Mechanical Engineering

# Identification and analysis of educational needs for naval architects and marine engineers in relation to the foreseen context of Maritime Autonomous Surface Ships (MASS)

Victor Bolbot, Oussama Methlouthi, Meriam Chaal, Osiris Valdez Banda, Ahmad BahooToroody, Anastasia Tsetkova, Magnus Hellström, Jouni Saarni, Seppo Virtanen, Douglas Owen, Du Lei, Sunil Basnet

Aalto University

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# Abstract

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**Abstract**
We are enduring the introduction of rapid digitalization, smart technologies, and digital connectivity in all industrial domains including maritime under the scope of the industry 4.0 revolution. At the same time, a plethora of challenges need to be faced during this digital transition in the maritime cluster targeting the maritime autonomous surface ships (MASS).
Therefore, this report aims at a holistic analysis and identification of the educational needs and competencies required in the maritime domain by the naval architects and marine engineers in relation to MASS and at deriving recommendations for the study program in relation to MASS at Finnish Universities (Aalto University, Abo Akademi University and the University of Turku).
To identify current and future education needs, first, the technologies that are/can be employed on MASS have been specified. Then the impact of MASS on the various maritime organisations and job skills has been identified. The study programs offered at other universities in Finland and internationally in relation to MASS have been additionally analysed. Based on the analysis results, recommendations for the study program have been derived. Agile framework to keep Finnish university programs corresponding with the maritime industry needs was also proposed.
The analysis results have demonstrated that an increased number of systems employing information and communication technologies will be employed on MASS. The new systems development will increase the demand for maritime professionals who are proficient both in the realm of maritime and computer engineering. Some occupations will remain largely unaffected such as hydrodynamic and structural experts, whilst some others will be slightly altered, such as the jobs of ship designer. Several jobs will be burdened with additional required skill sets, such as the jobs of ship managers. New job types such as remote pilots and surveyors, and maritime cybersecurity experts will also emerge.
Universities in Finland and globally have responded to the new demands by either updating their study programs or by providing dedicated master's programs, alone or in cooperation with other universities. They have included courses on advanced robotics or artificial intelligence in their study curriculum along with many others.
The investigated universities (Aalto University, Abo Akademi University and the University of Turku) offered courses already include MASS as part of their course's material. However, this material needs to be enhanced by including more aspects in relation to the systems being installed on MASS, digital twins, design challenges associated with MASS, and machine learning techniques used in maritime and maritime cybersecurity.
To keep up with the developments in the maritime, it is recommended to organise small biannual workshops in cooperation with industry which can be used to update the study curriculum.

**Keywords** Autonomous ships; autonomous technologies and systems; maritime jobs; maritime skills; impact analysis; educational programs

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## Disclaimer

This publication has been developed by members of the AutoMare project coming from Aalto University, Åbo Akademi University, University of Turku and is intended to be used as input to the discussions on and development of study program related to MASS. The content of the publication has been reviewed by the AutoMare participants from the above-mentioned universities but does not necessarily represent the views held or expressed by any individual member of the institution members of the whole AutoMare network or Advisory Board.

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## Executive summary

We are enduring the introduction of rapid digitalization, smart technologies, and digital connectivity in all industrial domains including maritime under the scope of the industry 4.0 revolution. At the same time, a plethora of challenges need to be faced during this digital transition in the maritime cluster targeting the maritime autonomous surface ships (MASS).

Therefore, this report aims at a holistic analysis and identification of the educational needs and competencies required in the maritime domain by the naval architects and marine engineers in relation to MASS and at deriving recommendations for the study program in relation to MASS at Finnish Universities (Aalto University, Abo Akademi University and the University of Turku).

To identify current and future education needs, first, the technologies that are/can be employed on MASS have been specified. Then the impact of MASS on the various maritime organisations and job skills has been identified. The study programs offered at other universities in Finland and internationally in relation to MASS have been additionally analysed. Based on the analysis results, recommendations for the study program have been derived. Agile framework to keep Finnish university programs corresponding with the maritime industry needs was also proposed.

The analysis results have demonstrated that an increased number of systems employing information and communication technologies will be employed on MASS. The new systems development will increase the demand for maritime professionals who are proficient both in the realm of maritime and computer engineering. Some occupations will remain largely unaffected such as hydrodynamic and structural experts, whilst some others will be slightly altered, such as the jobs of ship designer. Several jobs will be burdened with additional required skill sets, such as the jobs of ship managers. New job types such as remote pilots and surveyors, and maritime cybersecurity experts will also emerge.

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To keep up with the developments in the maritime, it is recommended to organise small biannual workshops in cooperation with industry which can be used to update the study curriculum constantly.

# Abbreviation list

| **Abbreviation** | **Description** |
|---|---|
| ABS | American Bureau of Shipping |
| AI | Artificial Intelligence |
| ARPA | Automatic Radar Plotting Aids |
| AUV | Autonomous Underwater Vehicles |
| AMT | Arctic marine technology |
| BV | Bureau Veritas |
| CCNR | Central Commission for the Navigation of the Rhine |
| CFD | Computational Fluid Dynamics |
| CHI | Chinese |
| CoC | certificate of competence |
| COLREG | Convention on the international regulation for preventing collisions at sea |
| CNC | Computerized Numerical Control |
| CTTX | Cybersecurity Table-Top Exercises |
| DPA | Designated Person Ashore |
| EN | English |
| FIN | Finnish |
| GOC | General operator’s Certificate |
| GMDSS | Global Maritime Distress and Safety System |
| GR | Greek |
| HTO | Humans, Technology and Organization |
| H | Human |
| HE | Hydrodynamic expert |
| HMI | Human Machine Interface |
| HVAC | Heating, Ventilation and Air Conditioning |
| IACS | International Association of Classification Societies |
| ICT | Information and Communication Technologies |
| IMO | International Maritime Organization |
| IoT | Internet of Things |
| SM | International Safety Management |
| ISPS | International Ship and Port facility Security Code |
| KET | Key Enabling Technology |
| LR | Lloyd`s Register |
| NA | Naval Architecture |
| NAOME | Naval Architecture, Ocean, and Marine Engineering |
| NOR | Norwegian |
| MASS | Maritime Autonomous Surface Ship |
| MDA | Model Driven Architecture |
| ML | Machine Learning |
| MLC | Maritime Labour Convention |
| MSI | Maritime Safety Information |
| T | Technology |
| O | Organization |
| PE | Project engineer |
| PFSO | Port Facility Security Officer |
| RCC | Remote Control Centre |
| ROC | Restricted Operator Certificate |
| RSE | Regulatory Scoping Exercise |

| | |
|---|---|
| SARUMS | Safety and Regulations for European Unmanned Maritime Systems |
| SE | Structural expert |
| SMO | Smart maritime operations |
| SMS | Safety Management System |
| SOLAS | Safety of Life at Sea |
| SQL | Structured Query Language |
| STCW | Standards of Training, Certification and Watchkeeping |
| STEM | Science, Technology, Engineering and Mathematics |
| VTS | Vessel Traffic Services |

# 1 Introduction

## 1.1 The background

We live in an era when novel systems employing the advancements in Information and Communication Technology (ICT) are being developed. An example of these systems includes the Marine Autonomous Surface Ships (MASS). A series of industrial and academic research projects aiming at the development of the autonomous has been globally launched [1–6]. The world's first autonomous MASS has already been demonstrated in 2018 [7] with application of autonomous technologies to a ferry. Other applications at various stages of development and autonomy include small city ferries [8], small container ships [9,10], inland waterway ships [11], fish feeding vessels [11], tugboats [12,13], military ships [14], large containerships[15] and research vessels [16] across the globe. From a broader perspective, technological and operational development of MASS can also be associated with digitalization of supply chains in relation to topics such as Industry 4.0.

## 1.2 The motivation

The introduction of the autonomous ships into real operation is anticipated to bring benefits with respect to the global $CO_2$ emissions, economics, maritime jobs accessibility, job satisfaction and safety [17,18]. This introduction will be accompanied with innovation in ship designs, ship operations, ship management and human-ship interactions, and supply chain management practices. Several Key Enabling Technologies (KET) such as autonomous navigations and advanced situation awareness systems will be required to be installed on the MASS, and other KET in other parts of the maritime ecosystem [19]. This transformation will incur changes on existing jobs or development of new job types within the maritime industry [20] potentially resulting in personnel shortages. This transformation can be facilitated, if the educational institutions properly respond to the expected changes by equipping the maritime industry practitioners with the knowledge and skills required for the MASS design and operation.

## 1.3 Existing research

The existing research in the field includes some examples of detailed analysis related to the educational needs for the future autonomous and digitalised ships personnel. Most of the studies has focused so far on the analysis of educational needs for the seafarers, such as provided in [20–27], without considering other occupations. Some general educational aspects in relation to autonomous shipping have been also covered on a prominent level in [28]. However, there is no analysis, which would ponder other types of professions in the maritime, as ship designer, marine systems designer, autonomous ships' manager, shipping chartering manager, logistics coordinator.

## 1.4 Aim and objectives

The aim of this report is therefore to implement an analysis of educational needs for naval architects and marine engineers and other potential professions in relation to MASS (such as other technical professions related for example to electronics, communications or mechanical systems, commercial managers in the shipping business and supply chains, lawyers) in relation to the next generation autonomous shipping with focus on Finnish universities (Aalto University, Åbo Akademi University, University of Turku). The specific objectives related to this general aim include the following:

A. The identification of potential future MASS technologies, operations, and probable time framework.
B. The identification of MASS impact on humans and organisations in the maritime industry.
C. The analysis of the presently offered study programs at Aalto University, Åbo Akademi University, University of Turku, and worldwide in connection with MASS.

D. The development of recommendations for study programs in connection with MASS.
E. The development of agile framework for updating the study program.

## 1.5 Report's scope and assumptions

This report has employed a series of assumptions for achieving the above-mentioned objectives:

- The analysis focuses on the Finnish universities (Aalto University, Åbo Akademi University, University of Turku) study programs' analysis and development.
- This report excludes the analysis of educational needs for Finnish applied science universities, which is provided in a separate report.
- When investigating the other international universities study programs, the in-depth analysis of the presented curriculum will not be implemented, unless it is linked to MASS.
- For the educational needs' analysis, the jobs related to the ship and marine system design and services provided by the Finnish companies will be investigated the most; however, global perspectives will be also incorporated.
- In addition, MASS development can be positioned to be related to technologies such as information systems integrating autonomous solutions and supply chain management. However, those technologies attract limited focus in this report.
- Because of the significant variety of jobs and the wide variety of ship types (cargo ships, passenger ships, container ships, ice breakers, offshore industry ships, military ships, etc.), this study, covers the generic maritime jobs in ship design, building, operations, and scrapping. Examples constitute jobs advertised by ship equipment manufacturers, organizations interconnected to the ship monitoring, maintenance, and operations, etc.

## 1.6 The report's structure

This report is organized as follows. First, the methodology that has been followed to elicit the report's results is provided. Then, the identified technologies that can be used on MASS are presented. In the subsequent section we present the analysis of the impact of these technologies on organisations, related jobs and required skills. The analysis of universities' study programs is offered in Section 5. In Section 6, we review the courses that are offered by the universities outside Finland in connection with MASS. In Section 7, we provide areas of opportunities for the universities study programs, whilst in Section 8 we present the agile framework for updating study programs. Lastly, we provide the main conclusions and findings of the overall report.

# 2 Report's methodology

## 2.1 Section outline

In this section, the methodology that has been followed to derive the report's results is presented. First, a methodology overview and rationale are provided. Then, the methodology steps are described in more detail.

## 2.2 The methodology overview and rationale

An overview of the report's methodology is being presented in Figure 1. As it can be observed, the analysis initiates with the identification of the MASS relevant technologies, and its impact on the humans and organisations (steps 1 to 3). In parallel, the study program at Finnish and other Universities is being identified and their relationship to MASS is being investigated (steps 4 and 5). Based on the outcomes of objectives C and D, areas of opportunities for the study program are being derived. Then, as a last analysis step, an agile framework is being proposed for updating the study program effectively in response to the developments in the maritime industry.

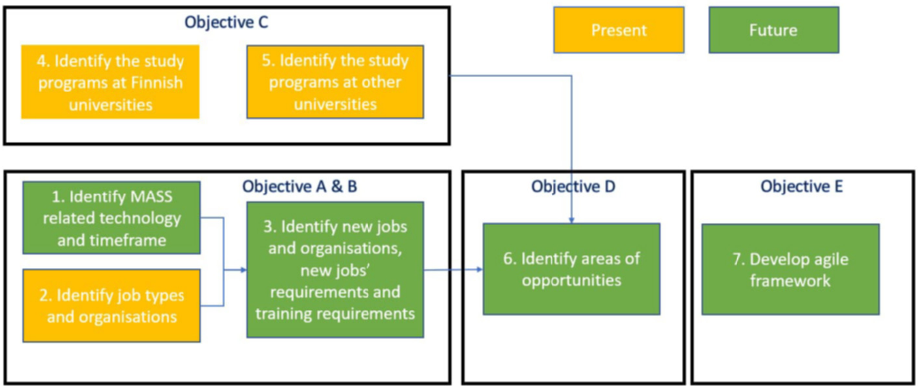


*Figure 1 Overview of report's methodology.*

The methodology presented in the Figure 1 and subsequent sections have been developed tailored to the main aim and the relevant objectives of the current report. The methodology is aligned with the Humans (H), Technology (T) and Organization (O) (HTO) concept (Figure 2), which can be used as a mapping tool in the context of systems and operations. The use of HTO concept is advantageous, since it offers a holistic view on operations and facilitates the consideration of novel systems' solutions [29]. The analysis starts with the T since the change in the used T influences the H and O.

The analysis of current educational programs is being implemented in parallel to the other methodology steps (1-3) as it is weakly dependent on the other results. Still, a small repetition of the analysis implemented in steps 4 and 5 is considered to align the conclusions in these steps with the findings from steps 1-3.

Once the results for objectives A, B & C are accumulated, then the areas of opportunities for the study programs are proposed. This is necessary since any informed areas of opportunities for the study programs would need to have identified the current state of the educational programs as well as the impact of MASS technologies on the general maritime community.

The development of the agile framework is set as the last step, since it is dependent on the findings generated and experience obtained during the previous steps of the methodology.

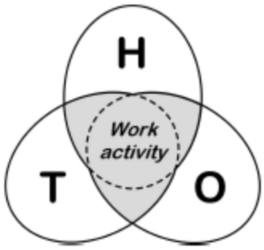


*Figure 2 HTO framework [29].*

## 2.3 Step 1 Identification of MASS technologies (T)

The aim of this step is to identify the employed technologies on MASS. The identification of MASS related technologies can be supported with a coherent and well-defined classification for the MASS technologies. Then, the generated information in this section is used then in the next sections to identify the novel jobs requirements.

There is a plethora of methods for classifying the MASS technology and types[30].

An early and popular definition of levels of *automated decision-making* was proposed by Sheridan and Verplank [31], which includes 10 levels of gradual transfer of control from human to computer. A similar reduced autonomy scale including only five levels, was proposed by Endsley [32]. A different framework for scale characterization was proposed by Parasuraman et al. [33] by dividing the *decision process* into four steps: 1) Data acquisition and sensory processing; 2) Information analysis or perception; 3) Decide action; and 4) Execute action. A variant of the same framework has been proposed by Endsley and Kaber in their research [34]. SARUMS (Safety and Regulations for European Unmanned Maritime Systems) has proposed six levels of control [35] which is also referenced by the UK MASS Conduct Principles and Code of Practice [36]. CCNR (Central Commission for the Navigation of the Rhine) [37] has specified automation levels for inland waterway vessels which includes 6 levels of automation. In AUTOSHIP project [38], a classification for MASS autonomy and control interconnected to functional breakdown has been proposed.

The classification societies also employ various definitions of levels of autonomy. DNV has 5 levels, including the fully manual mode [39]. Lloyd's Register uses six levels[40]. Bureau Veritas [41] defines five levels (or degrees) of automation as they also prefer not to use autonomy as a term. ABS [42] makes a reference to Sheridan's ten levels but proposes to group them into four stages. All classification systems are similar to Sheridan's classification and based on a gradual transfer of control from human to automation, typically manual – decision support – human in the loop – human on the loop and full autonomy.

Whilst International Maritime Organization (IMO) has not yet defined any specific scale for levels of autonomy, four "degrees" of autonomy have been proposed in the regulatory scoping exercise (RSE) [43]:

1. **Ship with automated processes and decision support**: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.

2. **Remotely controlled ship with seafarers on board**: The ship is controlled and operated from another location, but seafarers are on board.
3. **Remotely controlled ship without seafarers on board**: The ship is controlled and operated from another location. There are no seafarers on board.
4. **Fully autonomous ship**: The operating system of the ship can make decisions and determine actions by itself.

From the above-mentioned approaches to classifying the MASS, this report gives preference to the IMO classification, as the IMO classification is proposed to be employed at an international level. As the classification is applied on ship level, the analysis in subsequent sections is significantly simplified.

It should be acknowledged though in advance, that the classification of ships according to various autonomy degrees is not a clear cut and some fuzziness might exist, which is one of the limitations of the current exercise. The fuzziness stems from the fact that the ship might be operating in various autonomous degrees in various operating phases (sailing, port, manoeuvring close to the port). For instance, ship can be in a fully autonomous mode, when operating in the open ocean and then turn to remotely controlled, when operating close to the port or in an area with high traffic density. Also, this classification is not helpful from the Original Equipment Manufacturers (OEM) perspective, as systems might be operating in various autonomous degrees in different operating modes.

Considering these limitations, and using the IMO classification for autonomy degree, the MASS technologies' description is provided in Section 3. For the description, free access material from other projects on MASS such as MUNIN [19] and AUTOSHIP [11] and in series of other publications such as [44–48] has been employed. Feedback from AutoMare EduNeed contributors for the development of section 3 has been actively used. In this description, emphasis is given to changed and altered systems and operational procedures enabled by these systems compared with conventional shipping. The ship functions classification employed here is based on the functional description provided in the AUTOSHIP project [38]. Other classifications could be potentially used such as SFI [49], but AUTOSHIP project classification constitutes one of the most recent one and it is specifically tailored to the MASS need's.

A simple questionnaire is also used to determine the expected time framework related to the introduction of MASS with various degrees into the maritime industry. This questionnaire has a limited advisory role, as it is acknowledged that the introduction of MASS is associated with serious legal, financial, and technological challenges, which are difficult to overcome. The questionnaire is provided in Appendix A and the results in Section 3.

## 2.4 Step 2 Identification of currently offered jobs and organisations (H, O)

This step is implemented by conducting a comprehensive literature review in three sub-steps.

First, with the support of the literature, the most important stakeholders and organisations involved in the ship design and operations during the lifecycle are identified. This provides a search structure for identifying the currently available jobs in these organisations/stakeholders in the next sub step. The identified organisations / life cycle steps are to organize the material and investigate the MASS impact on organisations and jobs.

During the second sub-step, the currently offered jobs in the maritime industry in different organisations are being specified by investigating the relevant advertisements. For these jobs, the relevant requirements are detailed and presented in a tabular format which includes the job name and the required skill sets for various job types based on the relevant job advertisements and regulations.

During the last sub-step, the initially identified jobs and required skills are refined based on the feedback provided through the AutoMare network. This is implemented to avoid omissions in the developed information.

## 2.5 Step 3 Identify new jobs and organisations (H, O)

This step is implemented using the generated results from Step 1 and Step 2. This step relies heavily on the experience of the analysts, but also the findings of other studies on the realm of MASS. The analysis here follows similar structure as used in step 2. The analysis focuses on broad impact of MASS first and then proceeds with the various jobs' analysis.

During the analysis, the presence of autonomous technologies on ships as identified during step 1 (section 3) is considered and their impact on the various jobs is specified in terms of additional required jobs/knowledge/skill set. The additional required skills are presented following the same tabular format as for step 2. Feedback from the Advisory Board is used at a final stage of this report compilation.

## 2.6 Step 4 Identify the Finnish universities study program

This step is implemented by exploiting the available information about the Finnish universities' curriculum from open and confidential sources.

To this mean, first, the information about the openly available study programs and paths at Aalto University, Åbo Akademi University, University of Turku in connection with shipping is being specified. Based on that, the offered courses are also identified. This information is used to organize the analysis further in the subsequent sections.

Once, the courses are identified, the focus shifts to the material-related courses s. Here, the expected learning outcomes and study syllabus is used to investigate the course's contents and their relevance to MASS.

During the last optional sub-step of the analysis, the courses leaders are approached and questioned several questions in connection with their courses. These questions are used to assess the readiness and suitability of these courses in relation to MASS. An example of these questions is provided in Appendix B.

Finally, the summary of the study program is provided in this common report, whilst the detailed analysis of courses remains for internal use.

## 2.7 Step 5 Identify other universities study program

The list of the international universities has been derived based on the Shanghai ranking in the academic subject of the Marine/Ocean Engineering for 2021 [50] so that the top institutions are primarily considered. Further analysis has focused only on those study programs which are related to MASS, as it is outside the scope of this study to present the curriculum of universities related to Naval Architecture, Ocean, and Marine Engineering other than the Finnish universities. For the identification of the relevant study modules, such keywords as autonomous, complex, advanced, smart, robotics, digital, and intelligent shipping have been employed on the websites of the relevant universities.

An additional search using Google has been implemented with the support of relevant keywords. The investigation has focused on the first 50 results provided by google. The used keywords include the following: smart ships master course, autonomous ships master course, digital shipping master course, marine robotics master course. This search led to the identification of additional courses to the one identified using the previously mentioned procedure.

## 2.8 Step 6 Identify areas of opportunities

The areas of opportunities for the current study program enhancement are implemented with the support of previous steps. First, the new skills sets are aggregated in a list format. Then, based on this list the areas of opportunity for the courses and study programs are generated by the analysis leaders. The identification of educational solutions is the aim of another work package and will be addressed in depth in another report.

## 2.9 Step 7 Develop agile framework

Agile framework has been initially adopted for IT software development [51] and remains popular in this domain even now. Following its success, the companies in other domains and governments have adopted agile principles for management of their tasks [52] including educational sector [53][54][55].

The main principles of the agile framework have been introduced in "Agile Manifesto"[51]. As it is described in this document, the agile framework is based on a series of short repetitive cycles where amelioration is incorporated by the end of each cycle [52]. The agile framework is applied through the direct cooperation of customers with the product developers and constant revisions of the product, resulting in enhancements in regular periods of time. Considerable number of frameworks has been proposed and applied, such as Disciplined Agile Delivery [56], Agile scale [56], Large-scale agile scrum [57], Nexus framework [58], and many others[52]. Each agile framework type differentiates from the other frameworks based on the framework work philosophy, complexity, and other criteria[52].

The advantages of adoption of the agile framework include flexibility, the continuous tracking of the enhancement progress and the effective gradual development of systems [59]. Compared with other frameworks, agile framework allows rapid changes application to the systems and updates correlated to the technological developments.

In this report, the agile framework is adopted for updating the educational curriculum. The purpose is to enhance the study program periodically without significant effort to synchronize and update areas of opportunities and mentioned in Section 7 with the ongoing technological developments.

Among the large variety of available agile frameworks, we have selected the Scrum[60] as a basis for further developments, as the Scrum is designed for small teams and emphasizes the interactions and implementation of small iterations. However, our approach distinguishes on the time scale of proposed type of changes.

## 2.10 Section conclusions

As it has been elaborated in this section, the identification of educational needs is a task which requires a complex and elaborate procedure. In the described approach, mostly literature review accompanied by interviews and questionnaires has been adopted.

# Part A: MASS impact on the ships design and operations

(Covering Objectives, A and B)

# 3 The MASS related technologies (T)

## 3.1 Section outline

In this section, the potential technologies for use on MASS or in connection with MASS based on the IMO classification identified with the support of literature review are presented. The anticipated time framework for MASS introduction is also discussed.

## 3.2 The MASS description according to autonomy Degree 1

Degree 1 is used to describe [43]:

"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 with seafarers on board ready to take control."

This ship type can be used to describe the more sophisticated type of conventional ship, where the ICT is more extensively used. In this ship type, an increased number of sensors are installed on various ships' systems [61]and ships' locations, which are used to measure some critical parameters and generate the so-called big data. These sensors measurements in turn are analyzed with the support of big data analytics tools installed on programmable logic computational units on shore or on ship which reveal system properties unobservable otherwise. The ship is located in a new environment in which it exchanges the information with sophisticated systems present on the fairway and shore semi-automatically and under crew supervision.

In this type of ship operations, we might have novel bridge equipment with better user interface and self-diagnostics techniques, which integrates risk assessment with present traffic situation [62]. Also periodically unattended bridge can be in use in which the situation awareness systems detect hazardous objects or ships in ship's proximity and alerts the crew [62]. In the engine room, on deck and internal spaces an increased number of cameras and sensors is installed allowing the remote monitoring and control of various processes (loading, mooring, power generation, ship access control etc.). The equipment installed on the ship is maintained with the support of condition monitoring data and digital twins for better scheduling of maintenance procedures such as predictive maintenance [63]. The maintenance personnel might be equipped with exoskeletons to facilitate maintenance procedures. Underwater vehicles can be used for hull inspection and cleaning [44]. The entrance to hazardous locations on ships such as ballast and cargo tanks is limited since the manual inspection is replaced by appropriate remotely controlled or autonomous drones. Advanced tools facilitate the implementation of ship administrative procedures and reporting on the bridge, reducing the captain workload [62]. The ship accommodation is similar to the smart house concepts implemented on shore, where smart heating and ventilation are used[64]. Conventional as well as novel power and propulsion solutions are being employed to reduce greenhouse emissions. For better energy management advanced AI-based decision-support tools are employed.

On the shore, machine learning-based and integrated tools are used for better scheduling of maintenance, inspection, reporting to authorities, crew change management, bunkering and voyage management [65]. For the voyage management, weather routing software for route and speed optimisation is used. Several shore tasks are being automated to allow better shore personnel performance such as spare part procurement management. The ship crew and shore personnel feel much more connected to each other since shore personnel actively participates in maintenance and emergency procedures implemented by the crew through video calls [62]. Furthermore, the accumulation of big data and higher integration between ship and shore results in high communication bandwidth and the implementation of advanced cybersecurity solutions both on shore and on ship. The interconnection between shore and ship allows for exploitation of the ship as an additional sensor point for better weather prediction and identification of local GPS disturbances. The fairway is also altered as cameras and weather monitoring systems are added[66].

This ship type is depicted graphically in Figure 3. More detailed description of the ship type based on functional breakdown is provided in Section 0.

## 3.3 The MASS description according to autonomy Degree 2

Degree 2 is used to describe [43]:

"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 operate the shipboard systems and functions."

This ship type can be considered as intermediate between the previous ship type (Degree 1) and the fully crewless, remotely controlled ship concept. In this ship type, several functions are transferred from the ship to the shore. So, in this type of ships, navigation and pilotage can be implemented remotely resulting in the extensive use of periodically unattended bridges[5,67]. For that, the ship needs to be equipped with relevant situation awareness systems which will have to take into account the novel types of human machine interactions. The shore personnel might also undertake responsibility for cargo loading/unloading operations, mooring operations, software updates. This also results in higher reliability, cybersecurity, and bandwidth requirements for the communication system between the remote-control centre and the ship[68]. Still, the seafarers onboard can intervene in case of an emergency. Otherwise, this type of ship does not significantly differentiate from the previous degree type.

This ship type is depicted graphically in Figure 3. More detailed description of the ship type based on functional breakdown is provided in Section 0.

## 3.4 The MASS description according to autonomy Degree 3

Degree 3 is used to describe [43]:

"Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board."

This ship type significantly differentiates from the previous degree types. As the crew is removed from the ship to shore, there is no requirement for accommodation and superstructure, except for minimum facilities for personnel, which temporally is present on the ship, leading to weight reduction. This in turn allows for greater flexibility with respect to sensors and equipment locations on the ship.

The navigation and pilotage in difficult areas are conducted remotely thanks to advanced situation and navigation systems[62]. The docking and mooring can be also implemented remotely, so the design needs to be altered to allow remote docking or docking using only the personnel in ports [19]. The health status of ship systems components is monitored remotely, as well the cargo/bunkers/auxiliary systems´ condition. The installed systems have increased redundancy to allow reconfiguration in case of equipment failure. The maintenance is completely modified and approximates the maintenance procedures implemented in aviation as it is achieved in ports or dedicated maintenance hubs[67]. This in turn necessitates the use of prediction and health maintenance tools for all critical equipment. This ship type uses advanced communication equipment with other ships/ports to compensate for the lack of crew[69].

To allow salvage operations, specialised remotely drones are available[70]. These remotely controlled drones carry some basic resuscitating equipment and will support the drowning people to remain afloat, till human assistance comes. The implementation of other emergency actions is also supported with specialized remotely controlled drones or through the use of well-predefined minimum risk conditions. A remotely activated firefighting equipment is employed and relevant rearrangement of ship structure is implemented to reduce the potential of fire and the potential for fire propagation. The crew removal influences the damage stability requirements of the ship, resulting in structure alteration.

Even stringer requirements than that for the previous ship types exist for the communication system between the ship and the remote-control centre[62]. The operation of such ship types will require also change in the relevant infrastructure such as ports/ docks/bridges/fairways/VTS monitoring procedures. The responsibility for managing the ship administrative procedures is shifted from ship to remote control centre.

This ship type is depicted graphically in Figure 3. More detailed description of the ship type based on the functional breakdown is provided in Section 0.

## 3.5 The MASS description according to autonomy Degree 4

Degree 3 is used to describe [43]:

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

This ship type represents a ship, where all or most ship operations are automatized, but the presence of humans is still not excluded. The ship and remotely controlled systems are making decisions independently, but the human is intervening to override a wrong decision actuated by the system[67]. Theoretically a human could be present on such a type of ship, as a passenger or maintenance crew, but in this exercise, we considered this option as outside the scope and as an intermediate one between the ship with autonomy degree 1 and 4.

Therefore, in a ship with autonomous degree 4, the navigation and docking are implemented by the collision avoidance system with the support of situation awareness system. The navigation in such cases is supported using dynamic contours. The personnel in the remote-control centre can override a decision implemented by the collision avoidance system. In the machinery space, intelligent systems analyse sensor measurements, digital models and estimate current and future health status, estimate, and predict safety metrics, and make decisions based on that[71,72]. The system automatically implements a set of reconfiguration functions, e.g., switch over from faulty to healthy component , without asking for human permission. Similarly, the ship selects on its own a predefined set of minimum risk conditions in response to emergency situations.

This ship type also automatically optimizes its energy efficiency[19]. It can change its navigation path and the power plant configuration to ensure the least fuel consumption and maintenance procedures in response to anticipated weather and equipment health conditions. This ship also automatically combines various information types to compile noon and safety reports and automatically exchanges administrative information with the classification societies, local authorities, etc.

An increased number of functions in the remote-control centre is implemented automatically. So, the bunkering is organized by dedicated software analysing the fuel availability on the ship and in the destination port, predicted fuel prices, and anticipated fuel consumption similarly to sophisticated software tools used on Wall Street. The voyage plan and booking of charter services are automatically implemented based on the current and predicted market status[73]. Maintenance is also scheduled using the condition monitoring data, the destination ports, the spare parts costs, and the overall ship health status as for Degree 3. The implementation of ISPS and SMS is monitored with the assistance of dedicated software.

Compared with the ship autonomy degree 3, this ship type requires less or similar communication bandwidth with the remote-control centre and this communication link is less critical, as the ship does not so heavily rely on the decisions made in the remote-control centre. However, such type of ship will be highly vulnerable to cyberattacks due to its integrative and highly autonomous nature.

This ship type is depicted graphically in Figure 3. More detailed description of the ship type based on functional breakdown is provided in Section 0.

## 3.6 MASS technologies in a tabular format

An overview of potential systems according to different autonomy degrees [43] and function groups [38] is provided in Table 1.

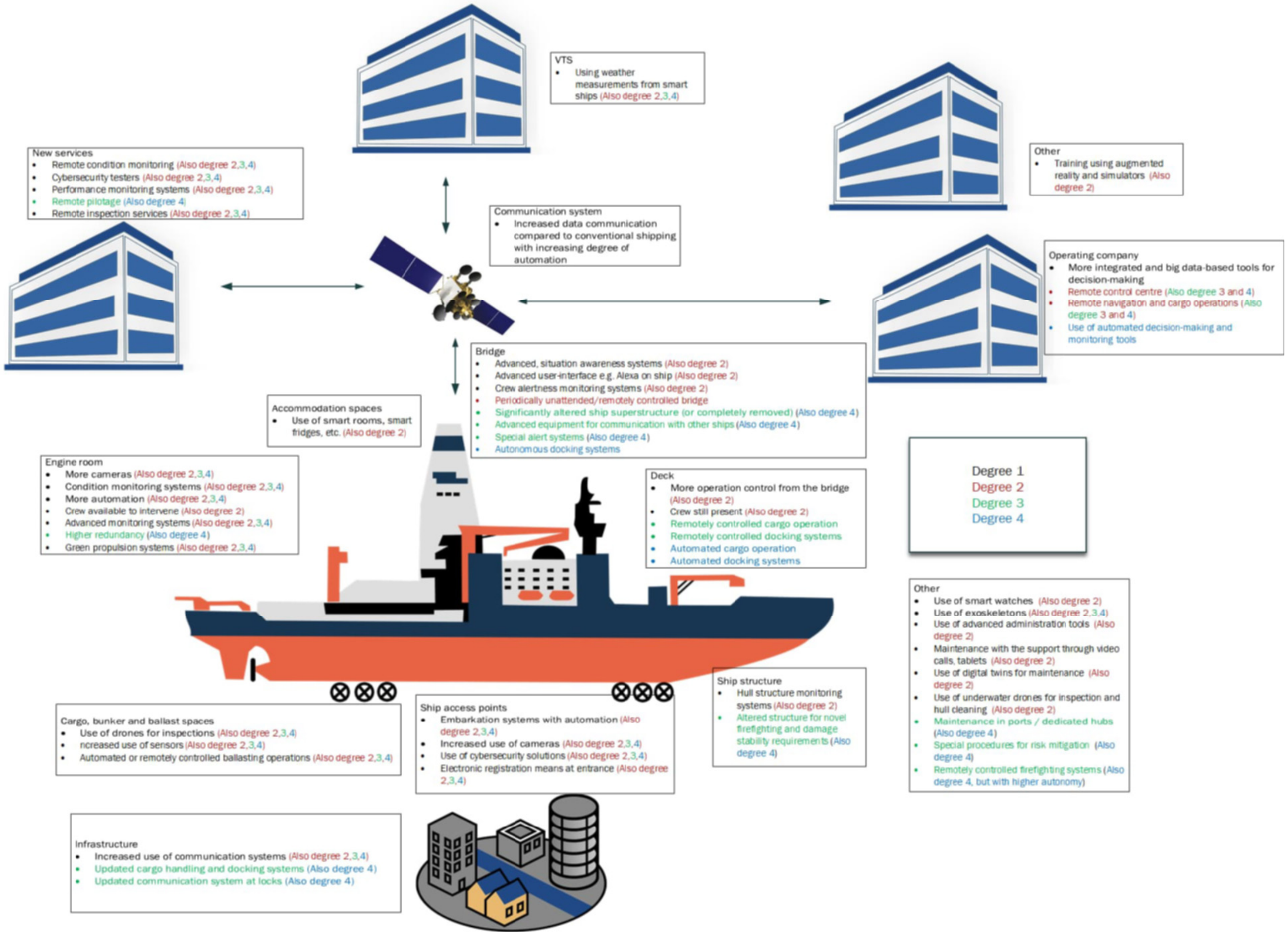


*Figure 3 Graphical description of technologies used according to different autonomy degree [43].*

*Table 1 The description of potential technologies employed in various MASS degrees.*

| n/n | Function | MASS degree 1: Used systems and related operations | MASS degree 2: Used systems and related operations | MASS degree 3: Used systems and related operations | MASS degree 4: Used systems and related operations |
|---|---|---|---|---|---|
| 1 | Navigation (situation awareness, ship control, voyage management, nautical communication) | The use of intelligent situation awareness system in cooperation with seafarers present on the bridge[67]<br>Updated bridge layout to accommodate novel systems[62]<br>Use of standard communication equipment for navigation as described by COLREGs (e.g., lights, whistle, horn[71])<br>Increased communication bandwidth for condition monitoring data exchange with the shore[62,67]<br>Systems monitoring the crew performance and alertness on the bridge[63]<br>Periodically unattended bridge[72]<br>Advanced communication systems[18] | The use of intelligent situation awareness and collision avoidance system which is directly interconnected to the remote-control centre<br>Altered bridge layout as for degree 1<br>Communication equipment interconnected to the remote-control centre[67]<br>Further increase in the data amount exchanged between the ship and the shore<br>Use of remote pilotage[5] | The use of intelligent situation awareness which is directly interconnected to the remote-control centre<br>Communication equipment interconnected to the remote-control centre[62]<br>Completely novel bridge concepts[19,69]<br>Use of remote pilotage[5]<br>Further increase in data exchange | Collision avoidance taking decisions for the navigation aspects[67]<br>Bridge design concepts similar to degree 3<br>Use of dynamic contours for navigation[19] |
| 2 | Deck operation -navigation support (cargo and ship supplies operation, mooring and anchorage, bunkering operations, pilot embarkation/disembarkation, helicopter operations) | Equipment operation using the onboard crew. More sensors might be installed, alongside with the local human machinery interface and condition monitoring systems for the deck machinery [44]<br>Additional cameras might be installed for better monitoring of the loading-unloading as the crew is obtaining more supervisory role<br>Automatic docking operation under crew supervision[73]<br>Automatic loading/unloading procedures under crew supervision[19]<br>Use of system supporting embarkation process through communication between the ship and accommodation ladder | Deck equipment controlled by the seafarers as for degree 1 or controlled remotely<br>Additional communication link to the remote-control centre<br>More cameras installed to support situation awareness | Deck equipment monitored and controlled from remote control centre[74]<br>Cameras ensuring adequate situation awareness<br>Remotely controlled docking operations<br>Novel docking systems requiring changes in infrastructure[44]<br>Remotely controlled loading/unloading[19] | Ship undertaking control actions for loading/unloading/docking on its own<br>Depending on the maturity technology, the remote operator will be available to intervene or not<br>Otherwise, same as for degree 3 |
| 3 | Cargo, stability, hull integrity (related to cargo, bunkering, hull integrity and strength, stability, and trim) | Monitoring of the ship stability and cargo/bunkers/ballast condition in the bridge control room using sensors/cameras[61]<br>Drones supporting cargo/hull inspection on ships[75]<br>More sensors installed for hull stress monitoring (interconnected to a digital twin of ship structure [61])<br>Use of loadicator and stability booklet as per standard procedures | Transfer of relevant information from the bridge control room to the remote-control centre<br>Remote control can intervene to the ship operation through remote control commands, but the crew might override it<br>Otherwise, same as for degree 1 | Remote monitoring of the ship stability and cargo/bunkers/ballast/structure condition using sensors/cameras[76]<br>Drones supporting cargo/hull/ship inspection on ships<br>Increased redundancy<br>Changers in structure due to the bridge removal[69] | Decision-making tools relevant to ship structure and loading conditions, integrating digital twin information, sensor measurements, loading conditions, weather predictions<br>Ship activating drones for routine inspection<br>Otherwise, same as for degree 3 |
| 4 | Machinery and technical systems (Power generation and operation, electrical systems, steering, propulsion and thrust, other technical system, system monitoring) | Use of conventional power generation systems<br>Use of green solutions compatible with the conventional ships<br>Greater use of condition monitoring systems[67][77]<br>Unattended machinery space (as on conventional ships)<br>More cameras installed, interconnected to engine and bridge control rooms<br>Systems monitoring the crew performance and alertness in the engine control room[63]<br>Use of exoskeletons for carrying heavy spare parts[44] | Similar to Degree 1<br>Additionally, it will be possible to monitor and control the equipment from the remote-control centre. Seafarers will be able to intervene in case of need. | Transfer of control to the remote-control centre[70]<br>Increased redundancy to withstand potential failure conditions[70]<br>More use of batteries and green energy solutions[44]<br>Increased number of cameras/microphones installed | Intelligent systems monitoring alarms and analysing their criticality dynamically[78,79]<br><br>More automated ships operations (automatic fuel change, reconfiguration, etc.[67].) |
| 5 | Security, safety, and emergency management (ISPS conformance, cybersecurity resilience, safety monitoring, emergency management) | Cameras at ship access points and safety critical locations e.g., bilge pumps, hull openings, watertight door's locations, fuel systems) [68]<br>Security system installed at the network connection between the ship and other systems [68]<br>Firewalls between the crew personal and passenger networks and the ship industrial network [68]<br>Intrusion detection systems [68]<br>Distress monitoring, identification and management systems supporting the crew using AI [68] Use of remote rebooting systems [68]<br>Otherwise, business as usual[68] | Similar to Degree 1<br>Transfer of monitoring data to the remote-control centre<br>Remote control centre updating the software in cooperation with seafarers[68]<br>Remote control centre activating equipment in cooperation with the seafarers [68] | Increased use of cameras and firewalls as for degree 1<br>Use of emergency plans and minimum risk conditions[70]<br>Use of reduced operation modes[70]<br>Special alert systems (alert to other ships in case of critical failures)<br>Use of resuscitating ship drones (in salvage operations)<br>Use of predefined safe emergency locations[70]<br>Remotely controlled firefighting systems[81]<br>Altered damage stability management due to crew removal[82]<br>Use of augmented reality to support decision-making and training [18,77] | Ships executing on its own a set of emergency rectification actions[67]<br>A future futuristic concept will employ robots or avatars for extinguishing fires or implementing resuscitation operations.<br>Otherwise, same as for degree 3 |
| 6 | Environment protection (systems controlling the fuel, lubricants, engine, ballast water treatment emissions, garbage, sewage) | More sensors installed<br>Use of dedicated condition monitoring systems [44]<br>Systems and operations as usual | Similar to degree 1 | Similar to degree 1 but with more remote control<br>Less problems with garbage | Ship making decisions with respect to ship power plant configuration, ballasting, lubricants [19] |
| 7 | Maintenance (technical and electronic systems) | More predictable failures thanks to the use of condition monitoring solutions[44,61]<br>Use of tablets, etc. by the crew<br>Remote assistance from the shore through videocalls[44]<br>Possibility for remote software installation[44]<br>Use of underwater vehicles for hull inspection and cleaning[44]<br>Otherwise, maintenance as usual using the same personnel | Similar to Degree 1<br>All the condition monitoring data transferred to remote control centre<br>Maintenance implemented by crew [19]<br>Use of underwater vehicles for hull inspection and cleaning[44] | Change of maintenance procedures to make them similar to the one conducted on aircraft i.e., only in ports not during sailing[67]<br>Use of underwater vehicles for hull inspection and cleaning[44] | Ship optimizing the load of components based on health and environmental predictions<br>A future futuristic concept will employ robots or avatars for maintenance[44]<br>Use of underwater vehicles for hull inspection and cleaning[44]<br>Otherwise, similar to degree 3 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Ship administration and planning (noon reports, commercial reports, crew passenger list, certificate lists) | Tools supporting the certificates status monitoring[44]<br>Use of digitalised certificates (paperless systems[44])<br>Automatic reporting systems integrating information [62]<br>Automatic crew hours reporting system[62]<br>Use of “Alexa” to support decision-making[83]<br>Fleet optimisation skills[77]<br>Use of cloud-based systems[84] | Certificates stored in cloud and accessible in the same way by the seafarers on board<br>Ship administration data transferred to the remote-control centre and compiled in the reports there<br>Use of “Alexa” to support decision-making | The responsibility for managing the ship certificates and generating reports will be transferred either to automatic systems on ship or to the shore | Ship automatically gathering information, compiling it into reports, and sending to the relevant authorities |
| 9 | Hotel (general accommodation services) | Use of smart rooms for accommodation (individual temperature regulation, room entrance based on footprints, smart lights, etc.[64])<br>Use of smart fridges in the galley[85] | Same as degree 1 | Minimum facilities for the personnel on the vessel in ports | Minimum facilities for the personnel on the vessel in ports |
| 10 | Logistics management (Managing charter, cargo, operations, port operations) | Use of Artificial intelligent algorithms for data analysis and decision support[86]<br>More integrated, real-time information systems/platforms<br>Use of “Alexa” to support decision-making [83]<br>More IoT sensors and information for Industry 4.0 capabilities | Same as degree 1 | Same as degree 1 with the constraint that only ports allowing crewless cargo operations or allow embarkation of relevant personnel will be used | Same as degree 3 |
| 11 | Voyage management (voyage management tools, arranging port services) | More decision support tools, integrated to other tools[61,67] | Same as degree 1 | Same as degree 1 | Voyage plan arranged by an automatic system on shore [87]with the human has only a supervisory role. |
| 12 | ISPS management | More advanced software solutions facilitating the implementation of Safety Management System (SMS) | SMS based on the data gained from the ship | Same as degree 2 | Automatic checking of ISPS implementation based on sensors measurements |
| 13 | ISM management | More advance software solutions facilitating the implementation of SMS<br>More advanced cybersecurity protection in the offices | Same as degree 1 | Same as degree 1 | Automatic checking of SMS implementation based on sensors measurements |
| 14 | Technical management (Equipment monitoring and maintenance planning, spare parts acquisition) | Planned Maintenance System integrated with condition monitoring data and supply department[61]<br>Otherwise, business as usual | Same as degree 1 | Will change to allow maintenance in ports/maintenance hubs<br>Will be heavily reliant on condition monitoring data measurements and predictions | Same as for degree 3 |
| 15 | Crew management (maintaining and planning crew lists, monitoring competence and workloads) | Decision support systems for arranging crew transfer<br>Smart watches monitoring the crew health[88]<br>Tools supporting the crew educational and performance level monitoring | Same as degree 1 | Rules relevant to shore will be applied therefore this operation will change | Same as for degree 3 |
| 16 | Lock and bridge control (Management of bridges and locks) | Remote locks and bridge management employing cameras and networks (not relevant to ship or ship operating company[89]) | Same as degree 1 | Communication equipment will be required to ensure that the communication between locks and ships is sufficient | Ship will be communicating on its own with the bridges/locks |
| 17 | River information system (management of ships in the area, receiving information, sending information) | Business as usual<br>Receiving actual weather conditions observed by ships (using them as smart sensors) | Same as degree 1 | Same as degree 1 | Same as degree 1 |
| 18 | Bunkering support (ordering and coordinating) | Bunkering monitoring systems interconnected with actual bunkering conditions (amount of available fuel/energy) and market conditions (current/expected price)<br>Real-time monitoring of bunkering procedures[90]. | Same as degree 1 | Same as degree 1 | Ship/ remote control centre making decision on where and when to bunker |
| 19 | Consumables and spare parts (ordering and transferring) | Use of smart fridges automatically monitoring the amount of food<br>Remote monitoring of water levels and other supplies | Same as degree 1 | Will need to be aligned to maintenance implementation in ports | Ship or remote-control centre computers analysing and making decisions on their own |
| 20 | Cargo handling (related to use of port facilities) | More integrated decision support systems<br>Use of automatic twist locks[91]<br>Automation of loading unloading/ procedures[62]<br>Interactions with portable devices[62], blockchain technologies[92] | Same as degree 1 | Infrastructure in port needs to be altered to allow remote control of the cargo operations | Same as degree 3 |
| 21 | Passenger and crew handling (support embarkation and immigration services) | Use of monitoring and integrated systems for better management with the support of tokens/fingerprints/smart watches<br>Otherwise, business as usual | Same as degree 1 | NA | NA |
| 22 | Mooring/Berthing - automated or manual services (Selecting the services) | Use of remote docking [5]<br>Otherwise, business as usual | Use of remote docking[5] | Use of remote docking[5] | Same as degree 3 |
| 23 | Local Sensor Systems | Use of ships as part of local sensor systems (weather conditions)<br>Cameras and environment monitoring systems added to the fairway[66]. | Same as degree 1 | Same as degree 1 | Same as degree 1 |
| 24 | Planned Response Services (Coordination with ship) | Use of cameras/information systems onboard ship<br>Use of videocalls | Same as degree 1 | Use of minimum risk conditions specified in ConOps based on risk assessment[70]<br>Redundancy in systems[70] | System choosing on its own the set of minimum risk conditions<br>Otherwise, same as for degree 3 |
| 25 | Aids to Navigation /MSI | Business as usual | Same as degree 1 | Systems able to recognize aids to navigation | Same as degree 3 |
| 26 | VTS (monitor and instruct ships) | Business as usual considering that conventional ships will be cooperating with smart<br>Receiving actual weather conditions observed by ships (using them as smart sensors)<br>Automation in several sensors analysis[18,62] | Same as degree 1<br>VTS receiving cameras images from the remotely controlled ships | Same as degree 2 | Same as degree 2 |
| 27 | Electronic port clearance message | More automated systems integrated with ship administration tools[44]<br>Business as usual | Same as degree 1 | Same as degree 1 | Same as degree 1 |

## 3.7 The anticipated time framework for autonomous ships introduction and technologies development

Whilst there is a considerable number of research initiatives related to MASS, as described in the introduction, it is the most likely that the MASS introduction will be gradual, and the MASS technology will be first employed on small ships operating in the inland waters or close to the shore [17]. This can be attributed to the fact that the national regulatory frameworks can adapt faster to the changes than the international regulatory frameworks. It is also anticipated that the introduction of MASS related technologies will be gradual due to the technological barriers, with vessels having reduced crew being introduced first, then remotely controlled vessels, followed by the vessels having full autonomy [17]. Obviously, this gradual development is anticipated to influence the timeline for the desired technical skills on the market, which in turn will influence the timeline for educational needs development.

In 2016, it was projected that by 2020 the operation of ships with reduced crew and increased operation will be more widespread (corresponding to degree 1 and 2 of autonomy according to IMO), whilst by 2025 the commercial use of remotely controlled crewless vessels in national coastal area will be possible ([93] as in [94]) (corresponding to degree 3 of autonomy). It was also projected that the crewless ocean-going ships will be a reality in 2035 ([93] as in [94]) (corresponding to degree 3 of autonomy). Similarly, in 2018 [95] it was projected that the first order for a new build autonomous and remotely controlled vessel in the Baltic Sea will be implemented in 2021 with actual commercial deployment by 2025. Some other researchers assumed that the use of remotely controlled vessels will be widespread by 2040 [96], whilst according to more optimistic projections widespread use of fully crewless ships can be anticipated soon [44].

Yet, these predictions have not been verified by reality. Yara Birkeland, which has been advertised as the world’s first crewless vessel and was about to sail in 2019 has been launched at the end of 2021 in the Norwegian coastal zone after a series of delays [97] and significant increase in cost[98]. It is also expected to operate as crewed for the first years. There are currently no regulations for a remotely controlled and autonomous ship for operation on the Baltic region. This can be partly attributed to the COVID-19 restrictions but also to the objective technical difficulties associated with the uncertainty surrounding the technology.

On the other hand, as it has been referred to [99], several companies are already developing KETs for MASS such as situation awareness and collision avoidance systems, remote control centers, automatic mooring systems. Several projects have developed or are developing the prototypes of MASS [8-16]. Some ship types such as research ships can be easily or are already automated[100]. The area of research is quite intense, and MASS is receiving growing attention from the industry.

However, other parameters, such as the legal and financial barriers, should also be considered. Based on the above information and the academics’ questionnaire presented in Appendix A, the time framework shown in Figure 4 can be suggested for MASS. This time framework has been derived based on a relatively limited number of responses provided (9 in total) and most of the participants have declared quite high uncertainty in their provided estimations. The introduction of smart ships and associated technology has already been initiated, and the introduction of various smart solutions in the context of existing conventional shipping is a nowadays reality. The wide introduction of partially remotely controlled vessels is expected by 2025-2035. By 2030-2045, fully crewless vessels operating in the coastal area might be widely available, although some prototypes will be introduced much earlier[101]. The introduction of fully autonomous ocean-going vessels might be widespread in maritime shipping by 2035-2050.

The appearance of vessels with various autonomy degrees will not be sequential, but concurrent, as various autonomous systems will be developed and tested on vessels with varying IMO autonomy degrees. In this respect, the estimations provided here are more conservative, than in the previously mentioned studies and publications. Due to the high uncertainty of the matter, we avoid using this information to generate recommendations regarding the timeline of educational programs amendments. The representation of Figure 4 is simply a helpful schematic, depicting the findings of the questionnaire. Instead, as a risk control option to the risk of having an obsolete study program, we opt for the use of agile framework provided in Section 8 to be aligned with the relevant industry developments.

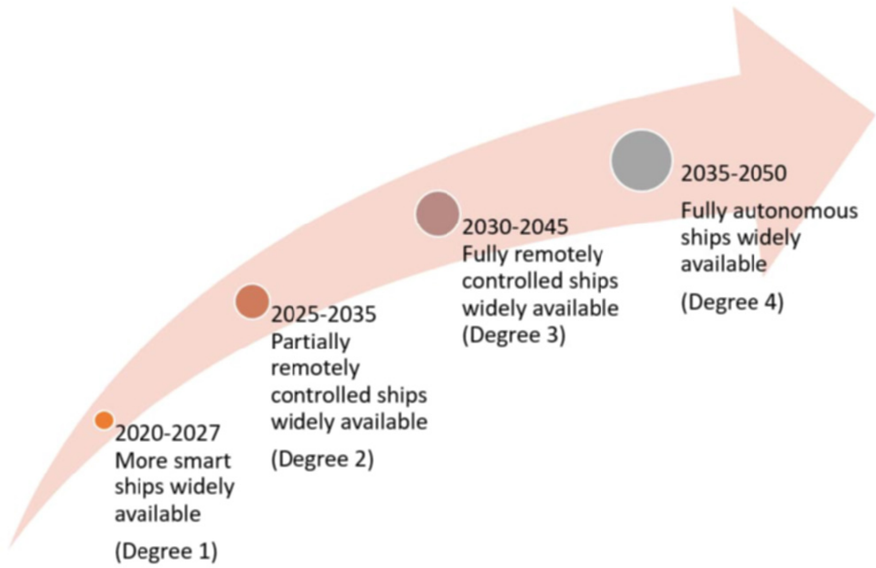


*Figure 4 The time framework for wide MASS introduction irrespectively of the ship type.*

## 3.8 Section conclusions

In this section, the various technologies, applicable to MASS of various autonomy degree have been identified and the time framework for MASS introduction has been proposed. The MASS will employ a series of technologies, which will be relying on the development in the realm of ICT such as the situation awareness system, collision avoidance system, remotely controlled and maintained systems, drones, novel upgraded fairways. It was identified that the implementation and use of ships with MASS degree 1 is becoming a more tangible reality, whilst higher autonomy degree ships are being slowly introduced in the maritime. Still, several KETs required for MASS operation will be developed in parallel and ships of mixed autonomy degree (operating either according to degree 3 or 4 in various operating modes) might appear earlier or in the intermediate time. Also, the time framework for the introduction of autonomy will vary with the ship size and with ship type.

# 4 Impact of MASS on humans and organisations (H, O)

## 4.1 Section outline

In this section, we investigate the impact of MASS technologies on the humans and organisations. First, we identify the different organisations/stakeholders responsible for the conventional ship's design and operations. Using the identified stakeholders, we identify the job positions and job requirements, relevant to the conventional ship's design and operation by considering ship life cycle activities. In the second part of this chapter, by integrating previously derived information, we investigate how the MASS technologies will impact the existing supply chains, regulatory and liabilities framework and jobs required skills in the various organisations.

## 4.2 The current jobs and organisations on the maritime market

This section analysis focuses on the maritime jobs existing in the maritime industry market. As maritime systems become more technologically advanced [102], the maritime community encompasses more jobs related to IT. These jobs are presented in Figure 5, which has been developed based on information provided in [103,104] and employing the feedback from AutoMare network. This figure also provides a brief overview of the main organization types in the maritime market.

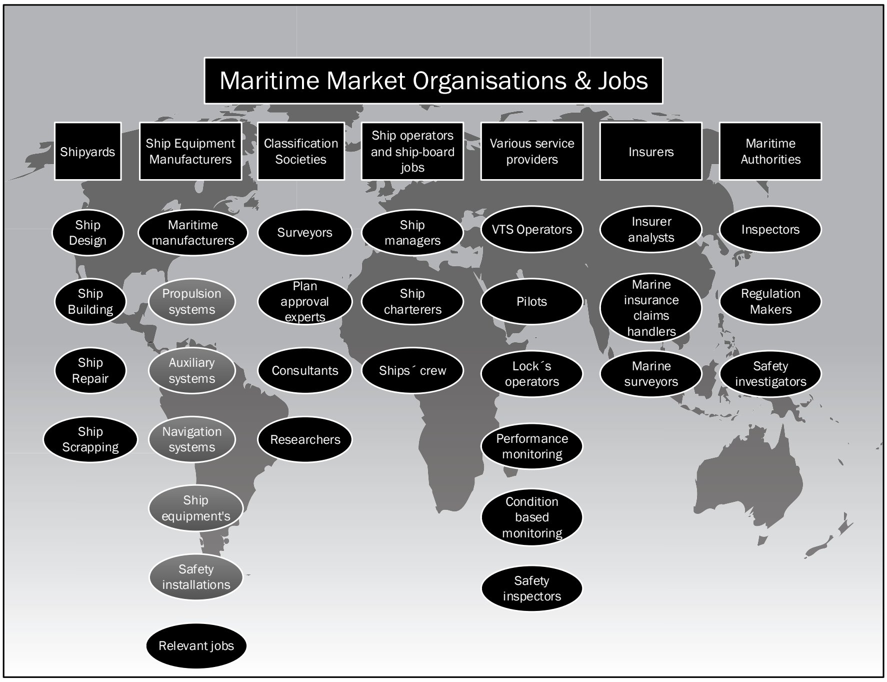


*Figure 5 Organizations on the maritime market related to existing ships.*

### 4.2.1 Ship design and building

#### *4.2.1.1 Ship design*

The list of main jobs that currently exists in the shipyards is provided in Table 2. This list includes the jobs related to ship design and their requirements. Some of these jobs might be also undertaken by the ship design office. For all these jobs in addition to the specified skills, good understanding and knowledge of the relevant regulatory and legislative framework is required [105].

*Table 2 The list of jobs and required skills related to ship design.*

| **Job** | **Required skills** |
|---|---|
| Design/Project Manager[106] | Master's degree in maritime technology with associated software tools are needed for the job. Understanding of issues related to ship integration is required. His/her main responsibilities are to ensure the proper collaboration between different disciplines and resolve problems during the development of the design process. |
| Structure designer[107] | BSc or MSc in a relevant engineering or higher education qualification with a suitable experience and strong knowledge in the ship structures (steel fatigue resistance and production methods) and design processes. |
| Ship designer[108] | Bachelor or Master of Science in naval architecture. The background studies cover, design, engineering, management, manufacturing systems, materials, and mathematics. Good knowledge of relevant tools and techniques. |
| Hydrodynamic expert[109] | Higher degree in naval architecture and hydrodynamics is required for this job. An average experience in association with hydrodynamic investigations (inclusive of undertaking PhD studies). Knowledge of relevant software tools is required. |
| Piping designer[110] | Associated degree in applied sciences that emphasizes modelling solid objects, architectural drawing, descriptive geometry, 3D AutoCAD techniques, electrical and mechanical drafting. |
| Electrical systems designer[111] | Bachelor's degree in electrical engineering or MSc or associated degree and experience in electrical engineering design and electrical installation.<br>Experience with design tools such as AutoCAD and 3D modelling software tools are required. |

#### *4.2.1.2 Ship building*

The list of jobs and required skills presented in Table 3 is related to ship building during the construction phase. These personnel follows plans and drawings set previously by designer (jobs presented in the previous section) and interact with different design departments and engineers mentioned in Table 2 to build and test the ship [106]. Some basic jobs have been decreased in number because of the technological advancements in a wide range of machinery and manufacturing processes [112]. Those jobs are replaced by programmable machinery pre-set according to specific needs, which offer greater productivity and accuracy.

*Table 3 The list of jobs and skills required for shipbuilding.*

| **Job** | **Required skills** |
|---|---|
| Welding designer [113]/Welding engineer [114] | Welding designers should have knowledge in chemistry, material science, fluid mechanics, heat transfer, thermodynamics, manufacturing optimizations and mechanics, to have a complete understanding of the materials joining process. |

| | |
|---|---|
| | These qualifications should be integrated into welding design and materials selection to prevent welding failures.<br>S/he should have strong technical welding technics and hold the related certificates, to perform welding supervisory tasks and control qualified welders, implement quality assurance procedures for purchasing materials, liaise with the class society and owners regarding statutory regulations and classifications standards. |
| CNC engineer (mill, router, grinder, or lathe) [115] | Basic knowledge of the traditional machining process and machinery operation. strong knowledge of computer numerical control Computerized Numerical Control (CNC) machines to set up operations, load programs to the relevant machine and write programs as well. S/he should have computing skills background to understand blueprint reading and Geometric Dimensioning & Tolerancing symbols and other software related programs, and knowledge of different type of machines and equipment. |
| Steel cutting engineer [107] | Bachelor's degree in materials science or engineering. The employee should have knowledge of metal cutting applications (turning, milling, etc.) and be familiar with cutting tool design and cutting tool manufacturing. |
| Installation engineer [116] | BSc or MSc in mechanical engineering with strong technical knowledge (mechanical, structural, electrical and ship systems) within the maritime industry. In this position, the employee is the central link between the shipowner, yard, consultancies, class, and the design team. S/he should have experience of each phase of the construction process and technical expertise to manage or retrofit the relevant installations onboard the ship. |
| Automation engineer [117] | BSc or MSc in electrical engineering or relevant technical study with onboard knowledge in ships or the maritime industry. The employee should have an experience in the design and installation of complex automation systems and be able to manage and work with construction phase stakeholders. S/he ensure compliance to all applicable requirements and specifications imposed by class and the customer, and support installation on board ships. |
| Commissioner, ship machinery systems [118] | Technical training and experience in ship machinery systems installation, maintenance and repair are required. |
| Welders [116] | Shipyards are usually strict on hiring qualified welders, each welder is tested after completing a specific training program, through his welding quality (non-destructive testing method). They represent one of the most notable members in shipyards and their contribution in the ships building process is crucial. Welders are skilled in all types of welding (ARC, MIG, TIG welding, etc.) |
| Structural fabricators [116] | They are required to have completed an apprenticeship program with the related theory terms which cover some advanced engineering techniques. They can understand engineering drawings and have the necessary skills to do, with accuracy, fabrication jobs. |
| Plumbers [116] | They are specialized in fitting and installing pumps, pipelines, valves, flanges… they have skills in the related field. Plumbers are required to fulfil an apprenticeship program with specified theoretical courses. |
| Electricians[116] | They are responsible of the installation of electrical equipment on board ships (electrical cables, motors and switch boards, navigational equipment…). They are required to have the necessary qualifications to read electrical drawings and to identify different components. |
| Riggers[116] | They are responsible for carrying out and shifting heavy structures and equipment. They are trained and certified to operate specific type of cranes. |

#### *4.2.1.3 Ship repair*

The ship repair jobs are provided in Table 4. These jobs represent the main tasks the yard requires to manage ships major maintenance, repair and retrofit. They are usually in continuous cooperation with other stakeholders, including ship equipment manufacturers, other repair companies (subcontractors), class societies and authorities, ships' crew, and operators to accomplish tasks required by shipowners within a prefixed timetable. It is necessary to highlight those other jobs, which represent the most important skilled workforce in the yard, are not mentioned at the table below, but they are working under the relevant departments and workshops to provide specific service or assigned work from ships engineer. These jobs are qualified welders, technicians, electricians, painters, carpenters, plumbers, fitters, riggers, skilled safety personnel, etc. and have already been provided in Table 3.

*Table 4 The list of managerial jobs in shipyard related to ship repair and retrofit*

| **Job**[119,120] | **Required skills** |
|---|---|
| Ship repair manager[121] | BSc or MSc in naval architecture. S/he is an experienced engineer who has fulfilled relevant positions related to the maintenance and repair process in the shipyard that emphasizes his/her in-depth technical background. The manager should be competent enough to manage substantial number, type of ships, and have good negotiation skills to deal with different ships managers and third party (ship suppliers or subcontractors). |
| Dock master[122] | BSc or MSc in mechanical engineering or similar. S/he is the link between the shipowner (superintendent, chief engineer, and master), yard and stakeholders. The employee should have a relevant experience in ship operation, ship systems and statutory regulations. Strong managerial skills are required to achieve ships repairs within the timetable. |
| Service field engineer[116] | BSc or MSc in mechanical engineering or naval architecture. S/he should have relevant experience in a specific ship machinery system (propellers, shaft sealing rings, engines, safety equipment, etc.). Good managerial and technical skills to meet the repair deadlines and deal with unexpected problems. |
| Dock yard mechanical engineer[123] | BSc or MSc in mechanical engineering. Good knowledge of shipyard operation and maritime environment. In-depth knowledge of maintenance and technical regulations. Should have managerial skills to lead the team of mechanical engineering group in yard and cooperate with stakeholders (subcontractors, ship owner/manager, and shipboard managers). |
| Dock yard electrical engineer[124] | BSc or MSc in industrial maintenance with a major in electricity. Good knowledge of shipyard operation, ports, and maritime environment. In-depth knowledge of maintenance and technical regulations. Should have managerial skills to lead and manage the team of electrical engineering group in yard and cooperate with important stakeholders (ship owner manager and shipboard managers). |
| Safety Officer[125] | Undergraduate employee experienced in the maritime industry and ship repair environment. S/he should hold safety related certifications and be familiarized with the relevant safety and security standards. The employee should have in-depth knowledge of how to use and deal with different equipment and safety installations in the shipyard and be familiarized with safety equipment onboard ships. |

#### *4.2.1.4 Ship scrapping:*

The ship scrapping jobs are provided in Table 5. Compared to the other jobs, the required skills involve the least of technical knowledge.

*Table 5 Ship scrapping jobs*

| Job | Required skills |
|---|---|
| Ship recycling operation managers [126] | The main responsibility is the organization of a sustainable dismantling process of ships and following of standard operation procedures. They are required to have a strong management and engineering knowledge. They should be familiar with ships recycling regulations such as The Basel convention[127] , The Hong Kong convention[129], EU ship recycling regulation[130], and local concerned authorities' policies. |
| Safety officers [131] | They are required to ensure the implementations of safety plans and measures, and to control the safe and the environmental sound operations, during the breaking process on board ships and in yard. Safety officers are required to have in-depth qualifications related to health, safety, and environment (HSE) standards, and be familiar with safety, security and environment protection equipment and installations to manage emergency situations that could occur (first aid, firefighting, oil spill control, etc.). In addition, they should have knowledge in ships scrapping procedures. |
| Workers [132] | Workers in the ship recycling industry represent the major labour force. They are employed to cut steel (manually using hand-held Oxy-LPG torch) and to dismantle ship's equipment. There are no strict qualification requirements for this kind of jobs. Nevertheless, workers should be aware about health, safety, and environment norms. |
| Brokers [133] or cash buyers | Brokers are intermediaries between ship owners and scrapping yards. They oversee regulatory and technical processes to finalize the smooth transfer of the vessel to the recycling phase. |

### 4.2.2 Ship equipment manufacturers

The list of main marine equipment manufacturers is provided in Table 6 and Table 7. Based on the jobs advertisement that are provided on the websites of these equipment manufacturers we have developed the list of the main equipment design and manufacturers jobs as in Table 8.

*Table 6 Marine equipment manufacturers*

| Equipment | Main manufacturers |
|---|---|
| Marine Diesel Engines | WARTSILA[134], MAN[135], MAK[136] |
| Diesel Generators | STX-MAN[137], WARTSILA, MITSUBISHI[138], MAN |
| Propellers | ROLLS ROYCE[139], WARTSILA |
| Stern tube seals | SKF[140] |
| Turbochargers | MAN, and ABB[141] |
| Centrifugal pumps, volumetric pumps | DESMI[142], IMO[143], ALLWEILER[144], GRUNDFOS[145] |
| Boiler | AALBORG-ALFALAVAL[146], SAACKE |
| EL Motors | ABB[147], HOYER[148] |
| Valves | ARI ARMATUREN[149], AMOT[150], DANFOSS, PLEIGER[151] |
| Coolers and heat exchangers | ALFA LAVAL[152] |
| Gearboxes and bearing block | VOLCAN, RENK[153] |
| Fuel and oil centrifugal separators | ALFA LAVAL[152], GEA WESTFALIA[154] |
| Fresh water generators and reverse osmosis | HAMWORTHY[155], ALFA LAVAL, ROCHEM[156] |
| Compressors | SPERRE[157], SAUER[158], ATLAS[159] |
| HVAC systems | NOVENCO[160] |
| Chiller compressors | YORK[161], JOHNSON CONTROL[162] |
| Hydraulic installations and deck machinery | TTS-MACGREGOR[163] |
| Steering systems | MITSUBISHI[138], ULSTEIN |
| Ballast water treatment systems | ALFA LAVAL, GEA group, HITACHI, VEOLIA, WARTSILA |
| Sewage evacuation and treatment system | EVAC[164] |
| Oily water separators | RWO[165], WARTSILA[166] |
| Fire extinguishing system HI Fog | MARRIOFF[167] |
| Fire detection systems | CONSILIUM[168], AUTRONICA[169] |
| Lifesaving equipment | VIKING[170], DAVIT[171] |
| Engine monitoring system | KONGSBERG[172], AUTRONICA |
| Integrated bridge system and navigation equipment's[102] | RAYTHEON, EGLOBE, KONGESBERG, ECPINS, SPERRY, JRC, TRANSAS, WARTSILA[173] |

*Table 7 Finnish shipyards main marine equipment manufacturers[174]*

| Field or equipment | Manufacturers |
|---|---|
| Energy, Environment and Propulsion Systems | ABB, AirNow, STEERPROP, YASKAWA, WARTSILA |
| Electrical systems, Automation, and components | HELKAMA, Promeco, Valmet |
| Safety and security, alarm systems | Marioff |
| Navigation systems | FURUNO FINLAND OY |
| Insulation solutions | PAROC SAINT.GOBAIN |
| Tools and equipment | TS-EN |
| Ship supply | CARGOTEC |
| Turnkey suppliers | MARKINEN, NIT |
| B-class CABIN and interior doors | ANTTI-TEOLLISUUS |
| Lilts & Escalators | KONE |
| Materials and components | nora |
| HVAC solutions | AirD |
| Empathic Building | TIETOEVRY |

*Table 8 List of existing jobs and their requirements*

| **Relevant Jobs** [175–177] | **Required skills** |
|---|---|
| Design Engineer | BSc in Science, Technology, engineering, and mathematics with an experience in MDA (Model Driven Architecture) engineering practices and processes. Modelling in 3D and creating technical drawings in Autodesk Plan 3D, Autodesk Advance Steel, Autodesk Inventor.<br>Confident with 3D modelling in a similar integrated tool (piping, equipment, structural).<br>Knowledge of system engineering processes. |
| Mechanical and thermal design | BSc is required, MSc degree preferred.<br>Knowledge of thermodynamic and engine simulation, understanding of material properties, metallurgical and mechanical processes.<br>Technical skills set, including MATLAB and basic knowledge of thermodynamics, heat transfer, mechanical design, and machine controls and relevant simulation tools.<br>For managing positions, experience in the specified field is required. |
| Electrical Design Engineer (Hardware Product Design Team) | BSc or MSc in electrical engineering is required. Good knowledge of power networks simulations, components functions and properties, implementation of relevant calculations.<br>Strong understanding of system design for assemblies or installations with lithium-ion batteries. E3D cable design and AutoCAD are software qualifications needed for the job. |
| Project Manager | MSc in mechanical engineering or business and relevant experience.<br>Strong possession of project management skills, ability to understand the basics behind the different processes used to design and manufacture the systems. |
| Fluid simulation Engineer | MSc in mechanical engineering, other qualifications are required such as expert knowledge of software tools (star CCM+, Ansys (CFX, ICEM CFD, CFD post), etc.).<br>Experience pre-processing, post processing and solving of CFD (computational Fluid Dynamics Simulation Software) simulation tasks related to internal combustion IC engines. To perform simulation to analyse flow behaviour of engine components and auxiliaries submitted to heat loads and flow dynamics. |
| Data Analyst | BSc in IT and automation. Knowledge of Structured Query Language SQL database and in general data analytic and data analysis. Knowledge of Python and R should be of advantage. As an IT engineer for equipment, s/he needs an understanding of engine machinery. |
| Automation Engineer | BSc degree in electrical or automation engineering. Familiar with PLC programming, design of control system and use of AutoCAD. An experience in the maritime industry is required as the engineer is working in developing and resolving solutions in deck machinery products and motion control. |

| | |
|---|---|
| Senior embedded software engineer-controls | BSc or MSc in computer or electrical engineering and should meet the required qualifications: C++ programming skills for embedded systems applications, architecture and design of embedded software modules and experience with PIC, Renasas, X86, and ARM microcontrollers. |
| System and integration engineer | BSc degree in computer science or software engineering and technical discipline (mathematics, physics, engineering). Required experience in the field of, electronic equipment, software development, network architecture and configuration. The engineer should have a great interest in technical and complex software systems. |
| Production test engineer | BSc degree in engineering or physics. The engineer should be familiar with LabVIEW, DOORs, and MATLAB. |
| Cybersecurity systems engineer | BSc degree in STEM and MDA experience, configuration, operations, and connectivity.<br>S/he should have experience in cyber tabletop exercise (CTTX). |
| Field service engineer | BSc degree in electronics, instrumentation, automation, or telecommunication with an experience in the maritime industry. Good knowledge of the relevant systems and ability to support the service processes. |
| Machine learning engineer | MSc or PhD degree in applied Math, Statistics, Physics, computer science or engineering. Strong knowledge of machine learning techniques, data analytics, statics, and numerical methods. Strong coding skills in Python and other programming languages.<br>This job type for using and developing Digital Twin technologies to digitalize the maritime sector. |
| Human factors experts | He should be experienced in a relevant field, to inform design and support qualitative and quantitative human error assessment. The employee should be able to develop and assess the Human Machine Interface (HMI). |
| Robotic engineer[179] | The employee should understand electronics, mechanics, and software. S/he should have qualifications to master the relevant tasks; Autonomous Underwater Vehicles (AUV) data systems, hydrographic, sensors, acoustic equipment, maintenance of electronics and mechanics equipment. |

### 4.2.3 Classification societies

Class societies are non-profit organisations introduced to protect the interests of shipowners, cargo owners and insurers. Among the most important are DNV[180], Lloyd`s Register of shipping (LR)[181], Bureau Veritas (BV)[182], the American Bureau of shipping (ABS)[183], Russian maritime register of shipping (RS)[184], Registro Italiano Navale (RINA) [185]and Nippon Kaiji Kyokai (ClassNK)[186]. More than 90 % of the worldwide maritime fleet tonnage is covered by the classification design, construction and standards set by IACS (International Association of Classification Societies) member's societies [187].

The classification societies exercise an important influence over the maritime safety through rules development, interactions with regulatory authorities, the verification of compliance with rules and regulations, technical support, and research & development. In this respect, the classification societies have a core relationship in the maritime industry by providing connection between various maritime stakeholders including shipowners, insurance companies, shipbuilders, and seafarers, promoting the maritime safety. To this mean, the class societies employ the surveyors who attend the ships for inspections and monitor the ship compliance to class rules. The class societies also influence the development of novel regulations at IMO and the national level through their research engineers. Furthermore, the class societies have personnel for reviewing the new building ship drawings and providing safety assurance for novel technologies. Lastly, the class societies offer consultancy services to the wider maritime community.

*Table 9 The jobs and required skills at classification societies organisations.*

| **Job** | **Required skills** |
|---|---|
| Surveyors[188] | Thorough knowledge and experience in classification rules and regulations especially of the IMO pillars (SOLAS, MARPOL, STCW, MLC) and other crucial statutory requirements for marine new construction and periodical survey work (ship's hull and machinery systems). In depth experience in marine repairs, material, and equipment surveys and ability to classify and certify merchant vessels based on their structure, design, and safety standards. |
| Researchers[188] | BSc or MSc from an engineering school, have an experience within the maritime industry and knowledge of classification field. Valuable experience in the field of digital and smart marine technologies as research will focus on developing technical and classification rules for digital and smart marine technologies, in communication, connectivity, data management and automation, human factors, safety, security, etc. The researcher should have the right skills a mindset of analytic approach, to work within R&D department. Advanced programming skills are required. Furthermore, in-depth knowledge in several fields for instance, autonomous vehicles and collision avoidance systems, sensors, cybernetic, robotics, computer vision, deep neural nets, artificial intelligence and ship operation and navigation [189]. |
| Plan approval experts[188] | Merchant navy officers' (mechanical engineer degree) or naval architect background. Extensive experience in the design, operation of propulsion and mechanical ship systems. The marine engineer purpose`s is to conduct design reviews of piping and machinery systems in compliance with regulations. |
| Consultancy (a marine consultant)[190] | Several specialists in their realm, who are knowledgeable in a specific area of ship operations or ship design. A marine consultant holds a BSc in marine engineering or marine system engineering. There are also some certification courses in a marine consultancy. |

### 4.2.4 Ship operator and shipboard related jobs

#### *4.2.4.1 Ship manager*

The Table 10 presents relevant ship companies' departments to operate and maintain ships in compliance with class societies, local authorities, and IMO regulations, standards, and requirements.

*Table 10 The list of job types on shore and on ship necessary for ship operations.*

| **Job type** | **Required skills** |
|---|---|
| Technical department | The technical department is staffed by highly experienced marine engineers or graduates with university degrees. The main purpose of the department is to maintain the fleet in accordance with class, national and international maritime standards:<br>-Superintendent: mechanical engineer who holds a master's degree and have an experience in ship operations. |

| | |
|---|---|
| | -Technical manager: a former superintendent with strong experience and managerial skills. |
| Safety department | The safety department employs mechanical engineers and deck officers (safety officer). They are required to manage security and safety plans and collaborate with technical department to maintain ship safety systems in accordance with regulations.<br>Designated person ashore (DPA) is usually a part of the safety department. S/he should have a degree in a relevant management or engineering field or have STCW certificates and an experience on seagoing in senior managerial position. Knowledge of relevant human factors is also of an advantage. |
| Crew department | The main concern is to maintain the fleet crewed in accordance with the minimum safe staffing crew list and to control seafarer qualifications and certificates updated to the international regulation's standards.<br>This department is staffed with naval officers knowledgeable in the updated regulations standards (STCW convention, MLC, etc.) and usually the department is headed by a former captain. |
| Spare parts department | They are mechanical engineers, and they should have strong knowledge of ship systems and their spare parts. |
| IT department | The IT department is responsible for maintenance of software systems used by ship and ship operating companies as well as cybersecurity and cyber defence.<br>IT department is staffed by computer science engineers. |

#### *4.2.4.2 Ship charterer related jobs*

Chartering is the act of renting the vessel from owners for fixed term for a short or extended period depending on the charter party and the type of chartering [191]. Chartering jobs are presented in Table 11.

*Table 11 Charters jobs and required skills*

| **Jobs** | **Required skills** |
|---|---|
| Ship charterer[192] | Degree in economics, trading, logistic and transportation. Some chartering companies prefer that the charterer has a little experience onboard ships for management level positions (e.g., executive operations). S/he oversees trading and chartering contracts, management of voyage documents, liaise with other parties (suppliers, surveyors, bankers, and customers) and control all phases of shipping process. |
| Shipbroker[192] | S/he is an intermediate between two parties in the shipping industry (charterers-shipowners or buyers-sellers of ships). The shipbroker is a graduate with studies background in shipping industry, business, economics, and logistics. |
| Contracts officer[191] | Big chartering companies, hire employees for preparing, reviewing, and negotiating contracts for specific products such as petroleum products and crude, or dry cargo. The contracts officer main responsibility is to prepare contacts and ensure that commercial terms are within the company agreed bounds. S/he is required to have basic financial analysis skills and be able to understand maritime and trade laws. |

#### *4.2.4.3 Ship crew*

In this section, the jobs onboard ship and the relevant educational requirements are being presented. For that, information presented in the 1978 IMO international convention on Training, Certification and Watch keeping for seafarers (STCW) considering the 2010 Manila amendments is used [193]. The STCW convention is one of the four pillars of the world maritime regulatory system. The other pillars are SOLAS, MARPOL and ILO Maritime Labour Convention.

Under the STCW convention, all seafarers are required to have completed the required seagoing service and have completed an approved education and training program to step forward to the next higher certificate of competency [193].

A typical ship-board organizational structure is presented below in Table 12 which explains several jobs (in connection with the seaworthiness of the ship) requirements and educational qualifications on board merchant vessels regarding their level of responsibilities. Other additional STCW specific certificates are required for seafarers working on board tankers and passenger ships engaged in international traffic, but they are outside the analysis scope.

*Table 12 Ships of 3000 gross tonnage or more and powered by main propulsion machinery of 3000 KW or more[194,195]*

| Jobs | Regulatory Requirements | Description and educational requirements |
|---|---|---|
| | **Deck department** | |
| Captain | Certificate of competence for Captain and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | Should have the required certifications as an officer in charge of navigational watch and have at least 36 months approved seagoing on-board ships, Nevertheless, this period can be reduced to 24 months if not less 12 months has been served as Chief mate.<br>Have completed education and training requirements as specified in section A-II/2 of the STCW code. |
| Chief Mate | Certificate of competence for Chief mate and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | should have the required certifications as an officer in charge of navigational watch and have approved at least 12 months of seagoing on-board ships.<br>Have completed education and training requirements as specified in section A-II/2 of the STCW code for Captains and Chief mates. |
| Deck officer | Certificate of competence for navigational watch officer and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | should have completed the competences required in section A-II/1 of the STCW code and have approved at least 12 months training program on board merchant ships of 500 gross tonnage or more, as a deck cadet. |
| Radio operators | General operator's certificate (GOC) or restricted operator certificate (ROC) and endorsement (flag state endorsement recognition)<br>Radio operator certificate of competence (CoC)<br>STCW certificates (Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization). | Have completed approved education and training and met standard of competence. |

| | | |
|---|---|---|
| Able seafarer deck | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization. | Have completed 18 months of approved seagoing service in the deck department, or 12 months and completed approved training.<br>Approved training onboard or ashore with at least 12 months of sea service. Standard competence is specified in section A-II/5. |
| Rating forming part of a navigational watch | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization. | Have completed the approved seagoing service, including 6 months of training and experience.<br>Must meet standard of competence specified in section A-II/4 |
| | **Engine Department** | |
| Chief Engineer | Certificate of competence for Chief Engineer and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | should have the required certifications as an officer in charge of an engineering watch and have at least 36 months of approved seagoing on-board ships. Nevertheless, this period can be reduced to 24 months if not less than 12 months has been served as second engineer.<br>Have completed education and training requirements as specified in section A-III/2 of the STCW code. |
| Second Engineer | Certificate of competence for Second Engineer and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | Should have the required certifications as an officer in charge of an engineering watch and have at least 12 months of approved seagoing on-board ships.<br>Have completed education and training requirements as specified in section A-III/2 of the STCW code. |
| Engineer officer | Certificate of competence as an officer in charge of an engineering watch and endorsement (flag administration authorities' recognition).<br>STCW certificates (GMDSS endorsement, Medical first aid, Survival craft and rescue boat, Advanced firefighting, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization) | Should have completed the competences required in section A-III/1 of the STCW code and have approved at least 12 months training program on board merchant ships powered by propulsion machinery of 750 Kw or more, as an engine cadet. |

| | | |
|---|---|---|
| Electro-technical officer | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, ship specific familiarization, Security familiarization. | Have completed no less than 12 months of combined workshops and skills training and an approved period of at least 6 months seagoing service as part of a training program.<br>Have completed education and training program as specified in section A-III/6 of the STCW code. |
| Rating taking part of an engineering watch | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization. | Have completed approved seagoing service, including 6 months of training and experience. During the special training period, the rating must have not less than two months seagoing.<br>Must meet standard of competence specified in section A-III/4 |
| Able seafarer engine | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization. | Have completed 18 months approved seagoing service in the engine department, or 12 months and completed approved training.<br>Approved training onboard or ashore with at least 12 months of sea service. Standard competence is specified in section A-III/5. |
| Electro-technical rating | National certificate of competence, Basic safety training, medical fitness, Basic safety familiarization, Ship specific familiarization, Security familiarization. | Have completed approved seagoing service training and experience not less than 12 months.<br>Qualifications that meet standard competence specified in section A-III/7. |

### 4.2.5 Various service providers

In addition to the general maritime stakeholders, there are various service providers. The service providers offer specified functions in exchange for monetary reward to the other maritime stakeholders such ship managers and owners [196]. A list of service providers is presented in Table 13.

*Table 13 List of service providers and required skills*

| Job | Required skills |
|---|---|
| VTS operator [197] | VTS operators should hold a certificate of VTS operator V-103/1 and have the minimum qualifications of watchkeeping officer which include seagoing experience and related certifications (Certificate of Competence, radio certification, radar/ARPA certificate). They should be knowledgeable in traffic management, equipment communication coordination and should be able to make decisions in emergency situations. The VTS training course is supported by VTS simulator exercises. |
| Pilots [198] | To exercise the profession of maritime pilot, the candidate must have the training certificates required by the pilot station standards which can be:<br>• Certificate of Master first class in maritime navigation<br>• The degree of higher studies of the merchant navy<br>• Captain's certificate for 3000 gross tonnage ships<br>Pilots should also have a seagoing experience specified by the administration state. A pilot must pass an examination to ensure that the candidate successfully fulfils specific requirements and then, get a Pilot License. |
| Locks' operators [199] | Canal locks do not need high qualifications to control and to operate canal locks. Some advanced locks, such as Falkirk wheel, are operated from a control room[200]. Operators should have knowledge of the related machinery and required mechanical systems. |
| Performance monitoring experts [201] | Several companies offer performance monitoring services on behalf of ship manager. To implement this function, the employee needs to have a good knowledge of ship hydrodynamics, of ships main systems, and ship hull fouling conditions. Advance performance monitoring solutions require understanding of artificial intelligence algorithms and big data analytics tools. |
| Condition based monitoring | This is a function enabled using machine learning and big data analytics techniques. The relevant employee needs to have a thorough knowledge of the related machinery and of the big data analytics tools. |
| Safety equipment inspectors[202] | A good knowledge of safety related equipment and equipment installation on board ships is required. |

### 4.2.6 Insurers

Insurers cover expenses associated with loss, damage or any accident that may happens to ships equipment and hull's structure, and any damage caused by the ship subject regarding to the maritime organisations and environment[203,204]. Insurers provide insurance to shipowners in exchange for monetary reward as stipulated in the related agreement. The list of marine insurance organization related jobs, in connection with functions and services provided to ships, is presented in the Table 14.

*Table 14 list of insurer jobs and their required qualifications.*

| **Job** | **Required skills** |
|---|---|
| Insurer analyst [205] | Strong knowledge of maritime law (MARPOL and COLREGs regulations), as well as criminal and civil law. Good knowledge of chartering process and involved parties' liabilities. |
| Marine insurance claims handler [205] | Experience with handling P&I claims or a legal background in handling shipping claims. S/he should have ability to deal with file administration, appoint marine surveyors and experts, and monitor their outcome from technical revenue and their point of views. S/he should also be able to assist them in damage investigations and collect all the necessary documentations. The employee is required to have an undergraduate level of education in economics, business, or related field. |
| Marine surveyors (marine insurance expert) [206] | The surveyor conducts a separate survey and an assessment of the condition of a ship. S/he acts as a specialist with tremendous amount of experience and massive knowledge of ships, ships equipment and regulations to handle different situations. Marine surveyor can perform marine warranty surveys, hull and equipment surveys and cargo surveys |

### 4.2.7 Maritime Authorities:

The main task of the national maritime authorities is to supervise the maritime industry. This includes the control of vessels registered in their flag according to national regulation and foreign vessels in their ports according to international regulations[207,208]. Furthermore, controls are applied through scheduled timetable or unexpected inspections. The main purpose of controls is to ensure that ship maintains high safety and environmental standards and crew onboard ships meet the needed qualifications in accordance with STCW regulations while working in good conditions regarding MLC convention (Maritime Labour Convention).

Port state and flag state control are established methods of controlling the technical and safety condition of vessels and ensure that vessels navigate according to appropriate standards. Inspectors who represent state authorities can check the implementation of the international conventions and standards related to the safety of navigation and environment protection for the flagged and foreign vessels within their jurisdictions. They are authorized to inspect ships and ensure the fulfilment of the requirements in maritime conventions (SOLAS, MARPOL, Load line, etc.) and take necessary actions against ships in evident non-compliance with these conventions[208]. Their required skills are provided in Table 15. Other investigated jobs include the regulations makers and team members of safety investigation group.

*Table 15 The required skills employed by the maritime authorities.*

| **Job** | **Required skills** |
|---|---|
| Port Managers[209] | Port managers are designated responsible for managing and planning port operations in safe and secure conditions. They cooperate with all port stakeholders. In connection with port security and international legislation, the Port Facility Security Officer (PFSO) is responsible for the implementation and revision of the port facility security plan. PFSO collaborates with Ship security officer, company security officer and port authorities in matter of security and security level[210]. The maritime safety committee has provided guidelines on the training and certification for PFSOs where security management skills are presented. BSc in engineering, logistics or business is required for port managers. |
| Inspectors[211] | Competent authority inspectors are marine engineers, naval architect, or merchant navy officers. The inspector must have a relevant university degree in the maritime industry and be trained in a school of ship safety inspectors. The inspector must have an appropriate knowledge of the provision of the international conventions and relevant flag state and port state control procedures. |
| Regulation makers[212] | An advanced university degree in maritime law is required. Strong legislation knowledge and excellent ability to provide legal advice to the Government and related authorities. He should have in depth ability to analyse legal instruments to ensure compliance with the IMO regulations. |
| Safety investigation authority group[213] | It is a group staffed by experienced captains, chief engineers (with master's degree in maritime management), safety officers and engineers, researchers in the relevant field and led by a chief marine safety investigator[213]. They need to be also knowledgeable in human factors. |

## 4.3 The broader impact of the introduction MASS on the maritime industry and supply chains

Automation and digitalization have been increasingly applied in maritime transportation [214–216]. MASS can be seen as part of a broader digitalization trend, capable of changing how the business is conducted [217,218]. Being a system innovation, the introduction of MASS requires changes in the current business procedures and the introduction of new roles. This means, the current business models of various stakeholders in the maritime market will be affected to a different extent and different opportunities for new business models will arise. Also, given the uncertainties regarding the legal status of MASS [219] and the unclear business case for MASS in commercial shipping[220] the implications of introducing MASS need to be clarified and taken into account in the business development of relevant business actors: shipyards, ship operators, ports, etc.

The benefits of implementing MASS will be enjoyed by different maritime business actors to varying degrees and in different ways. Currently, shipowners make the investment in autonomous capability on ships, though they may not operate the vessels. The logic in building and operating conventional ships has been maximizing financial benefits through cost reduction[220]. Hence, the shipbuilding industry focuses on standard designs for vessels carrying specific types of cargo (liquid or dry bulk, general or containerized). Minimizing capital investment in vessels while maximizing cargo capacity aims at reducing transportation cost and thus offering low freight rates to shippers. With MASS, new types of value may be created, especially for ship operators and shippers. Reducing crew on vessels can help solve problems ship operators face, such as rising crew costs (up to 45% of total operating cost;[221] ) and shortage of seafarers [220,222]. For shippers, opportunities to optimize supply chains may arise from the increased ship intelligence and higher operational flexibility of vessels without crew onboard [220] (see Figure 6).

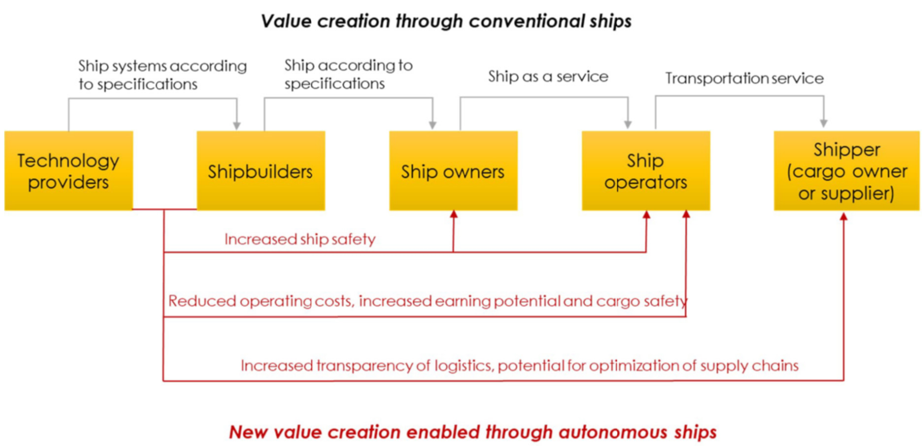


*Figure 6 Additional value created by MASS (adapted from [223]).*

The maintenance of MASS will also be affected by the removal of crew-related systems on the ship. However, increased automation will ultimately increase the complexity of the vessels. At the same time, ship intelligence can enable preventive and predictive maintenance [223,224], which can reduce maintenance costs in the long term. Another important benefit stemming from increased ship intelligence is the increased transparency of ship operations due to the bigger volumes of available data on vessel equipment operation, cargo condition throughout the voyage, detailed logs of the surroundings, i.e., situational awareness. The use of these data for investigating the causes of accidents or damages to the vessels and cargo can ultimately lead to decreased ship and cargo insurance and help mitigate risks in sea transportation [218].

Further, significant benefits lie beyond actual vessel operations, in the integration of MASS in the IoT[65,225], where other smart infrastructures and equipment, such as e.g. ports with autonomous mooring and automated loading and unloading, automated intermodal hubs, etc., are also part of transparent and automatized supply chains. This development can also be called Industry 4.0 implementation in the logistics chains. MASS supported by artificial intelligence (AI) have the potential to remove the inefficiencies in current logistics chains, thereby also reducing the environmental impact of cargo transportation. This stems from the combination of several 'ship intelligence' solutions, such as voyage optimization and optimal cargo loading, and digital innovations in other parts of the logistics chain, such as management of truck traffic in ports and multimodal logistics planning. The alignment of these optimization solutions can allow, for example, to reduce ships' idle time in ports and instead find optimal routes and speed profiles to deliver goods on time.

## 4.4 Impact of the introduction of MASS on legal and regulatory issues and on business models

The introduction of MASS in commercial shipping remains a challenging and uncertain concept. To achieve the benefits of autonomous shipping discussed in section 4.3, there is a need to change the business models of several business actors in maritime business. Also, new business models will emerge. Business development in such uncertain conditions requires understanding the business implications of introducing MASS in commercial shipping and addressing the barriers to their successful uptake.

One particular question concerns the division of roles between incumbent actors such as shipowners and operators and the 'digital newcomers', i.e., the providers of autonomous capability for ships. The role of the shipyard as a system integrator might be challenged by the potential of technology providers (related to ship intelligence), as the latter become indispensable in data ecosystem formation. The role of the shipyard is currently crucial in improving the interoperability of the systems, mapping the residual risks (also cyber) for system of systems[226].

MASS will naturally change the way ships are operated, thereby questioning the established role of the ship operator. Remote operations will require establishing RCCs, which need the resources and capabilities both of technology providers and incumbent ship operators and also establishing trusted operations. It is still unclear whose responsibility it is to develop and maintain RCCs – the shipbuilder or technology supplier [220]. This gives rise to new business models that would operate MASS. In the future, it is possible that MASS manufacturers would offer shared MASS alongside ownership offers [227]. Also, it is likely that some nations will manage to develop the clusters of RCC taking the lead in the development of MASS. Also, it possible that some companies will start providing their own services for RCC operation to the small companies. More distributely offered services are anticipated in the MASS context, e.g. except RCC service providers also other service providers are anticipated such digital service providers.

Finally, changes are also necessary to overcome the legal barriers to autonomous shipping. The existing legal framework for shipping is entirely based on the assumption that ships are manned. MASS raise several types of legal issues, the first being whether it is lawful to operate MASS in the first place and, if not, what regulatory changes are needed for that to be permitted, at international level and in EU/Finland. Is there scope for national or regional MASS operations in an interim period, while awaiting international endorsement?

Another main area relates to responsibility and liability, i.e., who is accountable when things go wrong? The existing maritime liability system is based on the premise that liability arises where a human being that is somehow linked to the operation of the ship has committed a fault or acted negligently. With MASS, the error leading the event may be very remote from the ship, it may be for example a software programming error that the ship operator had no chance of detecting beforehand. Who is liable in this case and how can the existing marine insurance mechanisms cover the new type of challenges? Such questions remain open and may vary significantly from one state to another. Should MASS be allowed to operate before we have settled the main liability principles? For businesses and vendors creating the solutions for Autonomouus maritime operations the legal liability issues needs to be solved. Even If MASS would be allowed to operate – companies might not be willing to carry the risk due to various risk appetite levels. Here a major disruptior like Amazon etc could change the field.

These broader considerations of MASS beyond the explicitly identified new jobs in shipping and shipbuilding operations are also likely to affect the educational needs in the marine industry as a whole. Besides the changes related directly to the professions in the named segments, professionals in other jobs will have an increasing understanding of how MASS operate. Cross-sectoral and inter-disciplinary understanding of the premises of autonomous shipping at large might also be beneficial for different kinds of professionals connected to MASS design, construction and operation.

Higher degrees of autonomy require bigger changes in many sectors related to maritime transportation and face higher legal and business barriers. Future education needs to address these challenges as well. Namely, the understanding of legal foundations and current barriers for MASS is important both for further policy development (e.g., how should regulation be changed?) and for directing technological innovation (e.g. how to prove safety of certain technologies enabling MASS in order to reach regulatory compliance?).

To provide another example, reconsideration of shipping business models is necessary in order to take full advantage of MASS, and the understanding of systemic implications of the introduction of MASS in maritime transportation sector is beneficial for professionals working with employing and operating MASS. New professions might also appear in relation to new business models triggered by MASS introduction. These include, for example, developers of digital platforms related to MASS fleet operations and management of supply chains that rely on autonomous shipping.

Some examples of jobs where knowledge of the business and regulatory implications of MASS introduction will be needed are listed below:

- Policy-makers in the field of maritime regulation
- Researchers and consultants in classification societies
- IT engineers of MASS enabling technologies (how technologies they develop apply and what are the business and legal premises of successfully implementing them on ships)
- Ship equipment manufacturers (how their systems create value)
- Developers of logistics business platforms
- Employees of ship charterers
- Developers including product owners, requirements analysts, test engineers.

## 4.5 The novel jobs and their requirements due to autonomous shipping

### 4.5.1 Ship design and building

#### *4.5.1.1 Ship design*

The industry 4.0 revolution [228] and MASS introduction will have indirect influence over the jobs related to the design process and shipbuilding. The ship designer will be required to know more about the particulars of the ship design related to the crewless ships, such as the estimation of weights and stability in novel context. However, the basic tools used during the ship design will remain the same. In addition, the ship designer should be aware of the novel regulatory and class society requirement for MASS, which are still under development. Novel positions might arise as part of ship design process, which will be required for ensuring that the integration of all the new systems is cyber secure (maritime cybersecurity engineer). More specific amendments are specified in Table 16.

*Table 16 The impact of MASS on ship design related jobs.*

| **Job** | **Additional required skills due to MASS** |
|---|---|
| Project manager | Very few, since the project management techniques will not change. However, the introduction of automation and the general industry 4.0 revolution might change the production process at shipyards. Therefore, the project managers should know about the novel automation techniques that will be used for shipbuilding and their particulars (resources required for the operation, cost and duration of equipment failure, the speed of manufacturing, repair, etc.). He/she should also be aware about the different requirements related to MASS KETs design and their requirements for integration into one network. Ability to integrate the systems and information systems and to provide holistic digital twins will be quite important. Strong communication skills will be important to communicate the complex design issues among multiple departments. |
| Structure designer | Very few, since the mechanical structures will not change. However, the introduction of automation and the general industry 4.0 revolution might change the production process at shipyards. Therefore, the structure engineer should know about the novel automation techniques that will be used for shipbuilding and their particulars (impact on mechanical properties due to automated welding, potential deficiencies introduced, the quality of assemblies and inspection procedures). Experience with structural analysis for MASS design will be of value. |
| Ship designer | The MASS might incur significant changes to the ship design as well the interactions with infrastructure as there will be no need for superstructure as mentioned in Chapter 3. In this respect, it will be necessary to properly understand the weight of novel additional equipment and to estimate the weight of the crewless cases. The practitioner should be equipped with the relevant techniques to be able to estimate the weight accurately. Practical experience with other design aspects such as the design of general arrangement, mooring arrangement and fire and safety plan for MASS can be also of value. The impact of software maintenance on the design should be understood. |
| Hydrodynamic expert | The MASS is expected to bring a little impact on the tasks of hydrodynamic experts, as the hydrodynamics is the same for MASS and conventional ships. Some practical expertise with air resistance calculations for MASS would be of certain value, though. |
| Piping designer | The increased automation will impact how the fluids and gases are being managed on ships. For a piping engineer it will be important to understand the different techniques that can be used to control the temperature, pressure, mass flow etc. in the piping system. S/he might also need to know how to program some basic parameters related to the flow control, e.g., to know how to program a PID controller in a ship piping network. |

| | |
|---|---|
| Electrical systems' designer | The increase in ship electrification will continue with MASS introduction, increasing the need for electrical engineers. However, in terms of tasks and essential knowledge, the requirements will experience slight changes. |

#### 4.5.1.2 Shipbuilding

The introduction of MASS will impose small changes in the manufacturing processes. The main procedures employed by the technicians will remain the same. Some changes are expected due to the use of automation during the manufacturing process; however, this is outside the analysis scope. Some minor changes are highlighted in Table 17. The importance of the automation engineers might rise due to the additional use of automated systems, and might be training required in respect for the installation of novel automation systems onboard ships [229], the role of shipbuilder.

*Table 17 Additional requirements due to MASS for shipbuilding related jobs.*

| **Job** | **Additional required skills due to MASS** |
|---|---|
| Welding designer/Welding engineer | No additional requirements |
| CNC engineer (mill, router, grinder, or lathe) | No additional requirements |
| Steel cutting engineer | No additional requirements |
| Installation engineer | Should be knowledgeable in the particulars related to installation of the novel KETs and novel technologies specified in Table 20 |
| Automation engineer | Might require training in additional systems installations such as collision avoidance systems or advanced monitoring systems. |
| Commissioner, ship machinery systems | Training related to installation of highly integrated autonomous systems<br>Testing of networks for cybersecurity might become an important service |
| Welders | No additional requirements |
| Structural fabricators | No additional requirements |
| Plumbers | No additional requirements |
| Electricians | No additional requirements |
| Riggers | No additional requirements |

#### 4.5.1.3 Ship repair

Whilst, the use of remotely controlled and crewless ships will change the way the maintenance tasks are implemented, it will not affect the ship dry docking procedures significantly. The service engineers might need to be trained to implement the maintenance for MASS KET. Nevertheless, this practically refers to the tasks implemented by ship equipment manufacturers services, and that is why it is referred to, below in the relevant section. Also, several automated tools might be used for the ship repairs, but this is considered outside the scope of the present analysis. General understanding about the maintenance procedures and arising legal and safety issues might be required by the dry-dock personnel.

*Table 18 Additional requirements due to MASS for ship repair jobs*

| **Job** | **Additional required skills due to MASS** |
|---|---|
| Ship repair manager | Understanding the maintenance context for MASS as well as the legal responsibilities |
| Dock master | Understanding the maintenance context for MASS |

| | |
|---|---|
| Service field engineer | Some additional requirements (pls refer to Table 20) |
| Dock yard mechanical engineer | Understanding the maintenance context for MASS |
| Dock yard electrical engineer | Understanding the maintenance context for MASS |
| Safety Officer | Understanding the additional safety and security issues arising when MASS maintained during drydocking |

#### *4.5.1.4 Ship scrapping:*

The ship repair jobs are provided in Table 19. Minor changes in required skills are anticipated there.

*Table 19 Ship scrapping jobs*

| Job | Additional required skills due to MASS |
|---|---|
| Ship recycling operation managers | Understanding of additional implications in connection to IT recycling. |
| Safety officers | Understanding of how the MASS design and equipment will influence the safety of scrapping |
| Workers | No additional skills |
| Brokers or cash buyers | No additional skills, unless they do not use AI based tools. |

### 4.5.2 Ship equipment manufacturers

As presented in Section 3, the MASS will employ a set of novel KETs. The manufacturers will have to respond to the market demands by developing the relevant KETs for MASS. This will increase the demands for the following professions, as presented in Table 20. There will be a need for equipment designer who are proficient in software-intensive systems design, expert in handling artificial intelligence algorithms in the maritime context, can apply automation techniques for novel design problems and are aware of novel human-machinery interactions that can arise in MASS context such as transparency, trust, etc.[230]. Novel systems facilitating the ship operations and exploiting control techniques will be developed, such systems supporting safe embarkation/disembarkations, safe evacuation on crewed ship, more automated systems for firefighting, advanced system and health monitoring tools, more solutions enabling remote control, more automated cargo handling and bunkering operations, advanced aids to navigation. This has been elaborated in more detailed in Figure 3. The increased use of sensors and cameras will require the equipment manufacturers to be aware of these issues and increase the need for such engineers[231]. Understanding about the liability and regulatory aspects will be required by the senior managers[230]. The need for cooperation between the different jobs described in Table 20 will increase, resulting in better communication skills required to reduce the potential for risk introduction. Development of trust calculation issues will be a must. Knowledge of handling complex systems will also be required.

*Table 20 Ship equipment manufacturers additional requirements*

| Job | Additional required skills due to MASS |
|---|---|
| Cybersecurity systems engineer | The cybersecurity will exercise much more key role in MASS than in conventional shipping. There will be an increased need for developing cybersecurity control barriers and novel protocols in the maritime context, driving the innovation to the next level. This will require understanding about both maritime system vulnerabilities and operational context, the communication networks used on ships, the impact of cyber vulnerabilities on systems safety and the human vulnerabilities. Understanding the concepts related to safety and especially to control systems will be required. Quick learning skills will be of importance due to the dynamic nature of the area. Knowledge of mini threat models assisted by |

| | |
|---|---|
| | AI, ML and chatbots will be quite important. Ability to develop new cybersecurity solutions. |
| Machine learning engineer | The use of AI and ML is already increasing in the maritime. The ML engineers must be both proficient in the AI and ML techniques but also have adequate understanding of the marine equipment and environmental problems in order to develop efficient AI solutions. Examples constitute voyage management tools, performance monitoring and maintenance management tools, administrative tools based on AI and ML, AI tools for cyberattacks detection, image and traffic situation recognition systems, decision-making systems based on AI, and so on. The engineers will also need to understand the performance requirements for different solutions developed using AI as well safety, verification, and validation requirements for AI[67]. Understanding the ethics behind the design of decision-making systems will also be needed. |
| Automation and software engineers | The increased use of collision avoidance and situation awareness systems will result in further need for designers which are proficient in both ship hydrodynamics and automation techniques. Due to stringent safety requirements, these systems will need to be rigorously tested. Therefore, the next generation engineers must be properly educated in formal verification and validation techniques. Novel monitoring systems will elevate the need to understand the various issues related to interactions between systems to new highs. Understanding the ethics behind the design of decision-making systems will be Important. Knowledge of aspects related to design of Internet of Things (IoT) will also be a valuable skill. |
| Human factors experts | The MASS will be not fully independent of humans and humans will be in the centre of every design solution even at the highest MASS autonomy degree. Therefore, it will be necessary to design a proper human-machine interface and consider novel human interactions. The advanced human-machine interface will need to be considered under the influence of increased automation and increased cognitive load due to reduction in the operator's number[230]. Unique skills might be required for the design of the remote-control centre. These experts will need to understand the maritime operations and environment to a sufficient level. |
| Production test engineer | The next generation test engineers should be aware of the relevant testing procedures for MASS autonomous equipment, e.g., collision avoidance system. They should be trained to understand the complexities of autonomous systems testing and should be learned to innovate. Skills related to remote connection will be also important. |
| Field service engineer | The field service engineers should be educated in using AI based tools properly and recognizing the failures caused by sensors, integration problems, software errors or cyberattacks. They should have basic knowledge rectifying them. |

### 4.5.3 Classification societies

The MASS will result in several novel inspection techniques and associated jobs. In brief due to MASS, more inspectors and engineers dealing with software and algorithms will be required. More detailed analysis is provided in Table 21.

*Table 21 The additional requirements for surveyors*

| Job | Additional required skills due to MASS |
|---|---|
| Surveyors | Due to the software-intensive character of MASS the next generation surveyors will need to be competent enough in software engineering and understand the relevant software functions and failures. The compliance with cybersecurity |

| | |
|---|---|
| | requirements will result in novel types of inspections, which will require personnel with novel skills to monitor compliance with cybersecurity requirements. The surveyors should have adequate knowledge in machine learning techniques to be able to interpret the results of condition monitoring systems. They must also understand the particulars of KET on MASS. They should also be professionally trained into effectively implementing remote drone inspections. |
| Researchers | Whilst some research engineers will have the same requirements with the one required for conventional ships; an additional set of researchers will be required in connection with MASS. The next generation research engineer should be competent at machine learning techniques, decision-making systems, computer and communication networks, cybersecurity issues, sensor particulars, automation, and control. They should be knowledgeable in human-machine interactions. The research engineers will need to have a set of skills from computer science and naval architecture and marine engineering department. |
| Plan approval experts | The engineers involved in the plan approval of KETs should be aware of relevant safety methods and testing procedures that are required for systems involved in autonomous decision-making on ships. Therefore, they should be aware of requirements for AI, software system, cybersecurity systems and the ways to verify compliance to the requirements. They should also be aware of performance characteristics of sensors used in the advanced automation systems. Simulation-based assurance will be the key in the future, so the engineers will require additional knowledge related to digital twins. |
| Consultancy (marine consultants) | The various experts should be aware of the relevant safety risks arising due to the innovation and should be able to accurately estimate the level of risk for MASS and methods to reduce the risk to acceptable level. Also, the consultants will need to have an additional set of skills as presented for ship equipment designers and manufacturers to be able to support them. |

### 4.5.4 Ship operator and shipboard related jobs

#### *4.5.4.1 Ship manager*

MASS will have a tremendous impact on the ship management due to the relocation of ships' crew from ship to shore. A list of anticipated changes is provided in Table 10. Except the general training on cybersecurity issues. The personnel will need to learn to interact with AI based systems, and to have proper understanding of potential software defects and sensor failures.

*Table 22 The list of job types on shore necessary for ship operations.*

| Job | Additional required skills due to MASS |
|---|---|
| Technical department | The technical department will continue to provide services required by conventional. The personnel should be able to learn to interact with automated systems remotely, to properly interpret the AI algorithms estimations and to learn the novel maintenance schemes. Technical department employees should be trained in remote inspections and remote support management. Similarly, with field service engineers they should be proficient in detecting cybersecurity, breaches, software defects, sensor failures. They should also be trained in novel maintenance techniques, such as condition-based and prognostics-based maintenance. |

| | |
|---|---|
| | The technical department should be aware to aid in any case of malfunction or total loss of the vessel control. Achieving this might become more challenging due to the skills' degradation issues[232], which will need to be addressed in the advanced educational programs.<br>Both the technical department and the Remote-Control Centre (RCC) engineers should be supported by IT department if the cyberattack or loss of connection happen [28,233,234].<br>There will be opportunities for outsourcing maintenance monitoring to other companies through relevant service agreements. |
| Safety department | The safety department should learn about proactive safety management through lifecycle enabled by advanced IT solutions. The personnel should be trained to employ advanced IT solutions for safety monitoring and controlling. The department will share some responsibilities with IT department with respect to cybersecurity implementation. |
| Crew department | The role of the crew department will decrease due to the reduced demand for seafarers. However, crew department will be responsible for implementation and development of novel training techniques in the context of MASS, therefore in shore term pressure will increase. The IT skills will be of significant importance to be able to interact. This experience will also be required for the remote control of ships. |
| Spare parts department | The role of spare parts department will diminish, as its functions with respect to procurement of spare parts will be increasingly undertaken by the AI algorithms and automated software systems, due to the increased connectivity. |
| IT department | The importance and size of the IT department will increase as the management of ship IT systems will be given to the IT department. They will also need to comprehend the skills related to the diagnostics of AI algorithms problems and issues. Gradual convergence of IT and OT related tasks will be proceeded. The IT will undertake responsibility for the software maintenance of the ship systems. Connectivity related expertise will be important in view of the need to ensure adequate communication between the RCC and the ships, such as satellites related expertise. So generally, the pressure on IT department will increase |

#### *4.5.4.2 Ship charterer related jobs*

The use of MASS might influence the way the chartering is implemented. The extensive use of novel systems based on AI for decision-support will require users who understand these systems and can override their potential errors and be able to make an ethical decision. It will be necessary to understand the legal aspects of MASS and how they might influence the ship operations. The ethics with respect to design and the operation of ships will become an important aspect to be considered by the charterers. The charters will have to learn to offer real-time monitoring of cargo services, and how this will influence the required skills for the crew that is sailing on the ships they operate.

*Table 23 Impact of autonomous ships on ship charters*

| Job | Additional required skills due to MASS |
|---|---|
| Ship charterer | Understanding of AI based tools [232]<br>Understanding of MASS operations<br>Understanding of legal aspects related to MASS<br>Understanding of impact of MASS on crew requirements and compliance with them |
| Shipbroker | Understanding of AI based tools [232] |

| | |
|---|---|
| | Understanding of MASS operations<br>Understanding of legal aspects related to MASS |
| Contract's officer | Need to understand the legal aspects related to MASS |

#### 4.5.4.3 Ship crew

Whilst, the need for seafarers will not vanish in the next decades, similar functions will be implemented by a reduced crew member number or by crew members who will be transferred on shore[44]. The engine department will be merged with technical department on shore as the automation will be progressing [44]. The captain on shore will be able to navigate the ship remotely, whilst several functions will be delegated to the safety and administrative department onshore. This will result in highly skilled personnel, but also with relevantly little practical experience [232]. The required familiarization certificate might need to be replaced by a familiarization with the HMI. Due to the decrease in the crew size, the issues associated with loneliness will be necessary to be addressed.

*Table 24 The MASS impact on ship crew related skills.*

| **Job type** | **Additional requirements due to MASS** |
|---|---|
| Engine department | The engine department will be merged with the technical department on shore. Ability to rectify equipment without seagoing experience, which will require advanced training facilities based on engine simulations. Ability to understand the software, cybersecurity and sensor related failures will be a must such as the basic cyber hygiene / baseline needs [233,235]. |
| Deck department | Ability to navigate the ship remotely with little seagoing experience, to interact and coexist with automated decision-making and support systems[232] advanced e-navigation systems[62]. Training in cybersecurity and the advanced systems use will be necessary[235]. Knowledge of relevant regulations[236] Strong digital skills[44] Training for emergency and safety awareness[237]. Training of the basic cyber hygiene / baseline needs. |

Both departments should have a holistic understanding of the cybersecurity, plausible threats, and equipment subject to external access. The communication equipment on board the MASS, and in the RCC, will be as important as the main propulsion and power plant system aboard. Therefore, future shipping engineers should grasp advanced skills regarding novel communication and software systems to ensure a reliable distance control of the vessel [232][236].

Thereby, the RCC will be equipped by versatile engineers who have general overview of the MASS systems and necessary sailing regulation (such as COLREG.), to steer and control the ship remotely. The future captain of the MASS will be the most experienced and skilled engineer. The future requirements and qualifications will be updated for the operation of smart shipping by the IMO and unfamiliar terms will be added for the RCC engineers' skills to steer this revolutionary technology. Each engineer will be assigned to a specific task, MASS communication officer, mechanical and power officer, propulsion officer, navigation and control officer, safety officer, etc. Apart from the familiarization of cadet engineer with ships systems on board, new simulators competences will be required to understand and become acquainted with interacting functionality and manage the different scenarios[238].

### 4.5.5 Various service providers

MASS will exercise a considerable influence over how the service providers do their business and their products. Novel services such as remote pilotage[5], remote systems' maintenance providers, remote and on site cybersecurity testers, RCC operators will be developed, whilst the personnel responsible for the interactions with MASS and developing innovative solutions will need to be trained to understand the specific characteristics of MASS. The use of advanced technologies will bolster the competition and use of novel algorithms and tools. Some specific details are provided in Table 25. Greater globalization and networking will render feasible greater spatial distribution of provided services.

*Table 25 List of service providers and impact on required skills due to MASSs.*

| Job | Additional requirements due to MASS |
|---|---|
| VTS operator | Should understand the particulars related to interactions with and managing MASSs |
| Pilots | Novel remote pilotage skills |
| Locks' operators | Training to interact with MASS going through canals |
| Performance monitoring | Understanding of MASS performance with respect to emissions |
| Condition based monitoring | Knowledge of advanced tools and algorithms that might be developed. |
| Safety equipment inspectors | Use of novel tools for remote inspection and testing of equipment |
| Cybersecurity independent testers | Several firms testing cybersecurity on ships already, which will be increased in the future in number and size. |

### 4.5.6 Insurers

The insurance will be influenced by the MASS introduction. To be able to identify the liabilities and determine a suitable premium, the insurer analysts should be trained to understand the liabilities issues connected to MASS and to be able to perform proper investigations and risk analyses for MASS[223]. The marine surveyors should be trained to understand aspects related to the safety, trust and ethics of MASS and be able to accurately assess them. This is elaborated in more detail in Table 25.

*Table 26 Additional requirements due to MASS for insurers related jobs*

| Job | Additional requirements due to MASS |
|---|---|
| Insurer analyst | Understanding of liabilities and ethics transformation due to MASS<br>Good understanding of MASS operations and safety issues |
| Marine insurance claims handler | No major influence |
| Marine surveyors | Should be knowledgeable in all aspects related to MASS operations and technical particulars. Should be able to understand the issues related to the software design, cybersecurity assurance, systems reliability and so on and to connect them to safety. |

### 4.5.7 Maritime authorities

The additional requirements due to MASS introduction to the maritime authorities are provided in Table 26. The inspectors should be trained in remote inspections and understand how additional safety requirements in MASS are complied with, and how this can be verified. The regulation makers should be trained both in regulatory and safety aspects to be capable to develop/update safety codes for MASS. The safety investigation experts should be capable of understanding the MASS operations and the ways MASS can fail.

*Table 27 Additional requirements due to MASS for insurers related jobs.*

| Job | Additional requirements due to MASS |
|---|---|
| Port managers (Terminal operators) | Understanding of cybersecurity issues [239], issues related to inspection, loading, unloading. |

| | |
|---|---|
| Inspectors | Understanding of MASS requirements and the ways to verify their compliance<br>Ability to perform remote inspections |
| Regulation makers | Good understanding of the relevant regulations, technologies, maritime environment, associated safety, liabilities and ethics implications and their interactions |
| Safety investigation authority group | Good knowledge and understanding of safety aspects for MASS. |

## 4.6 Section conclusions

With MASS and the digitalization of shipping and shipbuilding, there will be an increased demand for a set of novel skills. There will be an increased demand for ICT competencies (notably in the area of AI). In addition, knowledge of the developing regulatory frameworks and legal implications of MASS must be made available to a number of actors in maritime industry. Moreover, it is expected that MASS (or digitalization of shipping at large) will change trade routines and the way business is being conducted. Digital business models are also entering the transportation business. Management procedures and leadership approaches will have to take into account that some jobs are shifted onshore to remote operation centres. On overall MASS will have some disruptive impact on some jobs whilst some other jobs will remain the same. The ship design process and tools will need to be updated to consider aspects related to MASS design, but the imposed changes will be small. The ship construction and repair in dry docks will be influenced by the industry 4 revolution, but not as significantly as MASS design and operations. On the other hand, the ship equipment manufacturers will obtain many opportunities for innovation; as a result, there will be an increasing need for personnel proficient in maritime cybersecurity, professionals skilful in AI/ML techniques and knowledgeable in the design of specific KETs with high automation and who are aware of the marine environment, systems, regulations, design processes and humans' factors. The classification societies will also require people who are both proficient in the realm of computer science and marine engineering to be able to catch up with the developments. The surveyors will have to adapt to novel remote inspection solutions. The most profound impact will be on the shipboard related jobs due to the relocation of the ship crew from ships to the remote-control centre and constant interactions with novel systems. In addition, next generation seafarers will have to learn new skills to become competitive in the new era and to be able to understand aspects related to software design, cybersecurity, and artificial intelligence. Ultimately, the MASS introduction might lead to gradual merging of the technical department on shore and engine room department on ship. The other users of MASS will have to adapt to the use of novel maintenance solutions. Novel service provider will appear on the market, offering novel remote enabled services. Charters, insurers, and authorities will need to be trained in the novel safety and liabilities aspects arising due to MASS introduction.

# Part B: Analysis of educational programs at Finnish and international universities in connection to MASS

(Covering Objectives C, D, E)

# 5 Analysis of Finnish university offered study programs in relation to MASS

## 5.1 Section outline

This section is structured as follows. First, the currently offered study paths in Aalto Marine Technology group are presented and their relationship to the MASS is being briefly analysed. Similar analysis is conducted for University of Turku and Åbo Akademi University. The analysis findings are summarized in the conclusions' section.

## 5.2 Aalto University

The Aalto university offers to the MSc students several potential study paths [240] demonstrated in Figure 7, allowing them to pursue a variety of careers. These study paths brief description is provided in Table 28. Most of the study paths are planned considering the conventional ship types with primary focus on the tasks implemented by a ship designer. The study path 'Smart Maritime Operations' (SMO) is the most relevant to MASS, as it incorporates the developments in the ICT. This study path combines courses offered by the Maritime Technology group and the Computer Science department.

The current curriculum offered by the Mechanical department of Aalto University includes 35 courses [241]. If the recommended and optional courses from Computer Science department for the SMO study path are added, this leads to totally 60 courses. Detailed list of courses is provided in Appendix C.

The current courses offered by the Mechanical department cover mostly the aspects related to the ship design, such as the selection of appropriate hull, propulsors, propulsion systems, ship structure, etc. for various ship types, supporting the students in implementation of the various analysis types with emphasis on arctic environment.

The recommended courses from the Computer Science department include teaching material on human-computer interactions, information security management, data science and machine learning techniques, software engineering and so on. The courses offered by the Computer Science department are of generic nature and have applicability to a wider problems spectrum and not just maritime.

As described in the internal Aalto report, some of the offered courses already include material related to MASS. Examples constitute results of safety analysis of MASS and possibility to design MASS in ship design project. Also, the course offered at the Computer Science department addresses some of the problems arising due to the MASS and increased digitalization. Novel courses on artificial intelligence and machine learning are also being developed in Aalto. However, some areas of opportunity exist which are provided in section 7.

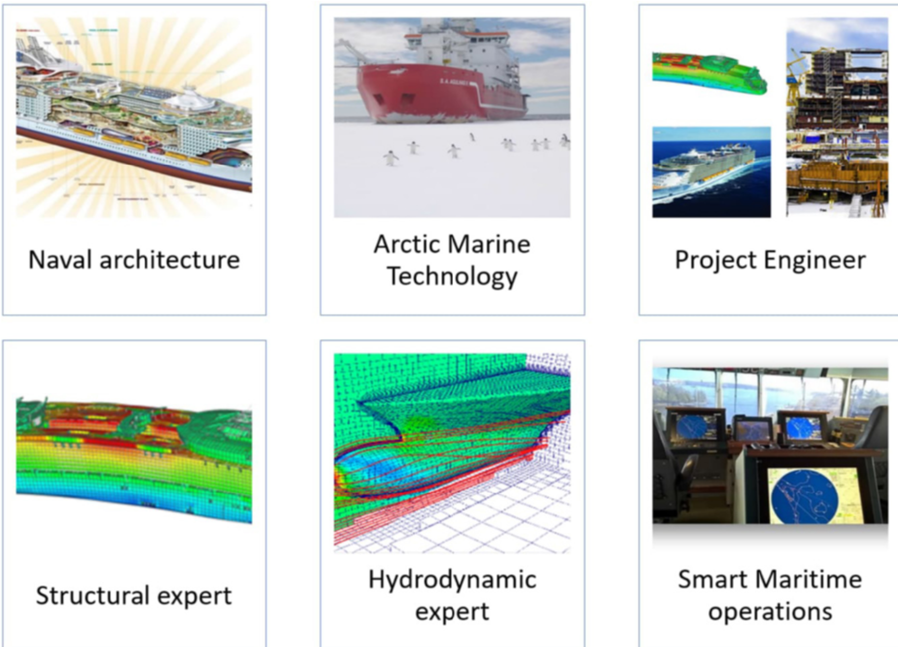


*Figure 7 The study paths at Aalto Marine technology group.*

*Table 28 The various study paths brief description.*

| a/a | Study path name | Brief study path description |
|---|---|---|
| 1 | Naval architecture (NA) | This study path correlates with the work of naval architect and ships designer, so it intends to train students willing to work in shipyard and design offices. |
| 2 | Arctic marine technology (AMT) | This study path gives more emphasis on development of technologies suitable for arctic environment and operations in arctic environment. |
| 3 | Project engineer (PE) | This study path develops the skills required for the shipyard project managers and equipment suppliers, as it interlinks the design and production processes |
| 4 | Structural expert (SE) | This study path is suitable for naval architects intending to deal in more detail with the structural design as part of overall design process. |
| 5 | Hydrodynamic expert (HE) | This study path is specifically designed for future experts analysing ship resistance, hydrodynamic loads, wave induced motions, ship propulsion, seakeeping using dedicated tools. |
| 6 | Smart maritime operations (SMO) | This is the study path for engineers focusing on the novel ship designs with high automation and strong use of the information and communication technologies. |

## 5.3 University of Turku (UTU)

The University of Turku does not offer bachelor's and master's degree in MASS. However, there are several programs in the Faculty of Technology, the Faculty of Mathematics and Natural Sciences and the Turku School of Economics that provide degrees in relevant fields and offer a variety of courses that are highly relevant to autonomous maritime training and education:

- Faculty of Technology
  - Department of Computing
    - Bachelor’s Degree Program in ICT
    - Master’s Degree Program in ICT
      - Communication and Cyber Security Engineering Track
      - Data Analytics Track
      - Smart Systems Track
    - Bachelor’s Degree Program in Computer Science
    - Master’s Degree Program in Computer Science
      - Artificial Intelligence Track
  - Department of Mechanical and Materials Engineering
    - Bachelor’s Degree Program in Mechanical Engineering
    - Master’s Degree Program in Mechanical Engineering
      - Smart Systems Track
- Faculty of Mathematics and Natural Sciences
  - Department of Geography and Geology
    - Bachelor’s Degree Program in Geography
    - Master’s Degree Program in Geography
- Faculty of Law
    - Bachelor of Laws
    - Master of Laws
      - selected courses available in the topics of maritime law, law & artificial intelligence
- Turku School of Economics
    - Bachelor´s Degree Program in Marketing and Value Chain Management
    - Master´s Degree Program in Marketing and Value Chain Management
      - Specialization in Operations and Supply Management
      - Specialization in Information Systems Science
    - Master's Degree Program in Global Innovation Management

The degree programs from the Department of Computing offer courses in the fields of communication technology, cybersecurity, data science, artificial intelligence, machine learning, autonomous systems, and smart environments from the ICT point of view. The degree programs from the Department of Mechanical and Materials Engineering focus on smart systems, intelligent control, and autonomous systems from the mechanical engineering point of view. The degree programs from the Department of Geography and Geology contribute with relevant courses, especially in the field of geolocation and geoinformatics.

In Faculty of Law there are no related degree programs or tracks related to MASS, but selected courses related to maritime law, law & artificial intelligence and liability are strongly linked to the field.

The degree programs from the Turku School of Economics at the program do not have a strong link to any specific sector or industry, as the provided knowledge is of generic nature. However, three tracks within the degree programs have contents that have connected with the MASS development. Within the degree programs of Marketing and Value chain management specialization in Operations and Supply Chain Management detailed view on management of supply chains, procurement, logistics and transportation is offered, which is still the operational frame also for autonomous maritime solutions. Another specialization in Information Systems Science focuses on management of information systems and IT projects, digital business models and IT security and ethics that becomes more relevant topics in the implementation of new technological solutions. Thirdly, the degree program for Global Innovation Management indirectly contributes to the need by emphasizing innovation management skills based also on international business and entrepreneurship. The program focuses on innovation process related agile and networking skills needed in technological or organizational development in multi organizational and multicultural settings. In addition to this degree program, there are selected broad-topic courses not specifically related to autonomous maritime, but it can support the practitioners in the field. Identified supporting topics include: 1) value creation and service perspectives for example in solution sales, 2) sustainability and responsible business study modules for example to implement sustainability goals within development processes and 3) corporate foresight. A detailed list of currently (academic year 2021-2022) available relevant courses from the University of Turku is given in Appendix D.

## 5.4 Åbo Akademi University (ÅAU)

In its current curriculum, ÅAU does not offer courses specific to MASS. However, a multidisciplinary module (20 ECTS minor) with courses from computer science, maritime law and business studies is current being offered (see Table 29). The courses form an interconnected package where MASS features as an important topic. In addition, there are plans to develop a new course on the legal aspects related to autonomous shipping in collaboration with UTU.

*Table 29 Courses related to MASS offered at ÅAU*

| a/a | Faculty | Course name | Level | Brief course description | How MASS is covered in the course | Language |
|---|---|---|---|---|---|---|
| 1 | Faculty of Social Sciences, Business and Economics | Maritime Law | MSc | • The context and development of maritime regulation<br>• Ships: building, sale, registries, mortgages, liens, arrest, salvage<br>• Shipowner's liability, special liability regimes<br>• Transport of goods, documents, chartering<br>• Insurance: marine, cargo<br>• Maritime labour law | • Legal issues linked to the introduction and operation of MASS will be part of the content (but the course is more generally oriented). Course is offered every second year. | English |
| 2 | Faculty of Science and Engineering | Maritime Business | MSc | • Current state and challenges in maritime business with the focus on maritime transportation<br>• The impact of maritime transportation on the environment and the society<br>• Innovations in maritime business: digitalization and clean shipping<br>• Outlook for smart and sustainable maritime business | • Impact of AS introduction on maritime business and supply chains<br>• Business concepts based on autonomous shipping Assessment of the environmental impact of AS | English |
| 3 | Faculty of Science and Engineering | Introduktion till Artificiell Inteligent | BSc | • The course gives an overview of Artificial Intelligence, and touches on all areas through examples<br>• The course encourages to a critical encounter with concepts from Artificial Intelligence<br>• The possibilities and limits of Artificial Intelligence are discussed | • Fundamental concepts of Autonomy (e.g., levels of autonomy) are covered<br>• The problem of validation of autonomous systems is introduced<br>• Navigation of Autonomous ships is discussed as an example of autonomy | Swedish |
| 4 | Faculty of Science and Engineering | Autonomic Software and Systems | MSc | • The courses introduced the principles of autonomy using the Mape-K reference architecture<br>• The course presents a comprehensive framework for the design of autonomic systems irrespective of their levels of autonomy, and their application areas<br>• Practical applications are discussed | • The course covers Autonomy including issues relevant for MASS<br>• Autonomous Navigation algorithms are discussed as examples | English |

## 5.5 Section conclusions

In this section, the study programs offered at three Finnish Universities, namely Aalto University, the University of Turku and Åbo Akademi University have been briefly analysed. The results indicate that the study programs at these universities already address some novel aspects being introduced through the autonomous shipping. However, areas of opportunities for further development exist, which are discussed in Section 7.

# 6 International universities study programs for MASS

## 6.1 Section outline

This section offers an overview of courses provided by the international universities in relation to MASS.

## 6.2 Results

The identified study programs overview is provided in Table 30. As it might be observed, several of the top universities such as TU Delft, Dalian University of Technology and The University of Western Australia currently offer only general courses in Naval Architecture, Ocean, and Marine Engineering (NAOME). Some top universities according to Shanghai ranking offer study programs especially focusing on autonomous ships, such as the University of Strathclyde and University of Southampton. There are also universities which offer joint study programs, such as the University of Toulon, NTNU, Universitat Jaume I, and the University of Lisbon. The education for autonomy has gained attention also from other universities, such as University of Aegean and Scottish Association for Marine Sciences. Several Chinese universities such as Shanghai Jiao Tong University and Wuhan University of Technology have included several courses tailored specifically to the MASS need's.

More detailed description of study programs is provided in the next sections by referring to the dedicated courses used in study programs.

### 6.2.1 University of Strathclyde - M. Sc. Specialisation in Autonomous Marine Vehicles

This specialization [242] offers the following modules: Modules related to big data analytics and machine learning, courses related to marine equipment modelling and simulations, system reliability analysis and a course on underwater vehicles. Additionally, it includes some optional modules related to inspection and survey, economics, regulatory framework, and maritime safety.

### 6.2.2 University of Toulon, NTNU, Universitat Jaume I, University of Lisbon - M. Sc. Marine and maritime intelligent robotics

This course [243] includes the following modules: Modules related to the transversal skills such as project management and scientific writing skills, modules related to the marine environment such as acoustics, modules related to the modelling and control of marine and robotic systems, the series of modules related to the artificial intelligence and machine learning, modules related to risk and reliability, module related to autonomous systems' legislation, modules related to sensors and controller design. Modules offered by the partners include modules related to tele robotics, multi-robot systems and underwater wireless communication (Universitat Jaume I), decision-making under uncertainty, control aspects, methodologies in computer science (NTNU), optimisation algorithms, decision systems, autonomous systems, computational systems, and communication networks (University of Lisbon).

### 6.2.3 University of Southampton - M.Sc. Marine Engineering and Autonomy

The course [244] includes the following mandatory modules: Module on advanced electrical systems, module on sensors and condition-based monitoring, module on ship design, module on marine engineering, module on navigation, control, modelling and simulation of surface and underwater robotic systems, and module on maritime safety and law. Several optional modules are offered in addition, such as module on materials failure mechanics, module on marine structure interactions with fluids, module on offshore engineering and analysis and module on renewable energy.

### 6.2.4 University of the Aegean in collaboration with the University of West Attica - M.Sc. New technologies in shipping and transport

The course [245] includes the following mandatory modules: ICT technologies in maritime, maritime management, maritime finances, project management, maritime insurance. The following two educational profiles are offered as an option: maritime management, automation, and control for marine systems. The modules of maritime management profile are related to organization and finances, whilst the profile of autonomous technologies include the following modules: design of automation and electrical propulsion systems, mechatronics, communication technologies, sensor technologies and advanced control and monitoring systems. The students are also obligated to attend seminars on diverse topics, such as radar technologies, maritime information systems, port management techniques.

### 6.2.5 Scottish Association for Marine Sciences - M.Sc. Marine Science with Oceanography and Robotics

This course [246] focuses mostly on the marine science related studies, but it also offers the following modules connected with robotics: statistical and experimental design, advanced math's and programming, marine robotics, marine instrumentation, and data.

*Table 30 Analysis of curriculum at foreign universities*

| a/a | University | Course offered | Level | Description | Country | Duration | Language |
|---|---|---|---|---|---|---|---|
| 1 | Shanghai Jiao Tong University | General courses in NAOME | BEng, MEng. | Whilst both B.Eng. and M.Eng. are offered, no specific reference to smart, robotic or autonomous ships was identified [247].<br>A course named Marine intelligent equipment and systems is on the plan. | China | NA | CHI/EN |
| 2 | Norwegian University of Science and Technology (NTNU) | General courses in NAOME<br>Marine and maritime intelligent robotics | MEng / MSc | NTNU does not offer a specialized M.Eng. program related to autonomous shipping. However, NTNU cooperates with other universities and takes part in their M. Eng. programs as described at Universite de Toulon below [243]. Also, some dedicated courses are offered in connection to the digital shipping [248]. Previously NTNU offered a course on machine learning in connection to ship autonomy [249]. | Norway | 2 years (1 year in Norway) | NOR/EN |
| 3 | Harbin Engineering University | General courses in NAOME | BEng., MEng. | Several courses in automation engineering [250] and power systems [251] are being offered, without specific reference to autonomous shipping. Some courses are offered related to automation and control. Separate courses related to navigation and control are being offered. | China | NA | CHI/EN |
| 4 | University of Strathclyde | Specialization in Autonomous Marine Vehicles | MSc. | A course developing skills and knowledge in autonomy and ICT technologies[242]. Analytical description of courses is provided in the relevant section. | UK | 1 year | EN |
| 5 | Dalian University of Technology | General courses in NAOME | BEng., MEng. / MSc | General courses and three second-class disciplines [252] are offered including Design and Manufacture of Ship and Ocean Structure, Underwater Acoustic Engineering and Marine Engineering. | China | 3 years<br>2 years | CHI/EN |
| 6 | University of Lisbon | General courses in NAOME<br>Marine and maritime intelligent robotics | BSc<br>MSc | University of Lisboa cooperates with other universities and takes part in their M. Eng. programs as described at Universite de Toulon in relation to autonomous shipping [243]. However, some dedicated courses are offered in connection to the system control at B.Sc.[253] and M.Sc. level[254]. Furthermore, a diploma in risk assessment, safety and reliability is offered [255]. | Portugal | 3 years<br>2 years | EN |
| 7 | Wuhan University of Technology | General courses in NAOME | BEng, MEng / MSc | WUT offers several courses for both B.Eng. and M.Eng.[256] in relationship to autonomous shipping, with a particular focus on ship design and safe operations. However, many of them are selective courses and designed for master students. The list of courses includes green technology and smart design, manufacture, and construction technology, etc.) and Marine and maritime intelligent robotics (automated navigation techniques, intelligent collision avoidance, ship motion control, and ship networking technology, etc.). | China | 3 years<br>2 years | CHI/EN |
| 8 | Delft University of Technology | General courses in NAOME | BSc / M Sc | Delft University of Technology does not offer a specialized M.Sc. program related to autonomous shipping[257,258]. | Netherlands | 3 years<br>2 years | EN |
| 9 | The University of Western Australia | The offered courses focus mostly on ocean engineering | MSc | No specific reference to smart, robotic, or autonomous ships was identified [259] | Australia | 1 year | EN |
| 10 | National University of Singapore | Maritime Technology and Management | MSc | The offered program seeks to train and equip graduates with key skillsets to enable next-generation port capabilities. The program offers a module related to digitalization of ports [260]. | Singapore | 1 year | EN |
| 11 | Universite de Toulon | Marine and maritime intelligent robotics | MSc | The course combines Robotics and Artificial Intelligence for the design of autonomous underwater and surface systems[243]. The first year is taught at the Universite de Toulon whilst the second at any of the following universities of choice: NTNU, Universitat Jaume I, University of Lisbon. More details are available in relevant section. | France | 1 year | EN |
| 12 | University of Southampton | Marine Engineering and Autonomy | MSc | The course focuses on the analysis and specification of marine engineering and autonomous systems used on board ships and other marine structures [244]. Analytical description of modules is provided in the relevant section. | UK | 1 year | EN |
| 13 | University of the Aegean in collaboration with the University of West Attica | New Technologies in Shipping and Transport | MSc | The program aims at integrating modern information technology knowledge and skills in shipping companies and maritime business management to enable the use of new, complex tools for communications, automation, and control systems [245]. The course has two profiles, one in maritime management and second in autonomous technology. More details are available in the relevant section. | Greece | 1.5 year | GR |
| 14 | The Scottish Association for Marine Science | Marine Science with Oceanography and Robotics | BSc | The marine science with oceanography and robotics BSc degree stream focuses on physics/engineering aspects of marine science[246]. More details about the course are available in the relevant section. | UK | 4 years | EN |

## 6.3 Section conclusions

Based on the analysis provided, several European and Chinese universities are offering courses related to autonomous shipping. Some universities offer M.Sc. on autonomous marine systems in cooperation with other European Universities such as NTNU, University of Lisbon, Universite de Toulon, Universitat Jaume I, University of the Aegean, University of West Attica. Some other Universities (mostly British) offer dedicated M.Sc. degree of autonomy such as the University of Strathclyde, University of Southampton, The Scottish Association for Marine Science. The Chinese universities such as Wuhan University of Technology and Harbin Engineering University offer additional courses under the scope of the same M.Sc. degree. On overall, the curriculum of the previously mentioned universities includes modules and workshops related to the big data analytics, machine learning and artificial intelligence techniques, sensors design, control and navigation of surface and underwater vehicles, control optimisation, information and communication networks, human-machine interface design, reliability and safety analysis techniques, maritime law, regulatory aspects, cybersecurity and connectivity in maritime systems, insurance framework, marine systems digital twins, modelling and condition-based monitoring, economics, mechatronics.

# 7 Identification of areas of opportunities in study programs

## 7.1 Section outline

This section is organized as follows. First, an overview of required skills for the next generation practitioners in relation to MASS is provided. Then, overview of the identified areas of opportunities in the university study programs are being presented in the subsequent section.

## 7.2 An overview of required skill sets

Based on the analysis conducted in sections 3, 4, and 6, the next generation maritime experts would require the following skills subsets:

1. Understanding of design, operational and maintenance aspects including the software maintenance of MASS.
2. Ability to control and troubleshoot the ships remotely.
3. Good knowledge of image recognition techniques for the design of object identification systems.
4. Understanding of radiocommunication equipment performance and design in the novel context.
5. Knowledge of decision support systems using big data analytics and machine learning techniques.
6. Capability to interact with systems employing big data and machine learning techniques such as the one used for decision-making, condition-monitoring, objects identification.
7. Knowledge of decision-making control algorithms and techniques design and use.
8. Understanding of issues related to sensors design and use.
9. Knowledge of digital twins' design and use for maritime systems, such as the digital twins of ship hull, marine engine, propulsion motors, and power systems.
10. Understanding about regulatory, insurance and liabilities aspects in connection with novel technologies such as MASS.
11. Management of MASSs such as ship maintenance, ship routing, crew change, certificates management.
12. Knowledge of reliability and safety analyses of novel systems, KETs and MASS, root cause analysis skills and accidents analysis skills.
13. Knowledge of advanced manufacturing processes on shipyards employing automation tools and their impact on the design processes.
14. Ability to design and audit cybersecure solutions and manage cybersecurity/security in the maritime and in the context of MASS.
15. Understanding of the economic aspects of MASS and related KETs.
16. Knowledge related to design and use of advanced KETs, which requires understanding of software design issues, human-machine interactions, anthropological issues related to MASS, human factors, relevant project management skills, verification, and validation techniques.
17. Understanding of integration aspects related to KETs during ship design and ship building process.
18. Knowledge related to ethical aspects related to autonomous decision-making.
19. Ability to design and use the Internet of Things on ship platforms.
20. Ability to design and use the virtual reality platforms.
21. Understanding of project management skills in the MASS environment.
22. Knowledge of novel tools used during design of MASS such as SysML, UML languages, virtual testing platforms, novel safety assurance methods.
23. Communication of complex issues in context of MASS.
24. Quick learning skills and ability to think creatively.
25. Knowledge of novel satellite communication systems.
26. Ability to integrate and design complex systems.

27. Understanding about MASS impact on the infrastructure design and how to integrate MASS with the infrastructure.
28. Knowledge of novel services being developed in the context of MASS and novel business models.

In the next section we provide more specific areas of opportunities that can be expanded in the universities study programs.

## 7.3 Areas of opportunities

For the mechanical engineering department courses, the areas of opportunities include the following:

- Inclusion of how the MASS will influence the design process and when it is possible to decide which autonomy degree is cost-efficient to assign.
- Aspects related to testing and verification of MASS can be included.
- Aspects related to the development of digital twins and their use could be considered.
- Description of novel KETs to be used on MASS could be expanded.
- Course on AI and ML techniques with practical examples from maritime could be further developed.
- Aspects related to autonomous winter navigation in arctic could be covered.

For the computer science department related courses, the specific areas of opportunities include the following:

- The maritime regulatory framework in connection with cybersecurity and the attack types on maritime systems could be analysed or courses dedicated to maritime security could be developed.
- Examples of software design for maritime systems could be included.
- Consideration of human-machine interactions in the maritime context could be presented.

For business studies related courses, the exemplary areas of opportunities include:

- Strengthening of data sharing practices and cultures in the maritime field to enable capabilities managing the supply chains with more digital, IoT and autonomous elements.
- Increasing co-creation settings involving different actors from supply chains to explore and illustrate MASS opportunities in supply chains as a refined system.
- Analysing and disseminating via e.g., education the potential of MASS in reaching sustainability goals and secure JIT supply chains.
- Project management courses on MASS could be considered.
- Novel courses in law, logistics, business, and information systems could be developed.

Some more generic areas of opportunities with respect to courses include the following:

- Course on collision avoidance algorithms and path planning algorithms could be included in the curriculum.
- Course on automation and control of physical processes could be included.
- Course on sensors and their failure patterns could be included.
- Course related to digital ethics and autonomous systems ethics could be considered.
- Course related to virtual reality could be included in the study programs.
- Course in maritime law for autonomous shipping could be developed.

Other areas of opportunities include the following:

- Teaching of study programs organized by Aalto University, Åbo Akademi University and the University of Turku. Lessons learnt from FiTech collaboration can be used for that. Close cooperation with industry on the study program can be pursued.
- Novel modules and study paths at universities can be developed.
- Organizing joint international study programs on the topic of MASS.
- Sending students as part of Finnish delegation to IMO meetings related to MASS.
- Organise industry courses on topics relevant to MASS.

More detailed understanding about areas of opportunities will be implemented in other AutoMare work packages.

## 7.4 Section conclusions

In this section, a summary of 21 identified required skills set has been. Based on that, areas of opportunities in the mechanical department, computer science department and business department have been identified. Also, some areas of opportunities for the novel courses and new study programs have been identified.

# 8 Agile framework for study program update

## 8.1 Section outline

In this short section, the agile framework as well as the main steps for applying the framework are being presented.

## 8.2 Framework description

The proposed agile framework in Table 31 applies incremental changes to the existing educational curriculum through periodical reviews. The framework is based on the principles of a continuous collaboration between professors, students, industry, and governmental authorities. The framework repeats the adopted methodology steps (presented in section 2) for the identification of educational needs. The rationale behind this approach is that the technological developments and therefore the impact of novel developments on the job market will be slow and gradual, therefore small workshops and limited-size questionnaires, using the information developed in this deliverable as a foundation, will be sufficient to capture the novel developments.

The presented concept follows the Scrum approach, but with the difference that the time scale is distorted. The daily scrum has been replaced by biannual workshops and questionnaire conducted every 5 years, whilst the sprint period is extended to ten years. This is implemented since the technological developments are slow and therefore revisions of such a considerable timescale will be able to update the educational needs properly.

There could be some major technological disruptions or "black swans" that would need fast training adaptations in the training. In these cases, the workshops with industry will need to be organized on the spot, without waiting for the disruption emergence.

*Table 31 The elements of agile framework.*

| Type of revision | Type of activity | Required resources |
|---|---|---|
| For each course, every year | Through the learning logs, the lecturers can identify the issues that the students are facing and the material which they require to be included in relation to MASS. The Aalto lecturers could also update the time framework for MASS (described in Appendix A) on an annual basis. The Aalto lecturer should also discuss on which technologies they consider as prominent and with high potential for use soon | Commitment from the course leader |
| Every two years | A small workshop where the academics provide an update based on their knowledge about:<br>• Novel systems developed and novel trends in relation to MASS<br>• Skills in demand on the market<br>• Changes in the offered courses at courses<br>• Novel study programs being offered at other universities<br>It is anticipated that the academics, through their participation in research projects orientated at MASS, relevant conferences and interactions with industry will be aware of the novel technological developments, and therefore will be able to produce a constructive and comprehensive feedback.<br>Based on the update we can identify the additional educational needs and set up the priorities for educational program development. | 1 half day workshop requiring input from the university's personnel |
| Every two years | This workshop should be similar to the one implemented every two years, with the difference that it will involve a wider spectrum of experts. People from industry should also be engaged, and their feedback included in the analysis. University alumni can constitute a valuable resource. | One person month |

| | | |
|---|---|---|
| Every five years | An extensive literature review on the technology developments, job advertisements, required skills, and novel study programs. Also, questionnaire of the maritime practitioners. | As for the report |

# 9 Conclusions

In this report, an extensive analysis of educational needs in connection with MASS has been conducted. To achieve the overall aim, several steps have been followed. First, the potential technologies that can be employed on MASS have been identified with the support of literature review and the expertise of the reports' contributors in Section 3. Then the MASS impact on the maritime jobs and their requirements has been specified in Section 4. In Section 5, the study programs offered at Finnish universities have been critically reviewed to recognize their relevance to MASS. In Section 6, the courses and study programs offered at various international universities respectively have been reviewed. Using the information derived in previous sections, a list of required skill sets and the areas of opportunities for study programs have been generated in Section 7. Then, lastly, an agile framework has been proposed for updating the study program in a sequential and constant manner in Section 8.

The main findings with respect to MASS technologies' evolution are as follows:

- The introduction in MASS will result/have resulted in several innovative technologies being developed exploiting the advantages of information and communication technologies. Examples are novel automation functions, artificial intelligence and machine learning algorithms-based systems, novel cybersecurity solutions. Such a use of novels systems allows the implementation of novel ship design alternatives.
- The introduction of MASS technologies is also expected to have broader (and potentially disruptive) commercial implications for how maritime trade and supply chains are organized in the future.
- It is anticipated that the introduction of MASS will be gradual, with automation being implemented on diverse types of ships with varying speed.
- Some ship types will be partially autonomous in the following decades, whilst on some other ship types, the use of automation can be considered already a reality or is anticipated soon.
- The wide use of fully autonomous ships is not anticipated to be soon, but some protypes might appear in the near future.
- It is acknowledged that it is difficult to predict with accuracy when the MASS is widely available and what type of technologies will be used on MASS. That is why it is necessary to follow the agile framework for study program update as described in Section 8.

The main findings with respect to the impact of MASS on humans and organisations are as follows:

- Several new job skills will be in demand in the maritime domain, such as the skill sets offered by both the maritime engineering and computer science/electrical engineering departments. These skill sets include knowledge of interactions between computers and humans, remote control and troubleshooting of maritime systems, understanding and the design of applications running on artificial intelligence / machine learning algorithms, software-engineering of maritime applications, understanding about critical sensors' performance, understanding about novel regulations and ethical issues related to the design and operation of maritime systems, novel maintenance schemes, cybersecurity skills, digital twins knowledge, design and use of internet of things on ships, use of applications running on virtual reality.

- The sea going personnel will be affected the most by the ongoing transformation. However, the ongoing digital transformation will also influence the ship operating companies and their business models, the maintenance procedures, ships' governance, and insurance.
- Several designs related jobs will remain unaffected, such as structure and hydrodynamic experts. However additional and novel jobs related to design of systems on MASS will emerge such as experts in collision avoidance. Some other jobs will need to be adapted to the demands related to MASS, such as ship designer job through understanding of MASS design aspects.
- The introduction of MASS will facilitate more decentralized and specialised services being offered. Several services will be offered remotely such as remote inspections, pilotage, troubleshooting, cybersecurity, performance engineering.
- The differences between the sea going crew tasks and the ship management company tasks will be gradually abolished, as more tasks will be implemented on shore.
- New skills are also expected to be needed in the management of a shipping business, especially in maritime law and digital business models.

The main findings with respect to the courses offered by the universities in relation to MASS are as follows:

- Several aspects related to MASS have already been incorporated in several courses at Aalto University, Abo Akademi University and the University of Turku.
- The universities as a whole cover aspect related to cybersecurity, artificial intelligence, and commercial and legal issues due to MASS.
- New courses related to the challenges owing to MASS are also being developed.

The main findings with respect to the courses offered by the international universities are as follows:

- Many universities are offering specialised MSc programs lasting either 1 or 2 years focusing on MASS or robotics.
- The offered study programs can be distinguished in study programs offered by a single university (mostly by British universities) or joint study programs, managed by several universities (Mostly by European universities).
- The Chinese universities are currently enhancing their study programs with additional courses without offering specialised MSc programs.

The main identified areas of opportunities for study program include the following:

- Many aspects related to the MASS design and operation can be incorporated into the courses.
- The content of courses offered in different schools and departments within our universities can have a more strategical adjustment to mark a strong path towards the development of smart ships and smart service concepts.
- Courses offered in the Computer Science and Electrical Engineering department represent examples of course content that could be related to the mentioned path. However, better integration with the courses related to automation engineers, software development and communications systems will be required.
- Aspects such as the one related to digital twins, radio-communication equipment and liabilities can be addressed in more depth.
- Specialized expert profiles can be offered by collaborative building degree programs, where topical modules offered in different universities can be studied as thematic specialization modules or minor subjects to strengthen and support the chosen major subject or track. Some valuable

experiences to achieve this could be learned from the FiTech collaboration between technology universities.

- There is also an opportunity to offer MASS-related education in the area of law, logistics, business, and information systems. It could either be done by updating current courses in these fields or by developing courses tailored for MASS-area, such as focusing on legal issues of MASS.

The main findings with respect to the proposed agile framework:

- It is recommended that the educational needs in the context of MASS are reviewed on a biannual basis using feedback from academics and industry, and every five years using a systematic analysis of existing literature to proactively identify the educational needs. Attention should also be paid to technologies which might have disruptive effect on autonomous shipping.
- Proactive standing against disruptive technologies should be taken.

It is expected that the material assembled in the report will constitute a valuable tool in the hands of the maritime practitioners. It can be used as a map for innovation and novel technology developments, but also as a map for education programs development in the maritime domain. Methodology presented here can be also adopted in other industry domains.

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# Appendix A The employed questionnaire for MASS

Pls indicate the year in your answer

1. When do you believe ships complying to MASS degree 1 will be widely available?
2. When do you believe ships complying to MASS degree 2 will be widely available?
3. When do you believe ships complying to MASS degree 3 will be widely available?
4. When do you believe ships complying to MASS degree 4 will be widely available?
5. How confident do you feel in your answers? (1=very confident, 5 =not confident at all).

# Appendix B The employed questionnaire for eliciting information about the courses

1.What topics relevant to the autonomous ships are covered in your course?

2.How many exercises have you included in relation to autonomous shipping in your course?

A. No exercises, very few, medium percentage, many, almost all

3.How many examples have you included in relation to autonomous ships in your course, when presenting the material?

A. No examples, very few, medium percentage, many, almost all

4.How did the students assess your content in relation to autonomous ships?

A. Positively Neutrally Negatively NA

5. How many students from maritime group usually attend this course?

(Question addressed at professors coming from Computer Science department).

# Appendix C Aalto offered courses

The table C.1 included the courses that are currently offered at Aalto. RE denotes recommended, O denotes optional courses.

*Table C.1 Aalto offered course*

| | | NA | AMT | PE | SE | HE | SMO |
|---|---|---|---|---|---|---|---|
| | **Common studies** | | | | | | |
| 1 | MEC-E1004 Principles of Naval Architecture | RE | RE | RE | RE | RE | RE |
| 2 | MEC-E1010 Dynamics of rigid body | RE | RE | O | RE | RE | |
| 3 | MEC-E1020 Fluid dynamics | RE | O | O | O | RE | |
| 4 | MEC-E1030 Random loads and processes | O | RE | O | RE | RE | |
| 5 | MEC-E1040 Dynamics of structures | O | RE | O | RE | O | |
| 6 | MEC-E1050 Finite element method in solids | O | O | O | RE | O | |
| 7 | MEC-E1060 Machine design | | | O | | | |
| 8 | MEC-E1070 Selection of engineering materials | O | O | RE | RE | | |
| 9 | MEC-E1080 Production engineering | O | | RE | | | |
| 10 | MEC-E1090 Quality management and metrology | | | RE | | | |
| | **Marine Technology** | | | | | | |
| 11 | MEC-E2000 Marine and Ship Systems Engineering | RE | RE | RE | RE | RE | RE |
| 12 | MEC-E2001 Ship hydrodynamics | RE | RE | RE | RE | RE | RE |
| 13 | MEC-E2002 Ship buoyancy and stability | RE | RE | RE | RE | RE | RE |
| 14 | MEC-E2003 Passenger ships | O | | RE | O | O | O |
| 15 | MEC-E2004 Ship dynamics | RE | RE | RE | RE | RE | RE |
| 16 | MEC-E2007 Ship structures and construction | RE | RE | RE | RE | RE | |
| 17 | MEC-E2009 Marine risks and safety | RE | RE | RE | RE | RE | RE |
| 18 | MEC-E2010 Computational fluid modelling | O | | | | RE | |
| 19 | MEC-E2011 Ship design portfolio | RE | RE | RE | RE | RE | RE |
| 20 | MEC-E2012 Computational marine hydrodynamics | O | | | O | RE | O |
| | **Arctic** | | | | | | |
| 21 | MEC-E4001 Winter navigation | RE | RE | | O | O | |
| 22 | MEC-E4002 Ice loads on structures | | RE | | O | | |
| 23 | MEC-E4003 Ice mechanics | | RE | | O | O | |
| 24 | MEC-E4004 Model scale testing in ice | O | RE | | | O | |
| | **Solid Mechanics** | | | | | | |
| 25 | MEC-E8001 Finite Element Analysis | O | O | | RE | | |
| 26 | MEC-E8003 Beam, Plate and Shell Models | O | O | | O | | |
| 27 | MEC-E8005 Thin-walled structures | O | O | | RE | | |
| 28 | MEC-E8006 Fatigue of structures | O | O | | RE | | |
| 29 | MEC-E8007 Fracture mechanics | O | O | | O | | |
| | **Production Engineering** | | | | | | |
| 30 | MEC-E7001 Production Systems Modelling | | | RE | | | |
| 31 | MEC-E7002 Manufacturing methods I | | | RE | | | |
| 32 | MEC-E7003 Manufacturing methods II | | | O | | | |
| 33 | MEC-E7004 Industrial Project | | | O | | | |
| 34 | MEC-E7006 Advanced manufacturing | | | O | | | |
| | **Engineering Materials** | | | | | | |
| 35 | MEC-E6002 Welding Technology and Design | O | | | O | | |
| | **Computer Science** | | | | | | |
| 36 | CS-C3120 Human-Computer Interaction | | | | | | RE |
| 37 | CS-C3130 Information Security | | | | | | O |
| 48 | CS-C3150 Software Engineering | | | | | | RE |
| 49 | CS-C3160 Data Science | | | | | | RE |
| 50 | CS-E3240 Machine Learning D | | | | | | RE |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 51 | CS-E4710 Machine Learning: Supervised Methods | | | | | | RE |
| 52 | CS-E4800 Artificial Intelligence | | | | | | O |
| 53 | CS-E4900 User-Cent. Meth. for Product and Service Design | | | | | | O |
| 54 | CS-E4930 Software Processes and Projects | | | | | | O |
| 55 | CS-E4940 Requirements Engineering | | | | | | O |
| 56 | CS-E4950 Software Architectures | | | | | | O |
| 57 | CS-E4960 Software Testing and Quality Assurance | | | | | | O |
| 58 | CS-E5220 User Interface Construction | | | | | | O |
| 59 | CS-E5310 ICT Enabled Service Business and Innovation | | | | | | O |
| 60 | CS-E5340 Introduction to Industrial Internet | | | | | | O |
| 61 | CS-E5360 Systems of systems | | | | | | RE |
| 62 | CS-E5795 Computational Methods in Stochastics | | | | | | O |

# Appendix D Current (2021-2022) relevant courses at the University of Turku

(FI) indicates that the course is instructed in Finnish (most Bachelor's level courses. Abbreviations BSc and MSc are added for some departments to separate between Bachelor's and Master's level courses.

**Faculty of Technology, Department of Computing**

| | | |
|---|---|---|
| **Artificial Intelligence and Machine Learning** | | |
| TKO_2114 | Tekoälyn perusteet (FI) | https://opas.peppi.utu.fi/fi/opintojakso/TKO_2114/21286 |
| TKO_2115 | Tekoälyn menetelmät (FI) | https://opas.peppi.utu.fi/fi/opintojakso/TKO_2115/21287 |
| TKO_8612 | Deep Learning | https://opas.peppi.utu.fi/fi/opintojakso/TKO_8612/8225 |
| TKO_3108 | Algorithm Design | https://opas.peppi.utu.fi/fi/opintojakso/TKO_3108/2296 |
| TKO_3109 | Advanced Algorithm Design | https://opas.peppi.utu.fi/fi/opintojakso/TKO_3109/3254 |
| TKO_3120 | Machine Learning and Pattern Recognition | https://opas.peppi.utu.fi/fi/opintojakso/TKO_3120/2298 |
| TKO_3121 | Machine Learning and Algorithmics Seminar | https://opas.peppi.utu.fi/fi/opintojakso/TKO_3121/3255 |
| | | |
| **Autonomous Systems and Robotics** | | |
| DTEK8085 | Autonomous Systems Architectures | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8085/9261 |
| DTEK1057 | Energy Efficient Embedded Electronics | https://opas.peppi.utu.fi/fi/opintojakso/DTEK1057/3465 |
| DTEK0079 | Hardware Accelerators for Robotics and AI | https://opas.peppi.utu.fi/fi/opintojakso/DTEK0079/20377 |
| DTEK0080 | Robotics and Autonomous Systems | https://opas.peppi.utu.fi/fi/opintojakso/DTEK0080/20378 |
| DTEK0081 | Perception and Navigation in Robotics | https://opas.peppi.utu.fi/fi/opintojakso/DTEK0081/20379 |
| | | |
| **Cyber Security** | | |
| DTEK8096 | Network Infrastructure Technologies and Security | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8096/3473 |
| DTEK2034 | Communication Technologies and Security in IoT | https://opas.peppi.utu.fi/fi/opintojakso/DTEK2034/6703 |
| DTEK8025 | System and Application Security | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8025/1894 |
| DTEK2029 | Human Element in Information Security | https://opas.peppi.utu.fi/fi/opintojakso/DTEK2029/3475 |
| DTEK0039 | Security Engineering | https://opas.peppi.utu.fi/fi/opintojakso/DTEK0039/3476 |
| DTEK8063 | Firewall and IPS Technology | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8063/4507 |

| | | |
|---|---|---|
| DTEK8060 | Protocol Processing and Security | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8060/3472 |
| DTEK8102 | Privacy and Security for Software Systems | https://opas.peppi.utu.fi/fi/opintojakso/DTEK8102/9932 |

**Faculty of Technology, Department of Mechanical and Materials Engineering**

| | | |
|---|---|---|
| KTEK0042 | Robotiikka (FI) | https://opas.peppi.utu.fi/fi/opintojakso/KTEK0042/24397 |
| KTEK0036 | Smart Systems Engineering | https://opas.peppi.utu.fi/fi/opintojakso/KTEK0036/24183 |
| KTEK0038 | Intelligent Control | https://opas.peppi.utu.fi/fi/opintojakso/KTEK0038/24188 |
| KTEK0039 | Smart Systems Modelling | https://opas.peppi.utu.fi/fi/opintojakso/KTEK0039/24189 |

**Faculty of Mathematics and Natural Sciences, Department of Geography and Geology**

| | | |
|---|---|---|
| MAAN6080 | Geoinformatiikan perusteet (FI) | https://opas.peppi.utu.fi/fi/opintojakso/MAAN6080/1845 |
| MAAN6732 | Paikkatietomenetelmät (FI) | https://opas.peppi.utu.fi/fi/opintojakso/MAAN6732/1849 |
| MAAN7764 | Geospatial Data Management and Visualization | https://opas.peppi.utu.fi/fi/opintojakso/MAAN7764/8677 |

**Faculty of Law**

| | | |
|---|---|---|
| TLS_0083 | Law and Artificial Intelligence | https://opas.peppi.utu.fi/fi/opintojakso/TLS_0083/6412 |
| TLS_0084 | Law and Artificial Intelligence: Contracts and Liability | https://opas.peppi.utu.fi/en/course/TLS_0084/6413 |
| TLS_0071 | Maritime Law | https://opas.peppi.utu.fi/en/course/TLS_0071/940 |

**Turku School of Economics, Department of Marketing and International Business**

| | | |
|---|---|---|
| MA032016 | Innovaatio- ja tuotejohtaminen (FI) (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/MA032016/21138 |
| MA033064 | Business Market Management (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/MA033064/4086 |
| MA033005 | Innovations and New Business Opportunities (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/MA033005/1195 |
| LG212001 | Toimitusketjujen johtaminen/Supply Chain Management (FI) (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG212001/1614 |
| LG212030 | Kuljetustoiminnot- ja markkinat (FI) (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG212030/1531 |
| LG213055 | The Strategic Role of Responsibility in Business (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG213055/4200 |

| | | |
|---|---|---|
| LG213103 | Toimitusketjujen johtamisen kvantitatiiviset sovelelukset (FI) (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG213103/3750 |
| LG213071 | Logistiikkapalvelut ja – markkinat (FI) (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG213071/3759 |
| LG213009 | Principles of Shipping Economics (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/LG213009/13597 |
| KV203004 | Managing International Innovation Development (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/KV203004/1177 |
| KV203232 | Project Management and Innovation (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/KV203232/3516 |

**Turku School of Economics, Department of Accounting and Finance**

| | | |
|---|---|---|
| YJ052012 | Ulkomaankaupan kuljetus- ja sopimusoikeus (FI) (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/YJ052012/1569 |

**Turku School of Economics, Department of Management and Entrepreneurship**

| | | |
|---|---|---|
| TJ092804 | Digitaalinen liiketoiminta (FI) (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ092804/1974 |
| TJ092022 | Emerging Technologies (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ092022/20903 |
| TJ092016 | Yrityksen tietojärjestelmät (BSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ092016/1883 |
| TJ093021 | Management of IS Projects (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ093021/1105 |
| TJ093238 | Digital Economy and Business Models (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ093238/4128 |
| TJ093107 | Governance and Strategic Management of Digital Business (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ093107/1109 |
| TJ093222 | Information Technology and Ethics (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ093222/1114 |
| TJ0931503 | Management of Information System Security (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/TJ093150/1113 |

**Turku School of Economics, Finland's Futures Research Centre**

| | | |
|---|---|---|
| FUTS3104 | Strategic Corporate Foresight (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/FUTS3104/21292 |
| FUTS3103 | Technology Foresight (MSc) | https://opas.peppi.utu.fi/fi/opintojakso/FUTS3103/21293 |

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