data indicates that the integrated technologies in ships' engine rooms and remote operation centers (ROC) are Industry 4.0 technologies that is being implemented in other industries. Over time, this could result in engineers from other disciplines potentially being employed to work onboard ships and in ROCs, offering a potential solution to the anticipated shortage of marine engineers in the near future.

As the transition to MASS progresses, the demand for creativity and swift problem-solving abilities will replace the need for specialized knowledge in a specific area. Future mariners should develop a proper understanding of the design and operational criteria of MASS and advanced marine engineering systems. Remote controlling and troubleshooting of ships will present challenges while decision support systems using big data analytics and machine learning techniques are creating new opportunities and challenges. Remote operators need to be able to interact with intelligent systems used for decision-making, condition monitoring, and object identification. Engineers need to understand issues related to remote sensing design and use. Proficient skills and ability in telecommunication, teamwork, and leadership, in addition to knowledge related to ethical aspects of autonomous decision-making, are needed. Figure 1 shows a summary of the new requirements for marine engineers.

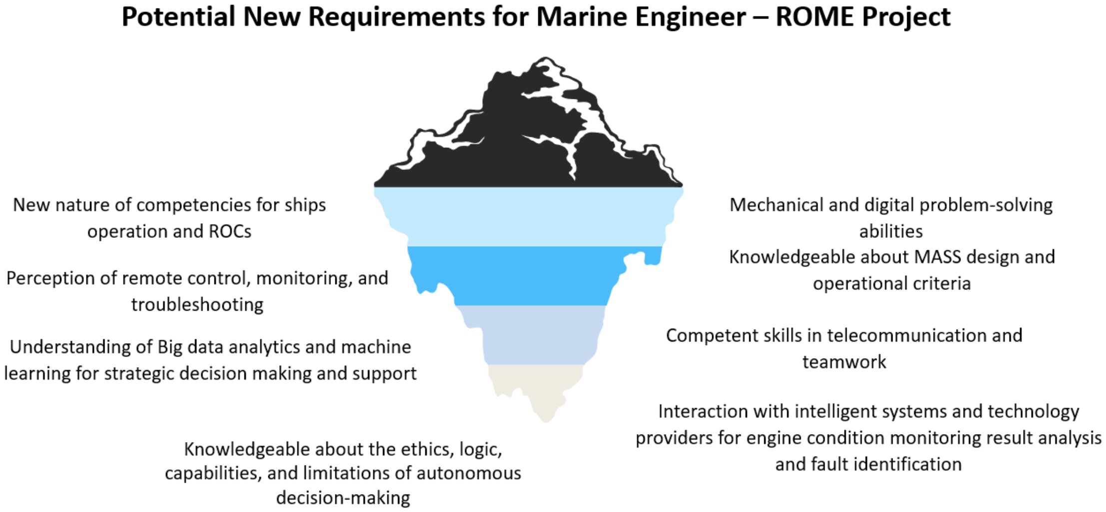


Figure 1 - New requirements for marine engineer – ROME project data

Recently, IMO established a Working Group to comprehensively review the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and to develop the roadmap and methodology to address the gaps in relation to training. These gaps include emerging technologies on ships and ship operations, e-certifications, cybersecurity, and simulation utilization for sea time and practical experience. Therefore, in conjunction with MASS Code development, the STCW Convention could be reviewed with the aim of addressing the current outdated training requirements while incorporating aspects of MASS. Action is required to review the tables of competence in the STCW Code to update competencies, KUPs, and training requirements that are outdated and no longer relevant. Moreover, to create a more efficient, safe, and harmonized workplace in relation to MASS and decarbonization, the research data suggests meeting the interoperability of new technological systems by assigning unified standards for manufacturing marine technologies.

Contents

1 Introduction

The maritime industry is witnessing transformative changes that are driven by Industry 4.0 and its advanced technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), Cloud Computing, and Cyber-Physical Systems (CPS) (Adonis, 2018; Baum-Talmor & Kitada, 2022; Bergmann, 2021). The new class of ships, known as smart ships, intelligent ships, unmanned surface ships, or simply autonomous ships, is part of this revolution (Emad et al., 2020). Autonomous ships are the perfect example of the adoption of Industry 4.0's advanced technologies onboard and ashore (Gu et al., 2021; Shahbakhsh et al., 2021b). Pioneering organizations and classification societies have defined their own degrees of autonomy based on their interests and projects (Shahbakhsh et al., 2021a). For instance, the classification societies such as the American Bureau of Shipping (ABS), Det Norske Veritas (DNV), Bureau Veritas (BV), and Lloyd's Register (LR) have their definitions of levels of autonomy, using levels one to four or six (American Bureau of Shipping (ABS), 2020; NYK, 2022; Rødseth & Nordahl, 2017; Rødseth & Vagia, 2020). However, to set a standard for this new class of ships, the IMO defines an autonomous ship to be a ship that can operate independently with little or no human intervention under the framework of the Maritime Autonomous Surface Ships (MASS) Code (IMO, 2018). The IMO defined four degrees of autonomy with different modes of operation, marking the beginning of a transition period from traditional shipping to smart, intelligent, and autonomous shipping (Emad et al., 2021). This transition highlights the gradual integration of advanced technologies onboard ships and ashore. As the degree of MASS increases, the presence of human operators onboard will decrease as they will gradually move to Remotely Operated Centers (ROCs). In degree two, remote operators from the ROC will control, monitor, and manage ship operations in collaboration with the crew onboard, while in degree three there will be no crew onboard. In the ROC, operators will utilize intelligent machines and smart systems for diagnostics and decision-making support (Emad, 2020a; Emad & Shahbakhsh, 2022).

As the workplace onboard ships and ashore becomes more technologically advanced, the existing jobs of seafarers will evolve, with new positions being introduced and existing ones transforming to align with intelligent technology (Emad, 2021; Emad & Ghosh, 2023). While the industry progresses rapidly in the development of this new class of ships, the IMO is not keeping pace in accommodating the regulatory aspects of integrating MASS into existing regulations and standards (Shahbakhsh et al., 2023). Analysis of current trends shows that over the next few years, the rapid rise of sophisticated automation tools including remote monitoring and operations, and the new ship designs will disrupt and hinder industry operations (Emad & Ghosh, 2023). These gaps widen as the ship propulsion system undergoes the dual trends of digitalization and decarbonization (Shahbakhsh et al., 2023). These trends and other advanced technologies are introducing new systems such as condition monitoring systems, health monitoring systems, dual-fuel engines using alternative fuels, and new concepts such as Safe Return to Port (SRtP) (Chen, 2023; Curran et al., 2024; Kim & Bae, 2023; Valcalda et al., 2023). Marine engineers will face a more complex workplace onboard ship and ashore while implementing decarbonization and digitalization, paving the way for increasing use of automation and remote technologies.

Although all attention is focused on the development of technology and regulatory framework for MASS, the training and upskilling of marine engineers who will operate and work with the new systems have not received much attention. With the introduction of MASS, the roles and responsibilities of marine engineers will evolve, and it is the responsibility of the IMO to address their training, and certification needs to prepare the marine workforce for the future. The ROME project was designed to address these challenges by investigating the future shipping workplaces and the roles and responsibilities of marine engineers in that environment. Based on the findings of this research, we provide recommendations that marine authorities and the IMO can use to incorporate these requirements into their plans for updating regulatory frameworks.

1.1 *Industry 4.0 and Maritime industry*

The world has undergone massive transformations through three previous industrial revolutions, which were driven by the introduction of steam power, electricity, and information and communication technology (ICT) (Liao et al., 2017; Xu et al., 2021). However, we are currently witnessing extraordinary shifts through the fourth industrial revolution, Industry 4.0. In this new era, the physical world is increasingly connected to digital realms, progressing toward a state in which the boundaries between the physical and digital worlds are increasingly getting blurred (Alexa et al., 2022; Lu, 2017; Angreani et al., 2020). While there is no universal definition for Industry 4.0, it is often viewed by researchers as a methodology that redefines and reshapes the physical aspects of industries through digitalization and autonomy. Industry 4.0 is driven by advanced technologies, including but not limited to (Devezas et al., 2017; Erro-Garcés, 2021; Frank et al., 2019):

- Robotics and automation
- Artificial Intelligence (AI)
- Cybersecurity
- Augmented reality (AR)
- Additive manufacturing (3D printing)
- Big data
- Internet of Things (IoT)
- Cloud computing
- Virtualization (Simulations and Digital Twin)
- Blockchain

The gradual deployment of these advanced technologies across various industries, including maritime, aims to enhance the monitoring and operation of navigation and machinery both on-site and remotely. This enhancement is achieved by installing advanced sensors in machines supported by artificial intelligence (AI) to collect and analyze data to assist humans in the monitoring and operation of systems, detecting faults, and planning for maintenance. Furthermore, the revolution in 3D printing technologies, also known as additive manufacturing, gives ship engine manufacturers the ability to build complex innovative designs (Bas et al., 2024; Bergmann, 2021; Emad, 2020b). For instance, Wärtsilä and Kongsberg, leading engine manufacturers, are utilizing advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and 3D printing in their factories. The 3D printing technology enables the design and production of lightweight metal engine components in-house, thereby reducing inventory and logistics costs (Aaltonen, 2024; Valcalda et al., 2023; Wärtsilä, 2018). Moreover, these ship engine manufacturers are pioneers in implementing Industry 4.0 technologies through the use of remote monitoring systems and deploying these technologies in engines and their components under the framework of 'Remote Condition Monitoring Systems' (RCMS) and 'Health Monitoring Systems.' These systems, designed to collect data via embedded sensors in engines and their components, transmit this data to manufacturers, who then use machine learning and intelligent software to analyze the data, diagnose potential issues, detect faults and anomalies, and plan for predictive maintenance. This approach is used for lifecycle management of engines and their components. Such systems are integrated onboard ships, and the results of the analysis assist marine engineers by providing technological support to alert and notify them about any potential changes, enabling timely rectification of issues (Han et al., 2024; Pagonis, 2024; Yu et al., 2024).

Industry 4.0 is now on its way to transforming traditional shipping into smart, intelligent, and autonomous operations (Emad & Shahbakhsh, 2022; Shahbakhsh et al., 2021b). Although the adoption of advanced technologies in the maritime industry may not be as rapid as in other sectors like aviation, mining, and automotive, significant changes are occurring (Alawadhi et al., 2020; Kansake et al., 2019; Nisser & Westin, 2006). These include massive shifts in maritime operations, services, travel routes, ship design, ship operations, trade trends, and most importantly, the labour market. As a result, the shipping industry is becoming increasingly interconnected in terms of ships, ports, and logistics systems (Chae et al., 2020;

Ichimura et al., 2022; Kitada et al., 2018). The adoption of Industry 4.0 is also evident in ports across the maritime sector. For instance, the introduction of the Intelligent Port, SmartPort, SmartPort Logistics, and SmartPort Energy. These systems employ sensors and advanced technologies to increase efficiency and productivity, with the Hamburg Port serving as a prime example of this deployment (Port-Hamburg, 2024; Vaio & Varriale, 2019).

Autonomous shipping features various operational models, crewing requirements, and designs. Many pioneering organizations, companies, and classification societies have launched various projects to assess the feasibility of autonomous ships (Baldauf et al., 2018; Emad et al., 2020). The concept of an autonomous ship was first introduced in the book “Ships and Shipping of Tomorrow” by Rolf Schonknecht, which predicted that one day ship captains would operate vessels from an office ashore (Roberts, 2018). However, testing and feasibility studies for autonomous ships began in 2013, two years after Germany coined the concept of Industry 4.0. Examples of these development projects, either completed or ongoing, include the Korean project for developing autonomous navigation systems with intelligent route planning, the European project for Maritime Unmanned Navigation Through Intelligence Networks (MUNIN), the REVOLT (DNV-GL) project, Norway's project for Autonomous Unmanned Vehicles Systems (AMOS), and the Rolls Royce project for the Advanced Autonomous Waterborne Application Initiative (AAWA) (KASS, 2022; Li & Fung, 2019; Munim, 2019; Preś, 2017). While these pioneers have defined various levels and definitions of autonomy for ships, in 2017 the International Maritime Organization (IMO), as the regulatory body, began setting standards for this new class of ships in the maritime industry (IMO, 2018).

1.2 IMO, Autonomous Ship and Seafarers

To address the various aspects of autonomous ships, the IMO initiated a Regulatory Scoping Exercise in 2017, involving the Maritime Safety Committee (MSC), the Legal Committee, and the Facilitation Committee of the IMO. This group is known as the Joint MSC-LEG-FAL Working Group on Maritime Autonomous Surface Ships (MASS-JWG). Through this committee, the IMO engaged with member countries to classify and define new categories of ships and to address the safety, legal, and operational issues related to MASS (IMO, 2020, 2022). Finally, in 2018, the IMO defined Maritime Autonomous Surface Ships (MASS) as 'a ship that operates at various levels of independence from human interference.' The IMO also defined four degrees of autonomy as follows (MSC.1/Circ.1638 on 3 June 2021, 2021):

- “Degree one: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but seafarers, according to safe manning certificate, on board ready to take control.”

- “Degree two: Remotely controlled ship with seafarers on board. The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.”

- “Degree three: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.”

- “Degree four: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.”

IMO highlighted that these degrees are designed to guide members and may change as MASS development guidelines and standards progress. Recently, IMO is emphasizing the modes of operation. It is based on the idea that a ship may experience all four degrees of autonomy during a single voyage. These definitions and categorization indicate that the transitional period during which the gradual implementation of advanced technologies onboard ships and onshore will reduce the presence of human operators. This means that the operations will gradually be managed from a Remote Operation Centre (ROC) (Emad & Ghosh, 2023; Shahbakhsh et al., 2021a).

In 2021, the MASS-JWG working group identified high-priority gaps in existing conventions and standards including SOLAS, MARPOL, COLREGs, and STCW that needed to be addressed. During the process, the group devised a roadmap to tackle these gaps. Based on that the IMO decided to develop a non-mandatory, goal-based MASS Code to address these challenges. The code aims to cover various aspects of MASS, including its purpose, principles, objectives, application, Remote Operation Centre (ROC) operations, certification and survey, risk assessment, software design and development, and human element including training. To fulfill the roadmap, it was suggested to release the Code in early 2025 for voluntary adoption, with mandatory enforcement expected in 2028 (IMO, 2023). While the progress suggests that MASS is being implemented in territorial waters, the international maritime industry is not yet to fully integrate MASS, suggesting more time needed to adapt to an environment where MASS and non-MASS ships can coexist. The new roadmap sets the May 2025 for the finalization and adaptation of the non-mandatory MASS Code, following an experience-building phase in the first half of 2026. From 2028, the IMO will start developing the mandatory MASS code based on the feedback from implementation of non-mandatory Code. The working group set July 2030 as the time for the adaptation of the mandatory Code and January 2032 for its entry into force (MSC 108 Report, 2024). This revision indicates that the industry needs sometimes to pave the way for the future shipping. Figure 2 shows the progression of the MASS Code development process (MSC 108 Report, 2024).

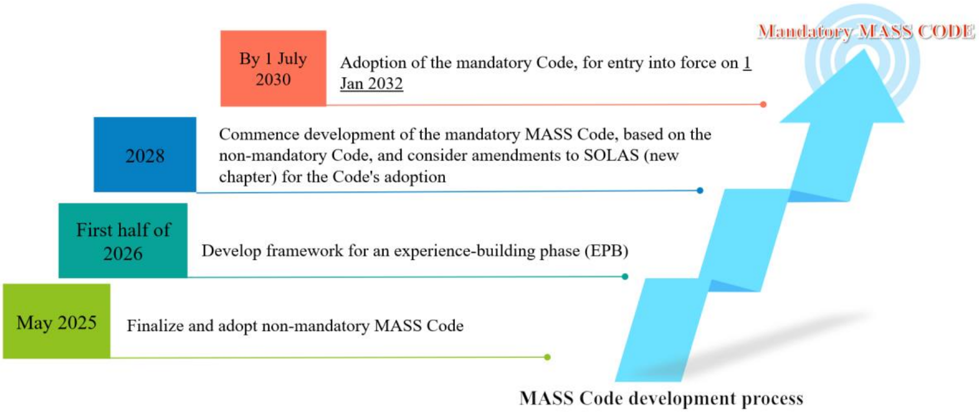


Figure 2 – New roadmap based on MSC 108 for MASS Code development process (MSC 108 Report, 2024).

The MASS Code aims to address the challenges arising from the adoption of advanced technologies onboard ships and ashore, as they transform the traditional physical workplace onboard ships to a technology-rich and digitally oriented workplaces, thereby making it smarter. This will evolves the existing roles, responsibilities, and work locations of its workforce.

In addition to safety, legal, and operational aspects of MASS implementation, the Code aims to tackle the emerging challenges faced by the workforce by addressing potential changes. It is introducing supplementary competencies, training, and familiarization for seafarers onboard MASS and in ROCs. The development roadmap for the MASS Code indicates that it will take time for seafarers to be competently trained as required by the Code. While IMO established a Working Group in relation to STCW revision to address existing and emerging gaps in seafarers' training, which includes but is not limited to emerging technologies on ships and ship operations, emerging technologies in education and training, and facilitation of training by utilizing simulators and cybersecurity. However, so far, there is no convention, standard, or amendment to directly address the maritime workforce development for the integration of advanced technologies onboard ships and ashore.

Maritime industry is deploying advanced technologies in the interest of digitalization and decarbonization to achieve smarter, more efficient, and greener operations. however, the current training programs, facilities, and tools are not aligned with the technological advancements being deployed onboard ships. This is a significant gap that prevent enhancing the capabilities of the maritime workforce to match integrating advanced technologies with expertise. There is a need for creating a new breed of workforce equipped with advanced tools, technologies, and knowledge with augmented physical, sensory, and cognitive abilities. The IMO, as the leading authority, needs to consider this rapid penetration of technologies on ships and ashore, and address these gaps by updating the STCW, accommodating the required supplementary competencies in the MASS Code, and creating the necessary training for seafarers.

As the industry explores and aims to address the different aspects of MASS and emerging technologies in relation to digitalization and decarbonization, it is important to focus on safety measures to ensure the safety of operation of advanced ships. One of these advancements is the Safe Return to Port (SRtP) protocol for the passenger ships. The SRtP was one of the elements which has been investigated in this project.

1.3 Safe Return to Port (SRtP)

The safe return to port is a safety concept that introduced for ships carrying passengers. SOLAS (Safety of Life at Sea) Chapter II-2 presented the Safe Return to Port (SRtP) to assure that ships are able to remain operational after a fire onboard or a major accident (SOLAS 1974, as amended). The regulation establishes design criteria for a ship's safe return to port under its own propulsion after a major incident, as well as to support the orderly evacuation and abandonment of the ship. The SRtP certification requires a series of operational tests, such as a simulated loss of the engine room due to fire or flood, that leads to failure of power generation, propulsion, and steering capabilities on one side of the ship. In that case, the ship should be able to maintain its steering capability from the dedicated SRtP-bridge if needed at the same time. To test the system and assess its performance it is required to perform a simulation exercise. During the simulation, the availability of essential systems for SRtP is monitored to see if any failures occur in the part of the ship intended to be used during the incident (the main and auxiliary systems). The goal of the exercise is to examine whether the ship can maintain the required essential systems in operation with only one power generation plant. Our research shows that the limited scope of the assessment procedure and the fact that the test is being performed while the ship is new and in perfect working condition, plus no passengers onboard, is a drawback in assuring the effectiveness of the proposed SRtP system. Additionally, we foresee that during its working life, the ship will progress to degree two of MASS with a reduced crew and remote operation from ROC (Koivisto & G, 2024). In that scenario, it is not clear to us, with engineers as the only crew onboard, how the SRtP system will be capable of delivering the required safety features (Koivisto & Emad, 2024). We recommend that the administrators and regulatory bodies, in the next revision of the regulation, consider the natural progression of ships into the 2nd degree of MASS with a limited number of engineers onboard to operate such a system. Additionally, we suggest that the simulation exercise that has been utilized to test the system can also be used to train the ship's future marine engineers (Emad & Kataria, 2022; Emad & Oxford, 2008).

1.4 MET - Marine Engineers - MASS

Tracing the development of autonomous and remotely operated shipping reveals a shift from initial hype surrounding unmanned ships to a more realistic application of automation that augments human capabilities in maritime operations. The role of maritime education in developing appropriate competencies under the IMO framework for the future of shipping is undeniable. Maritime education and training (MET) institutes should keep closely monitoring these changes and adapt accordingly, while continuing to operate under the IMO framework. We are in a transition period, and during this time, MASS and non-MASS ships will coexist, necessitating that MET institutes keep pace with technological advancements by updating training materials, tools, and facilities to upskill, reskill, and in some cases, deskill seafarers to operate both conventional and MASS ships. The primary focus of MET institutes should be on training mariners to be able to interact with smart and intelligent technology, to collaboratively make decisions. Human operators need to develop trust in technologies without becoming overly reliant, as the aim of technology is to augment human capabilities, especially in areas where human capacity is limited. There is a need to develop skills that enhance the understanding of technology, ensuring that as technology evolves, it remains comprehensible to humans (Lützhöft & Earthy, 2024; Mallam et al., 2020; Veitch & Alsos, 2022; Wahlström et al., 2015; Walter Colombo et al., 2021). In this regard, while pioneering groups research the technological challenges of MASS, the focus has predominantly remained on its navigation aspects. Even the draft non-mandatory MASS Code discusses the roles of the ship master and operator in relation to navigation, while the engine department receives considerably less attention.

The engine department is undergoing major transformations on two fronts: MASS and decarbonization, creating a more challenging situation for workforce adaptability (Curran et al., 2024; Ejder et al., 2024; Papanikolaou et al., 2024; Varbanets et al., 2024). For instance, most autonomous shipping research projects investigate remote and/or autonomous operations related to ships' navigation rather than the engine and machinery operations. Early projects, such as the Advanced Autonomous Waterborne Applications (AAWA) Initiative funded by Tekes (the Finnish Funding Agency for Technology and Innovation), resulted in the development of specifications and preliminary designs for the next generation of advanced ship solutions. However, the lack of involvement of marine engineers in the project led to the absence of proper equipment design that could facilitate ease of maintenance and repair (AAWA, 2016). The Project Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) was a collaborative research project co-funded by the European Commission under its 7th Framework Program, aimed at developing and verifying a concept for autonomous ships. The use of alternative fuels is growing but was advised against switching fuels as it was deemed not technically feasible (Porathe et al., 2013). In our research, we investigated M/S AURORA BOTNIA, which uses multiple fuel types—MGO, LNG, Biogas, soon methanol, and batteries of 2.2 MWh. Contrary to MUNIN's findings, our observations indicated that she has the capability of switching between fuels so smoothly that, unless indicated, the change was unnoticeable from the bridge. Another European-funded autonomous shipping project was ReVolt. The ReVolt project recommended avoiding internal combustion engines in favor of azipod thrusters powered by electric motors, supported by a single large battery pack (DNV GL, 2015).

Research on the future of seafarers, such as the HUMANE project (2018–2022) and the IAMU project No. 20190103 (2019–2020), emphasized human-centered autonomous shipping. These studies identified a need to develop or modify the competencies of maritime personnel, along with the necessity for reskilling and upskilling current seafarers. They highlighted that the demand for skills will increase, requiring an expansion in both the breadth and depth of competence profiles (Emad, 2020a, 2020b). Participants identified several key areas of competence, including maritime and technical, IT, legal and ethical, and core competencies. Core competencies include collaboration with technology, communication skills, and adaptability (Emad, 2020a; Lützhöft & Earthy, 2024).

Traditionally, the role of a ship's marine engineer is 'hands-on,' involving the repair, maintenance, and operation of various machinery onboard. However, the integration of advanced technologies may decrease the demand for marine engineers onboard and increase their demand onshore. Marine engineers will be required to remotely operate autonomous ships and repair and maintain their machinery when the ships dock at ports. The literature suggests that it is highly likely that a subset of tasks currently performed at sea will transition to land and be carried out from shore-based facilities. This transition will require marine engineers to transfer their knowledge from offshore settings to onshore environments. Consequently, this transformation in the job of marine engineers necessitates drastic changes in skills, competencies, and experience requirements (Emad et al., 2024; Koivisto & G, 2024). Currently, the global competency development regime for marine engineers is governed by the IMO’s STCW Convention. The STCW prescribes competence in four categories: marine engineering (i); electrical, electronics, and control engineering (ii); maintenance and repair (iii); and controlling the operation of the ship and care for persons onboard (iv). For autonomous shipping with unmanned ships, elements (iii) and (iv) will become obsolete, as there will be no personnel onboard. This shift fundamentally changes the role of the marine engineer from a skill-based 'hands-on' role to a 'brain-based' strategic planner (Weiss 2006; Lokuketagoda et al., 2017; Nasaruddin, & Emad 2019).

Current literature confirmed that the challenges of integrating autonomy are well understood but still need to be resolved. These challenges include, but are not limited to, the regulatory framework, responsibilities and liabilities, and the assurance of safety, security, and environmental protection. However, currently there is a lack of knowledge about what the marine engineer’s workplace will look like on autonomous ships and in ROCs. This gap has widened because current marine engine manufacturers are deploying advanced technologies in the main engines and their components to monitor the system's health through condition monitoring systems. Additionally, more and more ships (estimate >20% by 2023) are equipped with dual engines and alternative fuels, which have created additional roles and responsibilities, as well as new certification requirements. These seafarers are required to operate these new systems but have not received such training from MET institutes. The only training they have received is directly from manufacturers. As a result, there is a gap in identifying the skills and competency requirements for monitoring, controlling, troubleshooting, and maintaining the engines of future ships in terms of MASS and decarbonization. Therefore, this project aims to address this concern. First, the ROME project will provide a comprehensive understanding of the role of marine engineers in the operation and maintenance of recent new ships under construction. Second, the project will provide a comprehensive understanding of the role of marine engineers in the operation and maintenance of autonomous ships. Third, the results can help MET institutes use the findings to initiate and plan for required competency developments. Fourth, this study's results may guide regulatory bodies to make amendments and introduce new policies and procedures as deemed appropriate. In addition, the shipping companies, remote center operators, and port authorities can also benefit from this research by utilizing its outcomes to plan and prepare for when autonomous shipping becomes the norm.

2 Research Objectives

As MASS matures through pioneering industries, countries, and organizations worldwide, the roles of maritime operators both onboard ships and ashore will evolve. While stakeholders are focusing on the technological evolution and progression of MASS, the role of human operators, particularly those in the engine department—from a Chief Engineer, Second Engineer, and Electrical Engineer to ratings and engine cadet—are not receiving as much attention as those working in the navigation department. This research considers the fact that on new ships, digitalization connects various ship elements to the onshore center, paving the way for various degrees of autonomy and modes of operation towards MASS. Therefore, engine department personnel, critical players in the MASS ecosystem, need new knowledge, skills, and capabilities to interact with these intelligent systems and machines. Consequently, the ROME project is designed to investigate the future of the maritime workplace, focusing on the role of marine engineers in autonomous ships and identifying potential risks. This research aims to fill the gaps in this area, shed light on these issues, and pave the way towards safer and more efficient operations.

This project recognized the following research questions vital to be answered:

1) What will be the workplace for marine engineers in future autonomous shipping?

2) What are the scopes of marine engineers' role and responsibilities?

3) What will be the skill, competency, and experience requirements for marine engineers for monitoring, controlling, and troubleshooting the ship's engine?

4) What are the regulatory gaps and statutory actions required to make sure that the marine engineers will be ready to meet the demands of the emerging shipping industry?

The data were collected from stakeholders such as shipbuilders, flag states, classification societies, and shipping companies that ordered new ships or have newly built ships in operation. Remote operations centers like Wärtsilä and Kongsberg participated in the research. The ROME project investigated the future of the maritime workplace, the role of marine engineers in autonomous ships, and discussed their potential risks. This research project evaluated demands in the training of marine engineers and provides recommendations on how the findings of the research can be utilized in maritime education and training.

Sections 3 and 4 of this report discuss the vessels and ROCs investigated in this project as case studies within an ethnographic framework. Specifically, Section 3 provides information about the ships that are developing and implementing new technologies in terms of digitalization, decarbonization, and automation and the feasibility of future shipping. Accordingly, Section 4 of this report contains the remote operation centers that were investigated for this research. These two sections are supplementary to research methods in section 5 and complement each other as part of research methods, providing readers with proper familiarization as to why ethnography was conducted through these ships and ROCs to gather research data, in addition to utilizing qualitative questionnaires.

3 Vessels Investigated in the Project as part of Research Method

As explained in Section 2, as part of the research methods which will be explained in Section 5, the following newly built ships were visited, and their operators and marine engineers 'participated' in our research. Data were collected through ethnographic observation, qualitative questionnaires, and interviews. This section provides background information about the vessel and related information.

3.1 M/S AURORA BOTNIA

M/S AURORA BOTNIA, with IMO 9878319, built in 2021 by Rauma Marine Construction, was classified by DNV-GL. Figure 3 shows it at Rauma Marine Construction in Rauma, Finland, in 2021, ready for its final sea trial.

Figure 3 - M/S AURORA BOTNIA at Rauma Maritime Construction Rauma, Finland, 2021, - Ready for final sea trial (Source: Heikki Koivisto)

Table 1 provides information about M/S AURORA BOTNIA, including principal dimensions, passenger and crew capacity, tank capacities, and operational data for 2022.

Table 1 - M/S AURORA BOTNIA

M/S AURORA BOTNIA	
PRINCIPAL DIMENSION	Length overall 150,00m, length between p.p 137,50m, breath molded 26,00m, depth molded to main deck 8,90m, draught design 5,95m, deadweight 3500t @ design draught, GT24037, NT7249 and design speed 16 knots.
PASSENGER AND CREW CAPACITY	No. of persons onboard Crew: 65 PAX: 935, 29 passenger cabins seaside, 18 inner and two for disabled passengers. 16 drivers cabins and 46 crew cabins.
During the year 2022	During the year 2022, M/S AURORA BOTNIA had 1133 departures, passengers 267757, cars 55661 and freight units 22191. A record year, Wasa Line's turnover increased. Last year, 2023, was even better as 1 164 departures, passengers 279 590 and 63 647 vehicles.
Tank capacities	LNG 160,20m3, Diesel 476,90m3, Fresh water 442,60m3,
	Ballast 2058,40m3, Heeling tank 446,20m3 and Urea 20,50m3.

Figure 4 - M/S AURORA BOTNIA tank overview. (Source Heikki Koivisto)

Table 2 shows details of operational data for M/S AURORA BOTNIA, such as machinery and propulsion systems, battery usage, and performance under various conditions.

Table 2 - M/S AURORA BOTNIA Operational data

M/S AURORA BOTNIA
Machinery includes 4x Wärtsilä 8V31DF, 4400kW @ 750rpm; propulsion consists of 2x ABB Azipod DO1400, 5800kW; bow thruster 2x Wärtsilä VTT 14, 1500kW; and a battery pack by Leclanché, 2.2 MWh. There is a total of 4 main engines Wärtsilä 31DF: MDO, LNG, Biogas, and potentially methanol and ethanol in the future. Two main engines are in use for summertime sailing at sea, providing a speed of 17.5 knots. The 3rd engine is used for heavy ice conditions, and the 4th engine is used for Wärtsilä research at the new Wärtsilä production plant in Vaasa, Finland.
Batteries are in use most of the time on the route, maneuvering at ports with one main engine and batteries, with an additional main engine starting as needed for electricity or when the battery charge level drops to 30%. Batteries are charged during the day and night at the ports from ashore. There is also relevance between M/S AURORA BOTNIA and YARA BIRKELAND, as they use batteries from the same manufacturer. M/S AURORA BOTNIA is used as a real living lab by Wärtsilä, the leading marine engine manufacturer. Wärtsilä delivered an extra main engine/generator that was installed in the ship. They are closely monitoring and testing the engine and ship engines' operation onboard and online from their ROC. They analyze the data collected and periodically update their engine and power systems to optimize operations and produce knowledge on how marine engines can be monitored and operated from remote operation centers.

Figure 5 shows the port side battery department, and the emergency stop console as viewed from the bridge of M/S AURORA BOTNIA.

Figure 5 - The port side battery department and emergency stop console from the bridge - M/S AURORA BOTNIA (Source Heikki Koivisto)

M/S AURORA BOTNIA (Figure 6) operates a daily route between Vaasa, Finland, and Umeå, Sweden, covering 53 miles with a 6.3-mile buoyed fairway at Vaasa and a maximum speed of 15 knots, serving as a long bridge that encounters crossing traffic from the north or south on each journey.

Figure 6 - M/S AURORA BOTNIA's daily route; she is like a long bridge, meeting crossing traffic from the north or south on each journey. (Source Heikki Koivisto)

Figure 7 - Challenging navigation in ice conditions - M/S AURORA BOTNIA. (Source Heikki Koivisto)

Based on our observation and collected data, we determined that the Vaasa – Umeå line is a suitable candidate for autonomous shipping. During the high season, M/S AURORA BOTNIA sails the 53-mile trip in 3.5 hours. During the low season, they adopt slow-speed sailing to reduce fuel consumption, increasing the voyage time to 4 hours. Winter ice navigation will be a challenge for autonomous vessels. Ice conditions constantly vary according to winds and temperature. Very often, ice moves or stacks up in some areas.

Although the outermost buoys are normally removed for the winter, ice movement may cause the remaining buoys and spar buoys to be pressed under the ice surface. During wintertime, there is normally 20 to 40 cm of thick fast ice between Vaskiluoto and Ensten. The Port of Vaasa requires a minimum average ice class of IB and a 2000-ton deadweight to assist vessels. M/S AURORA BOTNIA can sail most of the time without icebreaker assistance. However, occasionally, due to wind conditions, moving ice may create dangerous situations that are managed in advance by the port authority. Last winter, the ice pressure was so strong that the shipping company canceled all departures for a day.

3.2 M/S MyStar

She was also built at Rauma Marine Construction's shipyard in Finland and delivered to her owner, Tallink Silja Line, in December 2022. Her LOA is 212.1 m, beam 30.6 m, depth 12 m, draught (full) 7 m, eco speed 21 knots, and max speed 28 knots. Her deadweight is 5,936 tons, maximum passenger capacity is 2,800, and she offers 3,500 lane meters for cars and trucks.

Main engines include 5 × MAN 5L51/60DF (5 × 9,334 kW), 2 FPP, tunnel thrusters, and bow/stern thrusters each at 700 kW. She is specially built to sail between Helsinki and Tallinn. The journey takes two hours; however, in practice, the voyage time is normally two hours and 10 minutes, as she typically departs 10 minutes earlier than the official departure time to save fuel. The Helsinki-Tallinn voyage is very popular. Helsinki became the busiest port in passenger numbers before Corona. In 2019, there were 12.2 million passengers arriving and departing annually from the Port of Helsinki. During the high season, there were 68 daily departures to Tallinn. Both ports are very popular among cruise passengers. Unfortunately, the number of cruise ships has declined from 400 to 100 this summer due to Russia's attack on Ukraine.

Figure 8 - M/S MyStar arriving at the Port of Helsinki, ready to activate six mooring pads. (Source Heikki Koivisto)

Both ports, Helsinki and Tallinn, have invested in automated mooring systems. As there are different ships using the same pier, the AIS signal is used to identify the approaching vessel, and the mooring equipment is activated accordingly. Currently, the mooring operation is controlled from the ship's bridge, with the possibility of being operated from the port. The plan for the near future is for the mooring system to operate automatically.

Figure 9 - Mooring devices, on left iPad using 4G/Wi-Fi and on right back-up using radio link. (Heikki Koivisto)

Due to the Russian attack on Ukraine in February 2022, marine traffic in the Bay of Finland has faced several challenges, including sabotage of the underwater infrastructure such as gas pipelines and electricity networks. Additionally, GPS interference and spoofing are disturbing shipping and airplane operations in the region. Our data shows that the Helsinki–Tallinn line is a suitable candidate for autonomous shipping; however, due to the reasons mentioned above, this will not be feasible at this time. Also, a challenge that needs to be addressed first is cargo safety on ferries. Reports show that there are yearly fires on the car decks, although there have been no reports of life-threatening situations as the crew is well-trained to fight the fire.

3.3 M/S Spirit of Tasmania IV & V

Newly built ships M/S Spirit of Tasmania IV, to be delivered from Rauma Marine Construction's shipyard in fall 2024, and her sistership, M/S Spirit of Tasmania V, to be delivered in the summer of 2025. These two new ships will replace the 1997 and 1998-built sisterships, Spirit of Tasmania I and II, currently serving on the Geelong–Devonport route (Australia).

Figure 10 - M/S Spirit of Tasmania IV at the build-up pier at Rauma Marine Construction's shipyard in Rauma, Finland, while M/S Spirit of Tasmania V is being built in the dry dock in the middle of the Finnish winter. (Source Heikki Koivisto)

The three ships M/S AURORA BOTNIA, M/S MySTAR, and M/S SPIRIT OF TASMANIA IV are built according to Safe Return to Port (SRtP) class notation. Although SOLAS (Safety of Life at Sea) Chapter II-2 introduced Safe Return to Port (SRtP), which requires ships to be able to remain operational after a fire onboard, it applies only to passenger ships with a length of 120 meters or more, constructed on or after July 1, 2010 (SOLAS 1974, as amended, 2014). As explained in above section, the purpose of this regulation is to establish design criteria for a ship's safe return to port under its own propulsion after a fire incident, as well as to provide design criteria for systems that are required to remain operational to support the orderly evacuation and abandonment of the ship. This requirement is important for ensuring the safe operation of the ship in emergencies as it requires that all cables are installed according to the approved drawing.

The SRtP tests require a simulated loss of the engine room in a fire, leading to failure of power generation, propulsion, and steering capabilities of the ship. The steering capability is also tested from the special SRtP-bridge. During the simulation, the availability of essential systems for SRtP is monitored to see if any failures occur in the part of the ship intended to be used during the incident (the main and auxiliary systems). The goal of the exercise is to examine whether the ship can maintain the required essential systems in operation with only one power plant. The limited scope of the assessment procedure and the fact that the test is being performed while the ship is new and in perfect working condition, with no passengers onboard, is a drawback in assuring the effectiveness of the proposed SRtP system. Additionally, we foresee that during the working life of the ship, it will progress to degree two of MASS with a reduced crew and remote operation from ROC. We predict that in that scenario, with engineers as the only crew onboard, the SRtP system will not be capable of delivering the required safety features. We recommend that while designing such a system, the administrators and regulatory bodies consider the natural progression of ships into the MASS operation systems with a limited number of engineers onboard to operate such a system. Currently, there are some national maritime regulations that set standards for the crew; for example, the first and last onboard must be the master. Also, for remote operations to take place in national waters of any country, the remote operator (equivalent to the captain) / (=captain) must be physically present in that country.

3.4 YARA BIRKELAND

The Norwegian container ship Yara Birkeland is expected to autonomously carry fertilizer in containers from the production plant in Porsgrunn to Port Brevik with zero emissions, and Table 3 explains the Principal Dimensions of Yara Birkeland.

Table 3 - Principal Dimensions - Yara Birkeland

Principal Dimensions - Yara Birkeland
LOA 80 m, beam 15 m, depth 12 m, draught (full) 6 m, eco speed 6-7 knots KYSY, max speed 15 knots, Cargo capacity 120 TEU, deadweight 3200 tons, propulsion azipull pods 2 x 900 kW, tunnel thrusters 2 x 700 kW, and capacity of batteries 6,8 MWh.

She started with a crew of five: Captain, Chief Officer, Electro Technical Officer (ETO), and two Able Seamen. Although fully crewed, this is surely the future of short-sea shipping concerning manning. In 2024, they are sailing with a Captain, Chief Officer, and an ETO. During the summer, they will start the tests to move the ETO to ROC Massterly. The ETO will perform the same operations in ROC Massterly as he would do onboard the YARA BIRKELAND, except for tightening the mooring ropes. As there are no autonomous ship class rules, DNV and Norway, as a flag state, are building rules according to several test periods. Sometimes meeting the class rules is challenging, as in the case of the Engine Control Room (ECR) when there are no engineers to attend the ECR.

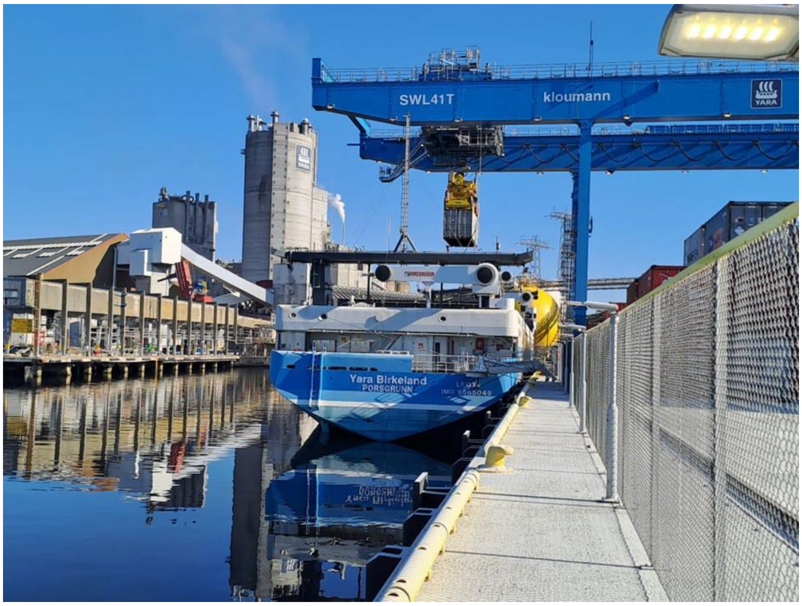


Figure 11 - YARA BIRKELAND loading full containers at their homeport Porsgrunn. (Source Heikki Koivisto)

She can carry a maximum of 120 TEUs, transporting full containers from Porsgrunn to Brevik and returning with empty ones. She sails at 06:00 in the morning and is back the same day between 16:00 and 18:00.

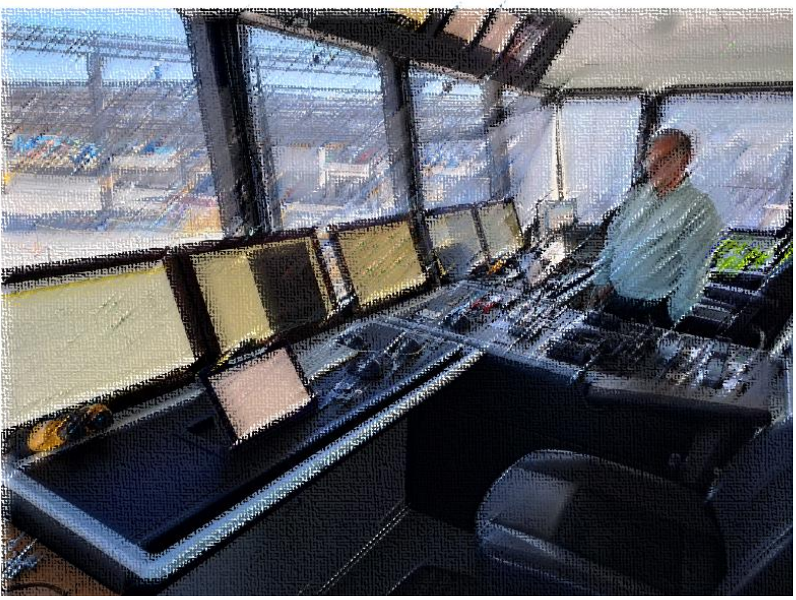


Figure 12 - The movable wheelhouse of YARA BIRKELAND looks like any bridge. (Source Heikki Koivisto)

Figure 13 - YARA BIRKELAND route from Porsgrunn to Brevik. (Source: MarineTraffic.com)

3.5 MARIT and THERESE

ASKO is a wholesaler and major distributor of groceries to restaurants and supermarkets in Norway. With a distribution hub on each side of the Oslo fjord, the company runs a significant logistics operation where trucks and road transport, including ferries crossing the fjord, are the main means of transport. Asko currently operates two sea drones: Marit and Therese. Each has a capacity for 16 trailers and the vessel type is Ro-Ro. The trailers are loaded and discharged with terminal tractors. The ports are fully automated (mooring and DC charging) and synchronized with the vessels' automated docking process. Similar to Yara Birkland, the implementation of an uncrewed operation is planned in several steps.

Figure 14 - Seadrone Therese moored at Horten, Norway. (Source Heikki Koivisto)

4 Remote Operation Centers (ROCs)

In this research, the research team members visited three advanced remote operation centers (ROCs) and conducted interviews and ethnography with their engineers and operators. Wärtsilä and Kongsberg, technology providers, remotely monitor their manufactured engines installed on different ships worldwide. They have the capacity but currently do not remotely operate their manufactured engines; however, depending on the type of contract, they provide consultation and feedback to engineers onboard and remotely assist them in the safe and optimal operation of their engines. Although both companies are marine propulsion system providers, they specialize in two distinct sub-fields: Wärtsilä is a leading manufacturer of internal combustion marine engines, and Kongsberg specializes in electric propulsion systems and azipods. Masterly, on the other hand, is established to provide remote operation services for MASS ships and is currently the ROC for Yara Birkland.

4.1 Wärtsilä

Wärtsilä, a Finnish company, manufactures power generators and marine engines for different sizes of ships. In May 2022, they opened a Smart Technology Hub in Vaasa, Finland, where, besides manufacturing engines, they set up and operate their remote operations centers. Wärtsilä has four such centers across the world, remotely monitoring about 3,500 engines online 24/7. They installed sensors and industrial IoT (Internet of Things) in critical parts of their products to allow them to collect a seamless stream of data from the operation and environment of their machines. These data feed into their sophisticated intelligent algorithm to allow their engineers to closely monitor the operation and diagnose problems and malfunctions even before they occur. It is partly done by using the Digital Twin technology, which allows direct connection and interaction with machines in a virtual environment.

Figure 15 - Wärtsilä remote operation center in Vaasa, Finland. (Source: Heikki Koivisto)

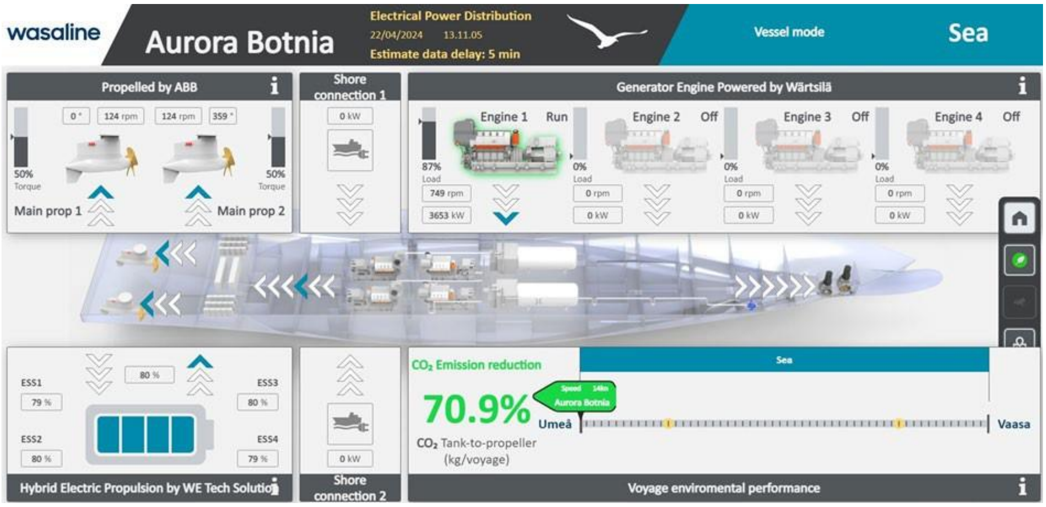


Figure 16 - Example of remote monitoring M/S AURORA BOTNIA engine operation from Wärtsilä Centre. (Source: Heikki Koivisto)

4.2 Kongsberg

Kongsberg's "Health Management" services are their ROC for monitoring their products installed on board ships. Their system is based on data collected by IoTs installed on their machines at the time of production. Data is then transmitted, collected, and analyzed via Kongsberg's connectivity solution and Global Secure Network to reduce the security risks associated with their assets. "Health Management" allows continuous evaluation of equipment condition for all equipment estimated to be critical for the operation of their machinery and propulsion system. This also allows for better-planned service interventions and minimizes operational disruptions. This service is based on long-term trends of data received from operating machinery. From the system, the shipping company also receives operational profiles, speed profiles, equipment load profiles, engine fuel consumption, and performance. Based on system analysis, operations can be optimized, emissions reduced, and benefits maximized from battery installations. Today, Kongsberg is monitoring more than 500 propeller units all over the world.

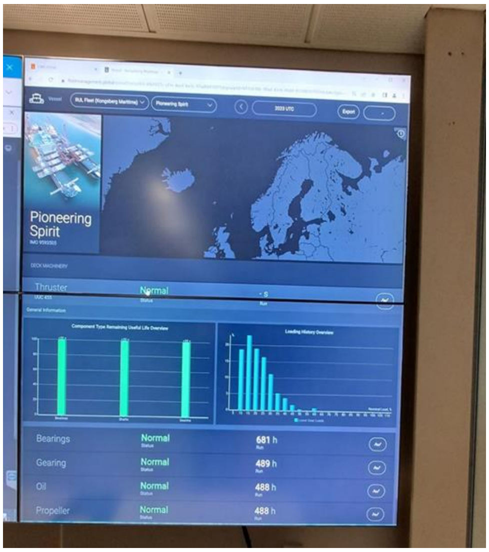


Figure 17 - Connection M/S PIONEERING SPIRIT (Source: Heikki Koivisto)

Figure 18 - Kongsberg Health Management Centre in Rauma, Finland. (Source: Heikki Koivisto)

4.3 Massterly

Kongsberg Maritime and Wilhelmsen have established a joint corporation, Massterly, which is set up to operate vessels such as the Yara Birkland, Asko AutoBarge, Reach Remote, and others from a Remote Operations Centre (ROC). The ROC, located in Horten, monitors and supervises the vessels' operations. It is equipped with several workstations and is designed to monitor and control multiple vessels for several owners simultaneously. In April 2024, Massterly received their own ISM DOC as earlier it was under Wilhelmsen's ISM, covering more than 400 ships.

Figure 19 - ROC Massterly in Horten, Norway. (Source: Heikki Koivisto)

5 Research Method

In the first stage of the project, research team members from two IAMU partner universities; Satakunta University of Applied Sciences, Finland (SAMK) and University of Tasmania's (UTAS) Australian

Maritime College, Australia (AMC) discussed their expertise and based their discussions on previous research outcomes and current ongoing projects within the scope of research objectives. In the second stage, to gain a better understanding of the future of work and the role of marine engineers, the research team members designed a qualitative research project titled 'Investigating the future of the maritime workplace and the role of marine engineers in autonomous ships.' The project's short title is 'Marine Engineering Training for the Future,' commonly known as the ROME project. The ROME project started in May 2023. The work was divided into six work packages (WP1 to WP6) in which both partner universities participated.

WP1: Study the status of remote operations onboard two recently built ships. M/S AURORA BOTNIA and M/S MySTAR, Safe Return to Port (SRtP) classification notation, M/S AURORA BOTNIA as a case study for advanced ships.

WP2: Establish a comprehensive understanding of the role of marine engineers in the operation and maintenance of autonomous ships. This work package started in September 2023 with a F2F workshop arranged in Finland linked to IAMUAGA23.

WP3: Recommendations to MET institutes to take initiative and make plans for required competency developments: The second F2F workshop in Tasmania was presented at the ICMAR Nav Conference.

WP4: The first TT-Line (an Australian shipping company) newbuilding ship to be delivered from Rauma, Finland in summer 2024 offering the latest research platform to reflect earlier findings.

WP5: Preparing interim progress and the final report in addition to dissemination of the results through the Journal of Maritime Affairs.

WP6: Project coordination administration from the beginning to the end of the project.

The project aimed to provide a comprehensive understanding of the role of marine engineers in the operation and maintenance of future ships. In the next stage of research, the team began performing a systematic literature review. Thus, to address the multi-dimensional impact of digitalization,

decarbonization, autonomous shipping, and advanced technology on seafarers, and more specifically on marine engineers as a goal of this project, the research team members utilized the Systematic Literature Review (SLR) to classify relevant articles, analyze, and synthesize results from the current literature to gain broader insights into this emerging domain and address the gaps in relation to the new emerging training requirements of marine engineers.

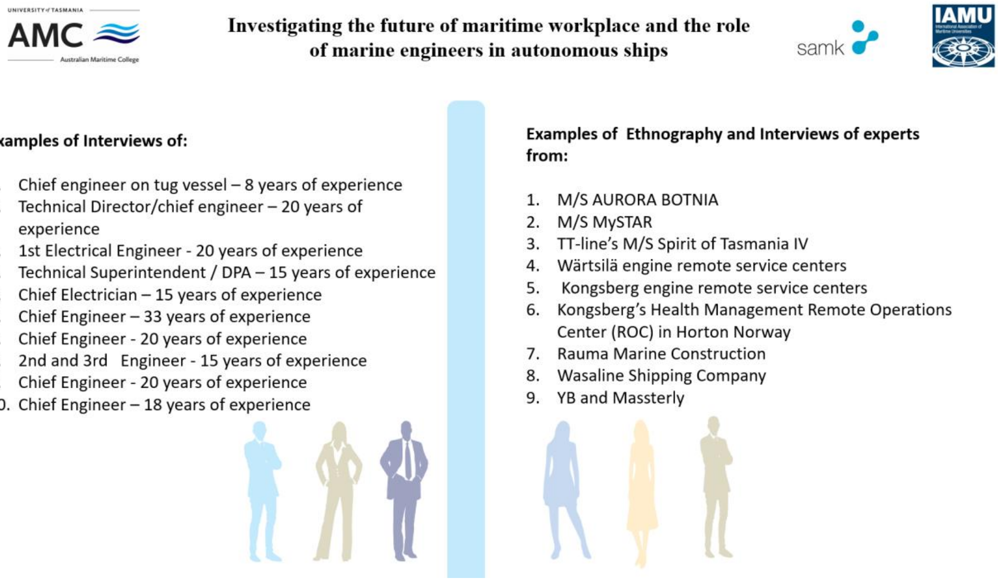
Major electronic academic databases including Scopus, Web of Science, and ScienceDirect were utilized to identify relevant articles. Multiple keywords such as Industry 4.0, Industry 4.0 technologies, advanced technologies, autonomous shipping, MASS, marine engineers, MET, training requirements, STCW, MASS Code, Remote Operation Centre, human element, Safe Return to Port, digitalization, decarbonization, transition period, unattended engine room, maritime education, and their synonyms were used. The results of the search included journal articles, book chapters, reports, conference papers, and regulatory websites through keyword combinations in different search engine platforms.

The combined search outcomes generated 132 articles in the identification phase. The screening and eligibility process was conducted to filter results, such as analyzing titles of articles, abstracts, conclusions, and skimming the main body to eliminate duplicated and disqualified results. At the end of the process, the total number of articles was reduced to 72. According to the SLR outcomes, it was evident that marine engineers, in the context of training requirements for future shipping and MASS, have not received as much attention compared to other maritime workforces.

In the next stage of research, based on the results of the systematic literature review and discussions, the research team members developed qualitative interview questions, designed an ethnography study, identified target groups, and crafted a follow-up qualitative questionnaire to gather all related information for a comprehensive result. The target group of experts to collect data from included various stakeholders with different positions, ranks, and a wide range of expertise with approximate number of 25 people, including:

- Shipowners,
- Seafarers,
- Classification Societies,
- Technology Providers,
- Shipbuilders,

In addition to qualitative interviews, to provide contextual data, the research team conducted an ethnographic study of the status of remote operations at three ROCs and onboard two newly built ships, M/S AURORA BOTNIA and M/S MySTAR. Additionally, data was collected during the construction of TT-line's M/S Spirit of Tasmania IV. These three ships were utilized as case studies for future shipping, as all three were equipped with the latest technologies and have the class notation Safe Return to Port (SRtP). Valuable data was collected during visits to Wärtsilä and Kongsberg engine remote service centers. Furthermore, Kongsberg's Health Management Remote Operations Center (ROC) in Horten, Norway, provided insight into the challenges of remote operations and the additional training needed for operators working in these centers. Section 3 and 4 of this report briefly provide information on ships and ROCs that mentioned here as part of research method ethnography. Figure 20 provides just examples of the experts and places where the target groups were interviewed, and ethnography was conducted.



Investigating the future of maritime workplace and the role of marine engineers in autonomous ships

Examples of Interviews of:

1. Chief engineer on tug vessel – 8 years of experience
2. Technical Director/chief engineer – 20 years of experience
3. 1st Electrical Engineer - 20 years of experience
4. Technical Superintendent / DPA – 15 years of experience
5. Chief Electrician – 15 years of experience
6. Chief Engineer – 33 years of experience
7. Chief Engineer - 20 years of experience
8. 2nd and 3rd Engineer - 15 years of experience
9. Chief Engineer - 20 years of experience
10. Chief Engineer – 18 years of experience

Examples of Ethnography and Interviews of experts from:

1. M/S AURORA BOTNIA
2. M/S MySTAR
3. TT-line's M/S Spirit of Tasmania IV
4. Wärtsilä engine remote service centers
5. Kongsberg engine remote service centers
6. Kongsberg's Health Management Remote Operations Center (ROC) in Horton Norway
7. Rauma Marine Construction
8. Wasaline Shipping Company
9. YB and Massterly

Figure 20- Examples of Research participants and Ethnography – ROME Project

The ROME research project utilized thematic analysis to explore and understand the data collected from qualitative interviews and ethnography. This method assists the research team in analyzing the findings derived from the participants' experiences, thoughts, behaviors, and expectations across the dataset. The method follows the below steps to extract the results (Kiger & Varpio, 2020):

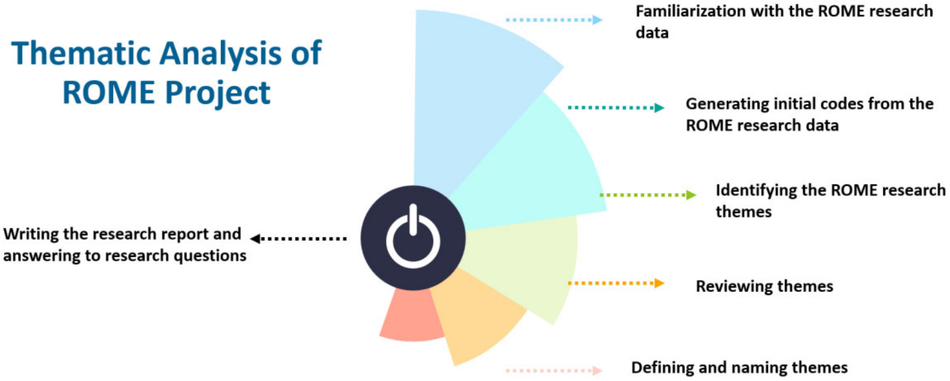


Figure 21 - Thematic Analysis of ROME Project

As shown in Figure 21, the research team members transcribed the entire ROME project data verbatim and familiarized themselves with the data, which was collected through semi-structured interviews and ethnography. In the next phase, the researcher retrieved the initial codes from the ROME data. Then, the researchers extracted major codes, which include workplace evolution, role expansion of marine engineers, training gaps, certification gaps, and regulatory gaps. The researcher rechecked the supporting data to confirm each theme's coherence and consistency with the data. In the last phase, the researcher addressed the research questions and answered the identified gaps and wrote the final report.

6 Results

The ROME project is designed to investigate the future of the maritime workplace and the role of marine engineers in the future shipping. The research goal is to evaluate the future demand for training marine engineers and provide recommendations on how it can be achieved through maritime education and training (MET). We studied the onboard state of a number of newly built and under-construction ships that utilize advanced technologies. Data was also collected from stakeholders such as shipbuilders, seafarers, flag states, classification societies, and shipping companies with new ships in operation. Remote Operations Centers like Wärtsilä, Kongsberg, and Massterly were also visited and consulted. The results of the research are based on data collected through semi-structured interviews, qualitative questionnaires, and ethnographic observation.

As explained, Industry 4.0 technological implementation across all industries is fundamentally transforming services, products, and operational methods. The marine industry, as the backbone of global commerce, needs to adapt to these technological changes to maintain its relevance and competitiveness. To achieve this, the maritime industry is gradually adopting the double-D trends known as Digitalization and Decarbonization, which are intertwined and paving the way toward the realization of remotely operated and autonomous ships. This shift toward digitalization, decarbonization, and autonomy is transforming the work and workplace onboard ships, both in the deck and engine departments, and is creating a new technology-oriented workplace ashore. Alongside the shift toward autonomous shipping, the move toward decarbonization has introduced hybrid and intelligent solutions for ship engine design and fuel flexibility. Accordingly, ship engine manufacturers are also utilizing Industry 4.0 advanced technologies, including AI, IoT, cloud computing, additive manufacturing, and digital twins to provide condition monitoring and health monitoring of engine room machinery and equipment, including but not limited to main engines, auxiliary engines/generators, pumps, fuel systems, steering gear, control and monitoring systems, and electrical systems.

Today majority of marine engineers are not fully aware of the changes that Industry 4.0 transformation toward MASS and more sustainable and greener operations is bring onboard ships and ashore. This is because the current MET system does not train marine engineers to work with advanced machinery and upcoming intelligent technologies. While the industry is moving toward changes and engine manufacturers, shipping companies, and ship building companies believe that using advanced technologies such as AI, autonomy, remote monitoring systems, and health monitoring systems can optimize marine operations and improve shipping efficiency. This shift calls for updates in training regulations, programs, tools, and certification standards to embrace this transformation and leverage the benefits of automation and decarbonization as intertwined trends. This research aimed to answer the research questions, which are detailed in the following four sections.

6.1 Section 1: What will be the workplace for marine engineers in future autonomous shipping?

This question aims to predict the workplace of marine engineers, which is being shaped by technological integration, specifically in the realization of MASS and green shipping. Participants in the research, both directly and indirectly, claimed that the advent of MASS technologies aligned with decarbonization will influence not only the roles and responsibilities but also the physical locations of marine engineers as they will work either onboard MASS degrees 1, 2, or 3 vessels or in Remote Operation Centers (ROCs).

Additionally, a new theme emerged suggesting that in near future marine engineers will work for marine engine manufacturing companies and will provide their services through Health Monitoring/Management and Condition Monitoring Centers. They will become integral to the MASS operation. As the engine department on MASS evolves into an intelligent system, the future marine engineers would be knowledgeable and capable of working onboard MASS, in ROCs, or as the employees of engine manufacturers.

Our data shows that the engineers at remote operation centers of engine manufacturers are not necessarily marine engineers. Given the existing shortage in the workforce market for qualified marine engineers, manufacturers resort to recruiting engineers from various fields and train them in-house. This approach by engine manufacturers may, in turn, partially address the shortage of marine engineers in the future.

As discussed, the advancement toward MASS will gradually evolve the nature of work, requiring marine engineers to upgrade their existing skill sets for troubleshooting and maintenance techniques to incorporate the integration of new and advanced tools, systems, technologies, and fuels. With the gradual progression of MASS to degrees two and three, seafarers will need to effectively collaborate and communicate with new team members who may be on board MASS, in ROCs, or at engine manufacturing companies’ Health and Condition Monitoring centers, following emerging communication protocols. Ultimately, the conventional physical workplace onboard ships will gradually morph into Remote Operation Centers (ROCs), while the number of seafarers onboard MASS decreases to near zero.

> *“When YB started 2022 there were five crew onboard. Captain, chief officer, electro technician officer and two AB:s. Today they are sailing with crew three, AB: s are off. Next phase during summer 2024 is that these three crews will stay onboard, and another ETO will be in ROC Massterly.” - (YARA BIRKELAND remote operator - project interview)*

The Ship and ashore sectors' physical workplaces will evolve into high-tech environments or a new form of Cyber-Physical Systems (CPS) through the integration of advanced and sophisticated technologies. These technologies require marine engineers to have knowledge of and be able to work with electronics, data analytics tools, software management, remote control technology, condition monitoring systems, engine components lifecycle services, digital technologies, digital twins, AI, automated, and autonomous systems. This highly advanced workplace requires marine engineers who are capable of overseeing intelligent systems and machines, interpreting data, and making real-time decisions. Thus, in addition to their traditional skill sets, their roles will require a blend of mechanical expertise and proficiency in digital and intelligent systems to handle the complexities of the modern workplace onboard MASS and in ROCs. While the integration of advanced technologies in ships will minimize the need for the physical presence of engineers onboard, this shift will bring more complexity for engineers who work remotely and even for those who may stay onboard the ship. Remote workers will need to simulate and predict the behavior of ship engine components through software and data analytics tools to be able to make informed operational decisions. Moreover, the transition toward decarbonization will introduce new types of fuels that require new engine designs and other related components. As stated by engine manufacturers, dual fuel engines, such as gas/diesel, battery/diesel, and Hydrogen/battery as well as alternative fuels with redundancy, will become more prevalent. Thus, the workplace onboard ships will gradually change, requiring new safety and security tools, technologies, and regulations. Additionally, participants stated that soon, other types of fuels, such as ammonia, methanol, and hydrogen will be used, leading to the emergence of a new type of engine with distinct technologies.

> *"As automation systems are advanced and utilized in processes that have not previously been automated, marine engineers and electricians will need to have a great understanding of the technology used on board, and this will need to be adopted into future training. There will still be a requirement for maintaining good knowledge and ability for mechanical systems, and how they integrate with the automation on board." – (Chief Engineer with 18 years of experience)*
>
> *"Skill will need to be diversified to deal with fault finding the autonomous software" – (Chief Engineer with 20 years of experience)*
>
> *"They have to learn basic academic training, in addition to the new digital skills" – (Wärtsila - Ethnography Notes)*
>
> *"In our company Massterly, the workspace as now will be in Horten in the ROC center there. However, the company are expecting a large growth and see the needs for a bigger place and possibilities for international expansion. So, in the future there might be many ROC centers around the world." - (YARA BIRKELAND project interview)*
>
> *"Working from a remote location away from the vessel itself will bring new challenges that we did not have before." - (YARA BIRKELAND project interview)*

Figure 22 - Some Features of Future Workplace for Marine Engineers – ROME Project

In summary, our data shows that the workplace of marine engineers will embrace the following transformations:

- The gradual shift from onboard roles to remote supervisory, operation monitoring, and remote troubleshooting roles
- New workplace with advanced monitoring tools and technologies such as health monitoring/condition monitoring of engine components, advanced sensors, and AI-driven diagnostics systems
- Reduced number of crew and new team members in ROCs
- New design of main engines and auxiliaries with alternative fuel
- Real-time data access and remote diagnostics in ROCs
- New workplace with the capacity to predict the behavior of ship components
- New workplace with requirements for understanding and skill sets in mechanical, electronics, and digital systems.
- New Workplace with requirements for data analysis and real-time decision-making capacity with the support of AI.

6.2 Section 2 - What are the scopes of marine engineers' roles and responsibilities? What will be the skill, competency, and experience requirements for marine engineers for monitoring, controlling, and troubleshooting the ship's engine?

These two questions aim to address how marine engineers' roles and responsibilities are expected to evolve to fulfill their professional capacities with the realization of MASS, and what skill sets they will require. As stated in Section 1, the integration of advanced technologies such as new sensors, intelligent monitoring systems, and new types of fuels, along with other advanced digital technologies, has the capacity to transform the traditional marine engineers' operational duties, maintenance responsibilities, safety management of the engine department, administrative tasks, and supervisory roles. Data analysis shows that the core traditional roles and responsibilities of marine engineer's onboard ships and in port, including maintenance of ship machinery, troubleshooting, safety checks, and repairs, will remain the same. However, with the integration of new and advanced technologies, alternative fuels for main and auxiliary engines, their roles and responsibilities onboard ships and onshore will evolve and expand to include strategic monitoring and controlling data from health monitoring systems.

> *"The scope and responsibilities of the marine engineer did not change, just the way how it's done have."*
> *- (YARA BIRKELAND project interview)*
>
> *"System monitoring and recording of live data." - (Chief Engineer with 20 years of experience)*

In this evolving workplace, the importance of basic, fundamental mechanical skills and competencies still is critical for engineers to diagnose mechanical problems. Moreover, they need to retain practical hands-on skills to perform essential tasks and repairs as required. Gradually, with the constant integration of new systems and technologies, they also need to gain an understanding of all electronic and digital systems.

> *"marine engineers need the basic skills mechanics to understand the working principles." "Basic skill in power electronics or electrical distribution and basic knowledge in welding, machining and some general knowledge is essential." – (Wasaline Shipping Company - Ethnography Notes)*

As the new and intelligent systems and machines introduce new roles, they require skills such as data analysis for diagnostics, predictive maintenance, and system optimization to extend the lifecycle of the systems. The adoption of advanced technologies in terms of MASS and decarbonization requires seafarers to engage in data-driven decision-making situations rather than purely mechanical tasks. Engineers need to adapt to working with advanced technologies and learn to collaborate with AI to interpret data from various IoT and advanced systems for diagnostics and operational efficiency. However, the roles and responsibilities of marine engineers in the ROC will be slightly different and more complex, as they will need to oversee, monitor, and control ship operation systems remotely, which presents new challenges and requirements, and accordingly necessitates new solutions.

> *"Working from a remote location away from the vessel itself will bring new challenges that we did not have before." - (YARA BIRKELAND project interview)*

This relocation to the ROCs redefines the interaction of marine engineers with ships, transforming them into intelligent systems comprising various categories. It also alters their interactions with the crew onboard MASS, ROC members, and even other ROCs. They need to develop new skills in communication, remote monitoring, and control, operating without being physically onboard the ships. This new ecosystem of work requires them to learn to rely on and trust advanced technologies and the information they receive from non-human agents (AI), and to understand the new systems' capacities and limitations through active involvement.

They must work with systems such as health monitoring or condition monitoring to stay alert to potential problems and accordingly plan for preventative maintenance. New and advanced simulation training for emerging new ships and modeling ports in terms of remotely bunkering, berthing large ships, or loading and unloading cargo is becoming essential. Engineers need to develop new skill sets and become competent through these training programs. Generally, these training programs with new tools and facilities help marine engineers as operators to gradually develop skills by handling different scenarios, allowing them to adapt to evolving port and ship conditions and technological changes.

> *"In terms of simulator training, we're trying to run a project for modelling the ports and new ships coming in and out of the port…." – (Rauma Marine Construction - Ethnography Notes)*

As ships become increasingly embedded with sophisticated technologies throughout the entire vessel, and more specifically in the engine department, the physical and cyber worlds become more integrated, forming a unified system to provide feedback loops that enhance safety, security, and efficiency. This is why awareness of cybersecurity protocols will become an integral part of a marine engineer's role. In the new technology-oriented workplace, where cybersecurity is becoming an inseparable pillar of MASS operations, marine engineers must be knowledgeable enough to address general cybersecurity issues and, more importantly, work closely with maritime cybersecurity specialists to address cyber concerns and potential attacks. While marine engineers are not expected to become cybersecurity experts, a fundamental understanding of how to protect systems from potential cyber risks will be critical. Additionally, marine engineers need to download, upload, and interact with new software, create backups, and transfer data between systems.

> *"Need to be more aware of the risks in cyber security. Rely less on firewalls. No OT systems should be connected physically to external or internal IT systems." - (Chief Electrician)*
>
> *"…be able to know how to download some software and updates into controller or taking a ghost copy of software of some components so that they can transfer them to the next if the system breaks down to transfer to the next PC or a PLC (PC is Personal Computer, while PLC stands for Programmable Logic Controller)" – (Wasaline Shipping Company- Ethnography Notes)*
>
> *"They will need to recognize and understand the risks around cyber-security." – (1st Electrical Engineer- 20 years of experience)*
>
> *"Need to be more aware of the risks in cyber security." - (Chief Electrician, 15+ years' experience)*

Moreover, marine engineers need to analyze data collected from various engine department components, such as rotating machinery, performance monitoring, and fault detection. They may use data from different sensors, oil quality monitoring systems, and torque measurement tools to plan for preventative maintenance. Expertise in AI and machine learning algorithms is crucial for accurately handling large data analyses. The integration of electronic systems into ships introduces new roles to manage and troubleshoot the electronic components of control systems. Additionally, marine engineers will gradually work with alternative fuels such as LNG, solar, wind power, ammonia, methanol, hydrogen, and electric propulsion systems, which will define new roles and responsibilities. These new roles will require them to ensure interoperability among different digital and physical systems onboard MASS and in the ROC, which may come from various manufacturers and technology providers. The advancement of technologies and new types of fuels will necessitate an expansion of marine engineers' roles and responsibilities. New roles include managing the efficiency of new fuels and understanding how to optimize new propulsion systems.

In terms of new types of fuels, the emergence of new safety and operational protocols, and sophisticated technologies, marine engineers need to be knowledgeable about IMO and classification societies' environmental regulations, standards, and best practices. They need to be aware of statutory requirements to ensure compliance with regulations and standards.

> *"dual-fuel engines are going to become more prevalent. Engineers are going to get gas experience or some alternative fuel."- (Rauma Marine Construction - Ethnography Notes)*
>
> *"they are designing today for the future while the rules and regulations are changing... Wärtsilä supporting their customer to convert their engine to be able to use other fuels in the future." - (Wärtsilä - Ethnography Notes)*

More importantly, marine engineers onboard MASS and, in the ROC, need to adapt to advanced technologies in the form of monitoring tools to diagnose potential problems and rectify issues such as changing bearings or maintaining the system. The research data shows that while the integration of advanced technologies will provide better monitoring systems and, in some cases, allow engine manufacturers to provide critical maintenance or cybersecurity specialists to keep the system safe, the roles and responsibilities of marine engineers will more accurately be described as a 'Jack of all trades.' This role requires a broad skill set to handle various tasks, including solid mechanical tasks and electronics maintenance and repair. Additionally, in some geographical situations, onboard engineers may not have satellite or internet connections, requiring them to be independent, self-reliant, and knowledgeable enough to solve issues on their own. This necessitates an understanding of the electronic, mechanical, physical, and digital aspects of the system to maintain it without external support, by referring to health monitoring systems or other monitoring tools and data sources.

> *"One of the key challenges is the over reliant on internet connectivity, either terrestrial or satellite connection. The key always is not too dependent on the internet quality or internet connection. So, they equipped the ships to have screens on board and doesn't need any internet connection." - (Kongsberg condition monitoring center-Ethnography Notes)*
>
> *"Engineers must be adept at identifying faults and taking corrective actions." - (Chief Engineer - 33 years' experience)*

Moreover, the data analysis shows that with the integration of digital and physical workplaces and close collaboration with different groups of stakeholders, marine engineers onboard MASS, those in the ROC, and mechanical engineers in manufacturing will, in some scenarios, need business, product, and system knowledge to maintain the systems and business operations. Some examples of these categories of knowledge, as provided by Wärtsilä, are listed below:

- Mechanical Design and Operation
- Engine performance evaluation
- Fluid chemistry
- Engine and plant control system
- Future fuels and safety
- Technical communication

- Operational Support toolchain
- Legal & financials

The research participants refer to the Safe Return to Port (SRtP) system, mentioning that while this system is compulsory for passenger ships, its concept may be adapted for autonomous shipping in non-passenger ships in various ways to meet specific requirements. One of the main aspects of the SRtP system is related to redundancy, which is closely linked with MASS. The principles of SRtP provide redundancy for engine and bridge operations, as well as various emergency and contingency plans and procedures. Marine engineers need to gain comprehensive knowledge and expertise in different ship systems and layouts to meet the requirements of SRtP.

> "*Safe return to port means that no matter what, we can get the ship back to a port with enough fuel to do that. SRtP even says how much food you got to have and even the requirement to have operational air conditioning." - (Rauma Marine Construction - Ethnography Notes)*

As the scope of marine engineers' roles and responsibilities evolves, effective and diverse forms of communication will become increasingly important, differing from traditional forms of communication. This communication could take the form of direct dialogue, ticketing systems, chats, and emails to inform, report, or solve problems. This new role will require them to interact with team members onboard the ship and, in the ROC, as well as with third parties for maintenance purposes, emergency situations, and monitoring system operations.

> *"Traditionally, manufacturers always send a service engineer on board to realise, what's wrong with that equipment. But now we have means to analyze a lot of that beforehand before sending anyone on board then you can already plan what you're going to do there."- (Kongsberg Condition Monitoring Centre- Ethnography Notes)*

Finally, the research data shows that in the transition period, marine engineers onboard MASS and in ROC need to have cross-functional skills that combine a mix of traditional solid foundational mechanical skills with emerging digital skills to manage the components of monitoring systems under the framework of CPS ecosystems.

> *"When going on cargo vessels engineers will need the basics skills of mechanics." (Wasaline Shipping Company- Ethnography Notes)*

The scope of marine engineers' roles and responsibilities will evolve and transform from direct control of the system to strategic oversight and decision-making in collaboration with intelligent machines and systems that support and augment engine department operations. In summary, the new roles and responsibilities, along with the necessary skills and competencies, include the following:

- Data interpretation and analysis
- Providing diagnostics and proactive maintenance
- Remote monitoring and control and troubleshooting
- Dual-Fuel engine knowledge
- Machine learning
- Proficiency in managing software.
- AI and IoT and other advanced technologies integration
- Safe return to port systems
- Mechatronic skills (combination of mechanical engineering, electronics, computer science, control engineering)
- Managing the operational health of engine components
- Electronic and digital system management (Operational flexibility)
- Practical and principal mechanical skills (hands-on experience)
- Alternative fuels and propulsion system management

- Deep understanding of digital and electronic technologies
- Cybersecurity and data protection
- Managing and controlling fuel efficiency
- Knowledge of lifecycle services
- Real-time decision-making and intervention
- New safety and security protocols concerning new fuels and electronic and digital systems
- Fuel-Saving measurement
- Adaptability and continues learning attitude
- Self-reliance and communication, and collaboration with specialists (Collaboration with contractor)
- Meeting regulatory bodies' requirements in terms of new fuels and technologies (Statutory and regulatory knowledge)
- Telecommunication and leadership
- Blending traditional with emerging skills

Figure 23 – Examples of Evolving roles and required skills & competencies for marine engineers – ROME Project

6.3 Section 3 - What are the regulatory gaps and statutory actions required to make sure that marine engineers will be ready to meet the demands of the emerging shipping industry?

This question aims to identify the shortcomings in the regulatory framework that hinder marine engineers from being adequately prepared for evolving shifts in the industry. Research participants generally believe that significant regulatory gaps exist due to current regulations not being designed for the emerging new class of ships equipped with sophisticated technologies, MASS, and alternative fuels. The current regulatory regime is predominantly designed for manned ships, which highlights a critical need for statutory actions and changes. These changes should involve creating new standards, regulations, amendments, or additional guidelines, sometimes accompanied by new certification requirements. The industry is rapidly shifting toward integrating advanced technologies and alternative fuels into ships and the ashore sector, while regulatory bodies are still lagging, affecting the policies and training programs of Maritime Education and Training (MET) institutes. Although the regulatory side is not keeping pace with industry advancements, MET institutes need to adapt to emerging technologies within the framework of the IMO. Consequently, METs may need to collaborate directly with engine manufacturers and providers of sophisticated technologies to train marine engineers in new principles and emerging alternative fuels.

> *"Our school system has to adapt also. Manufacturers learning courses be important of way towards autonomic vessels. This needs lot of together doing and standard system." - (Chief Engineer - 8 years at sea)*

> *"Qualification requirements lag behind fast development of automation." - (Chief Engineer - 20 years at sea)*

The research data highlighted a gap between the training provided by MET institutes and the hands-on training required in actual workplaces. In some cases, marine engineers need to obtain specific certifications from classification societies to work on ships equipped with new engine designs, dual fuels, and software and hardware designed for the condition or health monitoring systems of ship engine components. These gaps stem from existing regulations that are inadequate to equip seafarers to handle the challenges during the transition period toward remote, autonomous, and green shipping. Moreover, the research data emphasized the role of the IMO as the leading regulatory body in promoting standardization in the design and principles of technology and engine components to reduce heterogeneous trends. While some engine manufacturers have designed systems that communicate with each other and collect information—achieving interoperability—it is still highly recommended that all providers follow standardized methods to reduce the risk of disparate systems and varying operational methods and principles. The harmonization of new technologies and advanced engines and systems through regulations will assist in the international deployment of autonomous shipping technologies and the movement toward decarbonization. More importantly, it will smooth the transition and decrease the level of potential safety and security risks.

> *"This is another thing you cannot have a ship which runs on different products from different companies. Because now everything has to talk to each other. And if they're coming from different companies, different platforms." – (Kongsberg Condition Monitoring Centre- Ethnography Notes)*

> *"Our system can talk to whatever system and collect the data from whatever system, that's a requirement." – (Kongsberg Condition Monitoring Centre- Ethnography Notes)*

Moreover, the data shows that all aspects, and more importantly, the safety aspects of emerging fuels, need to be addressed by the IMO, followed by timely training provided by MET institutes. As discussed in previous sections, the nature of the safety, security, and operation of the main engine and its components will evolve with the introduction of alternative fuels. Marine engineers onboard smart ships, MASS, and in Remote Operation Centers (ROCs) need to know how to monitor, control, and respond to emergencies.

> *"what is needed in the future is also the safety aspect, alternative fuels. Challenge for alternative fuels. There are always risks. For example, Ammonia is poisonous. that's one thing to consider." - (Kongsberg Condition Monitoring Centre- Ethnography Notes)*

The research data highlighted that technologies for reducing human presence onboard ships and instead working from ROCs are already available and have been tested for feasibility through various projects in the engine department. However, regulatory and financial challenges, as well as a lack of skilled workforce, limit the adoption of these new technologies in terms of MASS and decarbonization. To accelerate the adoption and integration of new technologies, regulatory bodies need to accommodate the different aspects of these technologies and fuels by revising, updating, and creating standards and regulations. These updates will change the training time, process, requirements, and certification process for marine engineers and will also evolve the staffing and manning models onboard MASS and in the ROCs.

> *"The Marine Engineers does per now do not require any changes. There is however a ROC operating course in the making who probably will be some type of certification on the same line as DP certification. The gaps come to the requirements to have an ETO and/or engineer onboard a vessel." - (YARA BIRKELAND project interview)*
>
> *"Autonomy that might become reality on some routes but will be too expensive to maintain generally, the thing that is currently speaking for autonomous ships are lack of personnel not economy" – (Chief Engineer – 20 years of experience)*

As the industry transitions toward MASS and green shipping (decarbonization), marine engineers should undergo an adaptation process through new and updated educational and training programs that focus on electronic systems, advanced technologies (AI, 3D printing, additive manufacturing), alternative fuels, new forms of safety and communication, automation, and software management. Regulatory bodies are responsible for creating standards that ensure engineers receive proper training in both traditional mechanical skills and modern technological proficiencies. Additionally, the research data highlights the importance of effective collaboration with industry suppliers for specific system training and addressing the diversification of the main engine and related systems.

As discussed above, the current qualifications required for marine engineers are lagging behind the rapid progression of MASS technologies and the shift toward decarbonization. There is a critical need to update certification and qualification standards to keep pace with these advancements.

> *"Qualification requirements lag behind fast development of automation." (Chief Engineer, 20 years at sea)*

In this regard, the research data in this section highlighted the following certifications for marine engineers during the transition period toward safer and more efficient operations:

- Dual-engine operation certificate
- Safe Return to Port certificate
- Cybersecurity training certificate
- Remote monitoring and controlling certificate
- Advanced safety training certificate
- Environmental compliance certificate
- Electronics and software management certificate
- New certification for mechatronic competencies

Moreover, the research data suggested regulatory updates and statutory actions for the following areas:

- Updating emission regulations and training requirements
- Revising classification standards concerning MASS and decarbonization
- Updating and creating safety standards for new emerging fuels
- Incorporating advanced technologies into regulations
- Updating and creating new communication protocols
- Providing support for seafarers through model courses for emerging technologies
- Updating manning/crewing models onboard ships and in the ROC
- Updating navigation regulations and standards
- Creating regulations for remote monitoring systems related to bridge and engine departments
- Updating ISM and ISPS Codes
- Updating educational curricula
- Updating and creating new regulations related to cybersecurity
- Updating existing and creating new simulation training for MASS and ROC
- Promoting standardization and global harmonization with MASS technologies and the decarbonization

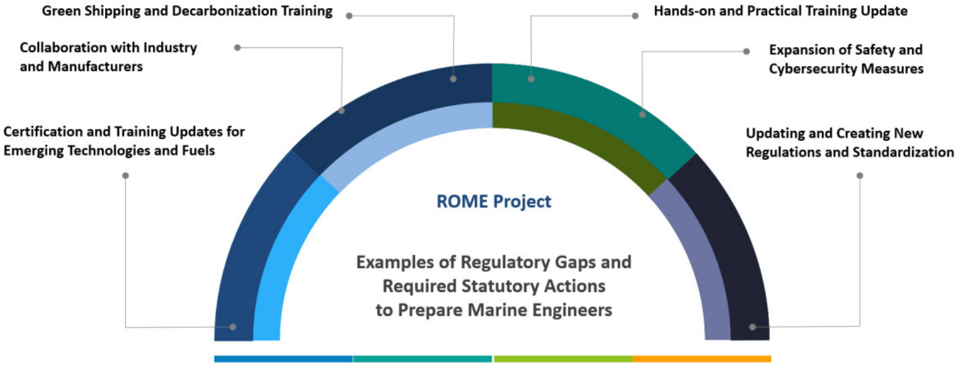


Figure 24 - Examples of Regulatory Gaps and Required Statutory Actions to Prepare Marine Engineers – ROME Project

6.4 Section 4- A brief overview of data results on cost and operational dynamics between traditional and autonomous ships!

The data from qualitative interviews, follow-up questions, and ethnography collected from different stakeholders across various sectors of the industry present diverse perspectives on the operational dynamics between current ships and future autonomous ships. The analysis supports findings that marine engineers, as the main players in the actual workplace onboard ships, are much more conservative toward change when discussed operation from remote operations centers. This conservatism is significant because remote personnel will the forerunners of autonomous shipping. Interview data indicate that shipbuilders are prepared to construct any remotely controlled or autonomous vessel or retrofit the existing ones if ordered. Classification societies are updating their class notations accordingly, but these updates will require time as they depend on the approval of marine authorities for operations. More importantly, the cost of new technologies and ship design could pose hindrances. For instance, questions like “Is building an autonomous ship much more expensive than building a similar manned ship?” highlight the complexities involved. The research data suggests that several aspects need consideration. For example, Yara Birkeland has batteries to power two azipull pods and two tunnel thrusters assist in berthing and unberthing, making it suitable concept for the 7 miles Porsgrunn – Brevik route. In future autonomous operations, for instance, the bridge is designed to be movable so it can be shifted to another new ship when all parties fully accept autonomous operations.

Comparing the cost of building a new ship with an autonomous ship of the same specifications is challenging because there is no established reference point. Calculating the price of a new ship with a conventional design is straightforward, as all statutory requirements are readily available. However, there is uncertainty about how regulations for autonomous ships will evolve. Additionally, the equipment and machinery for autonomous ships are not fully designed yet; those available are just prototypes undergoing testing. Consequently, they must be built as prototypes, which can be very expensive. By contrast, conventional ships can be constructed with off-the-shelf machinery and equipment at competitive prices. On the other hand, much of the equipment and systems on conventional ships are designed to support human life and safety. The absence of a crew on autonomous ships will result in considerable savings. Furthermore, the elimination of accommodation and human support systems makes autonomous ships much lighter and cheaper to operate. There would be more space available on the autonomous counterpart compared to the conventional design due to the absence of accommodation. On the operational side, the need for redundancy of systems on board autonomous ships, since there are no engineers to maintain them, is costly. A large number of IoT sensors are required to collect data and transmit it to ROCs. The cost of maintaining and calibrating these sensors might offset the savings from not having a marine engineer onboard. In conclusion, many trade-offs must be considered when comparing the costs of traditional and autonomous shipbuilding, as we have just mentioned a few of them.

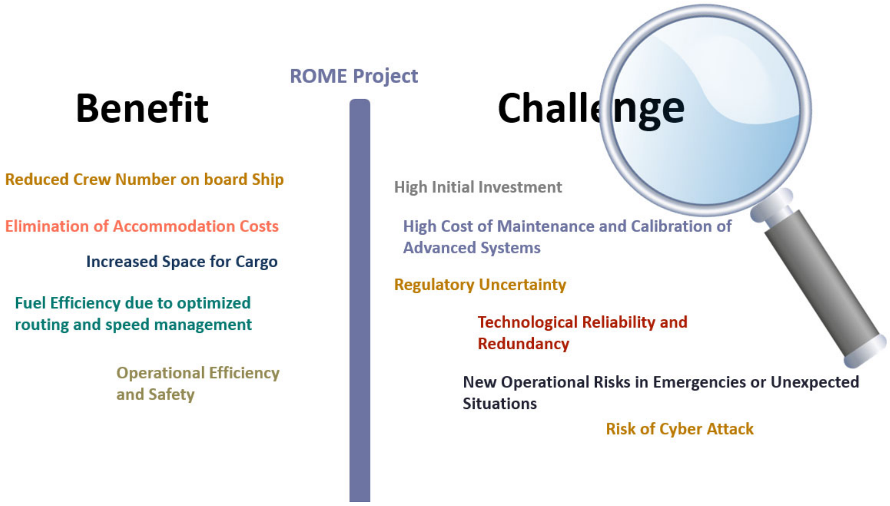


Figure 25 - Examples of Cost and Operational Dynamics for Transition from Traditional to Autonomous Ships – ROME Project

7 Conclusion

Emerging technologies in ships and ship operations, along with environmental challenges, have introduced the industry to new types of vessels, equipment, propulsion systems, energy sources, fuels, maneuvering techniques, and operations. These advancements require new standards of competence, functions, and levels of responsibility for the workforce. Concurrently, with the experience already gained from using digitalization and emerging technologies in education and training, further utilization of these technologies is anticipated. The industry is moving towards a more technology-oriented workplace in terms of MASS and decarbonization, aiming to achieve sustainable, efficient, greener, and autonomous operations. The integration of advanced technologies onboard vessels and ashore is aimed at supporting and augmenting maritime operations while maintaining human oversight and decision-making as core components. This research aimed to investigate the gaps in relation to how marine engineers can be equipped with the skills needed to work in a traditionally mechanical-oriented workplace that is gradually being integrated with sophisticated technologies and systems, including electronic, digital, sensorial, alternative fuels, and other advancements.

Our research data analysis highlighted several themes:

- **Existing Workplace Evolution and Emergence of New Workplace:** Advanced technologies related to digitalization and decarbonization will be integrated to enhance the quality of real-time data for efficient remote monitoring, controlling, and decision-making processes onboard ships and in Remote Operation Centers (ROCs).

- **Expansion of Existing Role of Marine Engineers and Emergence of New Roles:** Marine engineers' roles and responsibilities will evolve through the emergence of new roles and the transformation of existing ones, requiring constant interaction with intelligent machines and systems in addition to their traditional responsibilities. New roles will emerge with a high interface with advanced systems.

- **Skill Development Requirements and Training Gaps:** As technologies advance, workplaces onboard MASS and in ROCs become more intelligent, requiring continuous learning and adaptability from marine engineers. This necessitates the development of necessary skill sets through MET institutes.

- **Certification Gaps:** As new systems related to MASS and decarbonization are integrated onboard ships and in ROCs, these systems themselves require certification. Consequently, marine engineers should undergo new certification processes to obtain the necessary certificates.

- **Regulatory Gaps and Regulatory Update:** This theme emphasizes the need for updates in training requirements and certifications through revisions of the Standards of Training, Certification, and Watchkeeping (STCW), as well as updates to other regulations, rules, and standards such as the Safety of Life at Sea (SOLAS), International Safety Management (ISM) Code, International Ship and Port Facility Security (ISPS) Code, and the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs). These updates and modifications will necessitate active collaboration among regulatory bodies, industry stakeholders, technology providers, and MET institutes.

As the research results demonstrate, the evolving workplace demands a new skill set for marine engineers that includes mechatronic, machine learning, AI, cybersecurity, data interpretation and analysis, remote monitoring, and knowledge of dual-fuel engines. While research participants recognize that autonomous shipping and the shift to decarbonization are already underway, regulatory bodies are still catching up.

> *"Nothing can stand against technological improvements; it is all about reassuring 100% redundancies and how financially effective the operating of autonomous shipping. It will not be going to reduce the amount of work but shifting it and changing the phase of it." – (2nd and 3rd Engineer -15 years of experience)*

Therefore, reviewing the existing provisions in the STCW Convention and Code would allow for the expansion of teaching and teaching aids to supplement and support shore-based training, methods for assessing competence, and the approval and monitoring of training programs.

It is crucial that changes in training standards, especially those resulting from amendments to other IMO instruments, prioritize flexibility and efficiency in implementing new requirements while aiming to reduce administrative burdens. Notably, there is a pressing need to revise the STCW Convention and Code to incorporate cybersecurity awareness for seafarers, reflecting the increased reliance on digitally integrated and automated maritime operations. Furthermore, as the IMO's Joint MSC/LEG/FAL Working Group develops a non-mandatory MASS Code to facilitate the adoption of advanced technologies onboard ships and in ROCs, it is highly recommended that the findings of this research be considered. These findings could be used in the human element section of the MASS Code, addressing emerging challenges in human-machine coexistence and teamwork. This includes, but is not limited to, human-machine interface scenarios, roles and responsibilities, manning protocols, and training requirements. Importantly, the research suggests that as technologies become more integrated into the engine department and ROCs, and as vertical integration in engine operations advances, the need for certification and expertise among the workforce will continue to evolve. Over time, engineers from disciplines beyond marine engineering may be needed both onboard ships and in ROCs, offering a potential solution to the looming shortage of qualified marine engineers.

While the scope of this research does not extend to the new requirements for training providers in terms of developing expertise and curricula necessary to train qualified marine engineers, the analysis suggests that MET institutes trainers and course instructors should actively collaborate with classification societies, ship construction companies, and technology providers in pilot projects. This involvement from the early stages of integrating advanced technologies on ships and in ROCs will allow them to provide feedback, have their Say in the process, and even undergo training provided by technology providers. Furthermore, while the IMO is developing the MASS Code and revising the STCW to address existing and emerging gaps and the result is not available, during this process, it is highly recommended that MET institutes proactively offer general training courses related to Industry 4.0 technologies such as AI, IoT, cybersecurity, Cyber-Physical Systems (CPS), MASS, decarbonization, new and alternative fuels, and other related subjects. This proactive approach will help the maritime workforce, particularly marine engineers, to mentally and professionally prepare for the transition from traditional to autonomous shipping and to plan their future careers, accordingly, reducing resistance to this shift.

Historically, the shipping industry has experienced different transitions, such as moving from sail to steam engines, internal combustion engines, and gradually integrating automation. As marine engineers adapt to these changes, it is crucial for MET institutes to facilitate this transition smoothly by identifying gaps and collaborating with industry partners to address shortcomings. This collaboration is essential because, while intelligent systems are still in their infancy, constant improvement is required to ensure both machines and humans learn to work together for safer, greener, and more efficient operations.

Finally, digitalization and automation, as exemplified by MASS and green shipping, play an increasingly significant role in sustainability and reducing greenhouse gas emissions. Autonomous shipping has the potential to be viewed as a tool for cutting emissions while supporting maritime operations and maintaining human-centered decision-making. As autonomous operations in coastal and short-sea shipping are tested and their feasibility is proven over time, the workplace for marine engineers will evolve, significantly impacting marine engineering training that has already started. This shift necessitates changes in how we train our workforce, preparing them to collaborate with intelligent machines and systems under human-machine teaming.

Good seamanship is a traditional term including different aspects of ship operation. Accident investigation reports often blame the lack of good seamanship. The question is, will the artificial intelligence (AI) finally solve the everlasting problem of “what is good seamanship”?

This research outcome can benefit stakeholders by decoding the process and smoothing the transition of current marine engineers to MASS and ROCs. Moreover, it is highly recommended to initiate further research that addresses the challenges marine engineers face during the transition period, particularly in identifying the training requirements and skills needed by training providers in MET institutes. While researchers are exploring how seafarers transition to future ships, understanding the exact process for training providers and course instructors is equally important.

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