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A preliminary analysis of the impact of Autonomous Maritime Surface Ships in Marine Technology Education

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Abstract

This thesis is written to analyse the development of Maritime Autonomous Surface Ship its impact on technology and trends in shipping. The concept of Maritime Autonomous Surface Ship is introduced and projects that explore the concept and one which has been developed is reviewed. A review of Maritime Autonomous Surface Ships in Maritime Education and Training for seafarers is conducted to see the results of these studies.

The author analyses the courses taught at Aalto University to see how much of the Autonomous Ship concept is incorporated in the education of Naval Architecture students. A study of various courses offered at other universities is conducted and the technologies that are implemented in Maritime Autonomous Surface Ships are analysed. An evaluation of various education techniques is conducted to possibly formulate a plan to incorporate these techniques in the education of students of Marine and Arctic Technology at Aalto University.

Following the research, the viability of Maritime Autonomous Surface Ships to be incorporated is discussed and implementation of techniques in education are shown. A plan is formulated to see which technologies can be incorporated in which courses and a timeline is formulated to incorporate Maritime Autonomous Surface Ships in Marine and Artic Technology at Aalto University.

The author concludes that it is viable to incorporate Maritime Autonomous Surface Ships in education of Naval Architecture students by following the plan given.

Keywords Maritime Autonomous Surface Ship; Autonmous; Maritime; Marine Technology; Courses

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Preface

I would like to thank Professor Osiris Valdez Banda for his support throughout the journey of my thesis and through my mental health crisis. His support was really helpful, and he helped me a lot in finishing this finally. I would also like to thank my advisors MSc. Meriam Chaal and PhD. Ahmad BahooToroody who helped me with organising my work. I would like to thank my parents who pushed me and supported me throughout my journey of my thesis. I would like to thank my wonderful girlfriend Aleksiina Sarjanen who provided support and love through the lowest of my time. Lastly, I would like to that my friends Alice Petry and Emily Johnson who supported me.

Abbreviations

MASS	Maritime Autonomous Surface Ships
AAWA	Advanced and Autonomous Waterborne Applications
AI	Artificial Intelligence
AMV	Autonomous Marine Vehicles
ARPA	Automatic Radar Plotting System
ASV	Autonomous Surface Vessel
ATA	Automatic tracking Aid
AUV	Autonomous Underwater Vessel
CA	Collision Avoidance
CFD	Computational fluid dynamics
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea
DOF	Degree of Freedom
ECIDS	Electronic Chart Display Information System
EU	European Union
GNSS	Global Satellite Navigation System
IMO	International Maritime Organization
IST	Instituto Superior Tecnico, Portugal
MIR	Marine and Maritime Intelligent Robotics
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NTNU	Norwegian University of Science and Technology
OpenFOAM	Open-source Field Operation And Manipulation
PID controller	Proportional integral derivative controller
RADAR	Radio Detection And Ranging
RANS	Reynolds-averaged Navier–Stokes
SLAM	
UJI	Jaume I University
UTLN	University of Toulon
SCC	Shore Control Center

1. Introduction

1.1. Background:

Some 1.9 million seafarers work in the maritime industry, which accounts for roughly 80 percent of worldwide freight transportation [1]. The industry, however, is frequently claimed to be safer and more efficient if people were removed from the process. Maritime Autonomous Surface Ships (MASS), sometimes known as automated ocean-going commercial boats, would be able to sail the sea either with full autonomy or under the management of a remote land-based station. This station is called the Shore Control Center (SCC). The introduction of autonomous surface ships (MASS) that run on alternative fuels into the maritime industry will bring in new paradigm shifts in technologies which will improve the safety of shipping and will help in achieve reduction of pollution. On the other hand, new technology raises worries about the possible appearance of new types of risks, such as non-navigational hazards and cyber threats, which are examples of the types of dangers that are currently unknown. The advancements in the field of autonomous boats are the primary subject of this article. Additionally, the most recent projects in this space come from all around the world.

The maritime sector is no exception to the disruptive potential of autonomous ships. There will be no sudden appearance of autonomous ships on the high seas. Increasingly self-sufficient ships with smaller crews will begin to operate as technology improves and a proven track record of reliability is built up. As a result, it is expected that human ships will work alongside autonomous or remotely controlled ships in the future. Future traffic control solutions are particularly hard in situations where there is a mix of vehicles. With the introduction of this new technology, there comes a challenge with regards to how the autonomous technology is influencing the shipping industry and what is needed to be done in order to ensure that the current skills are enhanced and promoted alongside the new technology without having been declared obsolete as it will take quite a long period of time for such technology to be fully adopted in the shipping industry.

For as long as the modern human knows ships have existed. They were rafts first, then came ships with rowers, next we had sails on different sizes of ships, use of iron, steel and other metals [2]. We then graduated to using steam by burning coal for propulsion and then using fossil fuels in the power generation unit directly to cleaner energy like hydrogen fuels, and electric propulsion [2]. Our navigation technology has changed from using magnetic compass and sextants to modern satellite and radar systems which are very accurate [2]. Our communication has also come forward from using signal flags to radio and satellite communication which are very efficient and convey the message quickly [2]. In the area of command-and-control humans are still at the forefront but autonomous Psystems are the future [2] This thesis focuses of this future. Autonomous systems exist in areas of land vehicles, and they are proving to be quite successful. But the journey of autonomous shipping isn't that easy due to the vastness and complexity of the seas. Projects like Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) [3] and Advanced and Autonomous Waterborne

Applications (AAWA) [4] started this process by developing concepts of the Maritime Autonomous Surface Ships (MASS). Then projects like YARA Birkeland[5] made it a reality by testing a MASS in November 2021.

1.2. Problem Statement

One of the most significant challenges to the widespread adoption of MASS is education and retraining. This is because the new technology is coming with a fair share of challenges and complex dynamics that can be solved only through education. Despite the benefits associated with autonomous technology, training and reskilling is regarded as a significantly less significant challenge than the dependability of communication lines or the challenges posed by legal issues [6]. A research gap, or a chasm in the training of seafarers and the future of the shipping industry, was also highlighted on numerous occasions when it came to challenges that were associated with training [7]. It is therefore evident that there are mixed reactions and mixed information generated with regards to the impact of modern marine technology in influencing development of education in marine industry.

1.3. Aim and Research Questions.

This thesis studies the technology and research of MASS and proposed to answer the following research questions.

1. Is the broad spectrum of the concept of Maritime Autonomous Surface Ships (MASS) viable to include in the education of future Naval Architects?
2. How can this be included? (Procedure and possible timeline).

There is a necessity to evaluate Autonomous Shipping as a viable topic to be included in the education of Naval Architects as the technology is growing rapidly and since the MUNIN [3] project started in 2014, we already have tested a MASS in Norway namely the YARA Birkeland [5].

2. Literature Review

2.1. Autonomous Marine technology evaluation

Maritime Autonomous Surface Ships (MASS) are very few and the safety and security of them is more of a prediction than real world situations. It is essential to look at the problem from every angle if one is hoping to reduce the total number of potential risks. While there is nobody on board to repair it, even a little failure such as an out-of-gassing fuse or gasket might result in catastrophic consequences; as a result, reliability is an essential aspect to keep in mind when constructing such a ship. On the other hand, humans have been able to successfully place unmanned spacecraft into orbit and assure their continued usage for a significant amount of time over a number of years. Because of this, one may make the reasonable assumption that the dependability theory is sufficiently evolved to deal with an issue of this nature. Because of the difficulties associated with the autonomous contemporary ship's navigation in open sea, one of the main concerns is making sure that the cargo is safe [8].

2.1.1 Defining Autonomy and Levels of Autonomy

Before delving into the concerns of safety that are associated with unmanned boats, the language must be defined more precisely. In the literature, the term "autonomous" is used to refer to any vehicle that does not have an on-board crew. But with MASS there are various levels of autonomy defined by different regulatory authorities. In this thesis IMO, Bureau Veritas, and Lloyds Register are seen as below. These are taken from the papers published by regulatory authorities who set the standards for shipping. These tables are used to show the level of autonomy in MASS.

Table 1 IMO MASS Levels Classification[9]

Degree One	Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
Degree Two	Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions
Degree Three:	Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
Degree Four:	Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

Table 2 Lloyd's Register Autonomous Vessel Classification [10]

AL 0)	Manual: No autonomous function. All action and decision-making performed manually (n.b. systems may have level of autonomy, with Human in/ on the loop.), i.e. human controls all actions.
AL 1)	On-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data is provided by systems on board.
AL 2)	On &Off-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board.
AL 3)	'Active' Human in the loop: Decisions and actions are performed with human supervision. Data may be provided by systems on or off-board.
AL 4)	Human on the loop, Operator/ Supervisory: Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and over-ride.
AL 5)	Fully autonomous: Rarely supervised operation where decisions are entirely made and actioned by the system.
AL 6)	Fully autonomous: Unsupervised operation where decisions are entirely made and actioned by the system during the mission.

Table 3 Bureau Veritas Autonomous Vessel Classification[11]

Degree of automation		Manned	Definition	Information Acquisition	Information Analysis	Authority to make decisions	Action initiated by
A0	Human operated	Yes	Automated or manual operations are under human control. Human makes all decisions and controls all functions.	System Human	Human	Human	Human
A1	Human directed	Yes/No	Decision support: system suggests actions. Human makes decisions and actions.	System	System Human	Human	Human
A2	Human delegated	Yes/No	System invokes functions. Human must confirm decisions. Human can reject decisions.	System	System	Human	System
A3	Human supervised	Yes/No	System invokes functions without waiting for human reaction. System is not expecting confirmation. Human is always informed of the decisions and actions.	System	System	System	System
A4	Full automation	Yes/No	System invokes functions without informing the human, except in case of emergency. System is not expecting confirmation. Human is informed only in case of emergency	System	System	System	System

2.2. Projects of Autonomous Ships

2.2.1. Yara Birkeland

The MV Yara Birkeland is a self-sufficient container ship that has a capacity of 120 TEU developed by Yara Marine and Kongsberg. When the Yara Birkeland project was initially conceived, its objective was to create the first fully autonomous logistics concept in the world, one that would encompass the management of industrial sites, port operations, and vessel operations [5]. The vessel launched in 2022 can be shown below.

Figure 1 Yara Birkeland [5]

2.2.2. AAWA (Rolls-Royce)

Rolls-Royce was the leader of the Advanced Autonomous Waterborne Applications Initiative (AAWA) in partnership with various cargo, ferry, design companies namely Finferries, ESL Shipping, Deltamarin. AAWA is an initiative that focused on developing autonomous waterborne applications [4].

The partners such as universities, naval architecture firms along with navigation equipment makers, classification societies to investigate the various aspects of achieving self-navigating ships on a large scale. The goal of this investigation is to develop self-navigating ships that can operate independently. This project provides the specs and preliminary drawings for any advanced ship solutions that are developed. The sample dream ship image can be seen below

Figure 2 AAWA model[4]

2.2.3. MUNIN

As part of the EU's Seventh Framework Program, the European Commission had co-funded the MUNIN (Maritime Unmanned Navigation via Intelligence in Networks). This project intended to design and test a conceptual autonomous vessel that has level 3 autonomy which means that it is controlled by the SCC[3].

A lack of seafarers in the future, as well as considerable growth in transport volumes, are some of the issues facing maritime transport in the EU. It is possible to circumvent these difficulties using the notion of an autonomous ship. As a result, ships are able to operate more efficiently and competitively, and their environmental performance also improves. "Seafaring" may also become more socially sustainable by minimizing the amount of time crew members spend away from home. Sample autonomous ship image can be seen below in this picture.

Figure 3 MUNIN concept[3]

2.3. Review of MASS in Maritime Education and Training.

Two papers were analysed in detail to understand how MASS affects Maritime Education and Training. The lists given in the section 2.3.2. are lists of technologies that were analysed by the author which are listed below

2.3.1. E-Navigation, Digitization and Unmanned Ships: Challenges for Future Maritime Education and Training by M. Baldauf et al. [12]

This study has been carried out as an attempt to distinguish between the understanding of controls by Experienced Seafaring and Experienced Non-Sea faring personnel operating Unmanned or Autonomous Marine Vehicles from onshore or remote locations. The main purpose of this study is to help in identifying the needs of this sector and designing of education material or curriculum for future generation of students who would be interested in the operations of unmanned marine vehicles and sea traffic control. In short, the paper discusses an objective regarding the requirement of training and equipment needs of operators who would be working as navigators or drivers at Remote Ship Control Centres.

The Study was basically carried out by dividing 24 participants into the groups of 2. All groups were either made up of only Experienced Seafarers or only Experienced Non-Seafarers. A total of 12 groups were formed. Each group was given a similar situation in which they had to, with the help of a simulator; maneuver a same vessel. All participants had to sail from point A to point B ensuring maximum safety and efficiency. All conditions including traffic, weather, visibility, Current etc. were exactly the same. The Experiment was carried out over 2 sessions of ten minutes each. In the first part, half of each type of group had access to full bridge controls including engine control, rudder levers and full bridge view. The other groups were given controls access via mouse and keyboard only. In the second part, while all traffic and other conditions were kept the same, the controls given to the respective groups were reversed. So the groups that had access to only keyboard and mouse got full bridge control while the other groups had to settle for limited access. All groups always had access to Vessel Traffic Systems[12].

The experiment came up with some interesting observations. None of the groups managed to reach the destination in the stipulated time. All but one managed to steer the vessel safely avoiding collision. Experienced Seafaring participants were more compliant in their navigation with respect to current COLREGS (Collision Regulations) rules that the Non seafaring participants who seemed to break the traffic rules more often. However, the non-Seafaring groups seemed more creative in their approach to avoid collision. This indicates that COLREGS may need updating in future.

Although a in-depth study is further required, the conducted experiments concludes that Non Seafaring personnel were able to complete the given assignment. Experienced Seafarers are more used to contacting Vessel Traffic Control with the use of VHF. The use of Full Bridge View is an essential part that was used to try to successfully complete the experiment. Longer Exercises of simulation would be required to generate more data and further design the requirements of training and course curricula.

2.3.2. Marine Autonomous Surface Ship – A Great Challenge to Maritime Education and Training by W. Deling et al. [13]

The authors of this paper speak about different level of Automation that will be in place over the coming years. The Levels of Automation were in this paper were identified like that of the IMO regulations (Table 1).

These levels of automation speak of different level of human intervention, either by on board or on shore seafarers. These levels of Automation are bound to generate some specific challenges and needs in term of Maritime Education and Training (MET) of these seafarers. This paper through its observations and research, predicts a well-studied requirements of MET in the near future.

There is an in-depth analysis of the main technologies that are to be used in different levels of MASS. These technologies were identified by the author from the literature of LI Wenhua et al. [14] are listed as

- Cyber physical systems,
- Integrated bridge systems,
- Environmental Information perception,
- Collision Avoidance path planning,
- Track Control,
- Internet of things,
- Cloud Computing and
- Big Data.

All the above technologies have been studied and reported in detail and more importantly how they would benefit MASS.

In the analysis of the future requirements of MET, the authors state that, the current curricula are based on the requirements specified by the STCW (Training, Certification Watch- keeping and competence of Seafarer) convention and code. With the upcoming scenario of MASS, it would be greatly required to introduce a lot of different curricula to MET in the immediate future. In this relation, there is a list of subjects that would be most important for educating the next generation of students. These are non-existing in the present MET Curriculum or there are not enough facilities. They are listed as

- Network communication knowledge (Exists to some level presently),
- Data Mining knowledge,
- Artificial intelligence knowledge,
- Autonomous navigation,
- Fault Diagnosis,
- Remote control,
- Environmental information perception and
- Internet of things [13]

There is mention of one more aspect that would require to be addressed and that is psychological stress resistance. This is presently covered to some level only.

The paper concludes with the idea that there will be rapid progress in deploying Marine Autonomous Surface Ships or MASS in the world of sea transport. There is a definite argument and conclusion that in future higher skills than those existing today would be required to operate MASS. This clearly means that more specific subjects would be required to be inducted into the present MET system all over the world as the traditional education system would not be sufficient to impart the much-needed knowledge and develop the skills that would be actually required by the operators of MASS.

3. Methodology

In this section we will see the contents of the courses covered at Aalto University, analyze them, and see which courses cover MASS as in the teaching of the course. Next, we will analyse the technologies developed specifically identifying the major development in the key areas of ship design. We will also discuss the key teaching methods other than classroom teaching to support the courses. This analysis will then help us formulate a plan of action in the next section of how all the technologies should be included in the education of Naval Architects.

3.1. Official content of Courses taught in Aalto University Marine and Arctic Technology Engineering taken from SISU

The syllabus from each of these courses was taken from SISU to analyse which courses have syllabus of MASS. This analysis will help in determining what

3.1.1. Principles of Naval Architecture:

The course introduces the framework of ship design and teaches how to use the design spiral. The mission is defined, and the main dimensions and power requirements are defined using statistical methods. Hydrostatics and hydrodynamics are used to define the hull form and the general arrangement. Then the structure, equipment and machinery is defined conceptually using references. The weight is defined using statistical methods and initial geometry. The student is expected to understand the different disciplines of the design process and the tools used to design a ship. The student is expected to remember basic terminology and notations of naval architecture and search specific literature for different tasks. No autonomous shipping is covered in course structure but a few project topics of autonomous ships are defined.

3.1.2. Ship Design Portfolio:

Students work in a group to further the design of the ship in the Principles of Naval Architecture course first outlining the drawbacks of the design and improve the design. The skills and knowledge got during the M.Sc. studies are utilised and the design process is furthered. The structure, hull form, hydrodynamics, general arrangement based on the ship mission are defined. The hull structure, limited weight calculations and cost analysis is also done. The students are expected to work in groups, learn and use relevant tools like NAPA. The students should demonstrate critical and creative thinking. They also need to understand personal strength and weaknesses and create a personal development plan and portfolio. There is no autonomous ship content in the course unless it is in any project.

3.1.3. Ship Hydrodynamics:

The course covers ship resistance and the possible phenomena responsible. Assessing the effect of the hull dimensions and its features on the resistance and theoretical and experimental principles along with scaling laws are taught. The principles if propellers and propulsions of the ship are taught. Knowledge on how to estimate the power of the ship is gained and how to describe the effect of flow parameters on propeller cavitation and the effect of erosion. This knowledge is used for preliminary design of propellers. The manoeuvring and rudder principles are taught and the basic indices to describe the manoeuvring and testing methods to assess performance. Rudder types and turning capability are taught. The course does not cover any autonomous shipping.

3.1.4 Ship Buoyancy and Stability

This course teaches the hydrostatics of floating objects, stability of an intact and a damaged ship. It also includes the dynamic roll motion and stability failure modes in waves. The course also covers subdivision of ships, and probabilistic approach to damage ship calculations. Students are expected to apply this knowledge to their own ship project to design their ship. No autonomous ship curriculum is covered in this course.

3.1.5. Marine and Ship Systems Engineering:

The course covers the concepts of system of systems engineering, ship and marine traffic systems and the integration of these systems in ship design, systems modelling, design methods and tools like NAPA, CFD. It also covers propulsion and plant management, navigation and manoeuvring systems, auxiliary power systems and their management, automation of systems, auxiliary operation, ballast and trim management. In the power plant system it also covers the energy sources and different fuel types such as diesel, electric, LNG. It also covers modern types of motors, exhaust systems and systems to treat the exhausts, HVAC systems, heat management systems. It also covers non mechanical systems such as the Electric systems, Fire safety systems, IT and communication systems which help in ship traffic management and special systems for arctic shipping. This covers some level of autonomous shipping.

3.1.6. Ship dynamics:

This course covers the ship theory in context if seakeeping and loading. It covers concepts like linear surface wave theory, 6 DOF ship motions, strip theory and 3D panel methods to evaluate the rigid body motions and hull girder loads. Hydroelasticity of ships is introduced. Concept of motion control equipment like ballast tanks are taught. The non-linear effects of surface waves, ship dynamics and motions and loads are taught. The students are expected to assess the seakeeping abilities of the ship and the students are expected to use the mathematical models taught to assess the danger associated with irregular surface waves. The students are also expected to understand the concept of loading of rigid and flexible ship idealisations in waves and apply those principles for a rational ship design. No autonomous ship design or concepts are covered.

3.1.7. Ship Structures and Construction:

This course covers the concepts of loads on marine structures, analysis of the stresses and deflection of the hull girder and the substructures caused by these loads. It also covers the load carrying capacity of the ships and the structural performance which includes loads of the superstructure and load of cargo/passengers, the reliability of the structure, material selection and production. The students are expected to assess the structure and its effects on safety, production and maintenance of the ship, the process of it constructions and how the structural design is linked to other principles. No automation is taught in this course.

3.1.8. Marine Risks and safety:

The course introduces the basic concepts and frameworks of engineering risk and safety. These concepts are linked to the methods of hazard identification, risk analysis and safety engineering. An overview of maritime safety regulatory regimes and main regulations are taught, and the concepts of design and operation are discussed in greater depth. The student is expected to explain all the above and apply the knowledge to the design of ships. No automation regulations are covered here.

3.1.9. Ice Mechanics:

This is an introductory course on the mechanics of ice. No prior knowledge of ice mechanics is required but basic knowledge of solid mechanics is necessary. The course focuses on the sea ice mechanics, formation of ice, different types of ice and the mechanical properties of ice as a material. This knowledge helps in the analysis of the ice loads on ships and marine structures. The course does not cover autonomous shipping.

3.1.10. Winter Navigation:

This course covers the winter navigation system in the Baltic Sea, definition of the sea ice conditions in the Baltic Sea, the mechanical properties of ice and the functioning of a ship in various sea ice conditions. It also focuses on how to design ships in sea ice and the loads induced by the ice on the ships. The students are expected to use the principles taught to understand the effects of ice on the ship and calculated the power requirements by calculating the resistance on the ship and how to design the hull with considering the loads. It does not cover automation.

3.1.11. Ice Loads on Structures:

This course covers the different loads on an ice breaker and marine structures. It defines different loading scenarios of loading like loads due to intact sea ice, ice ridges and rubble. It also covers the process of ice breaking and ice induced vibrations during the process of breaking. Analytical and statistical models are discussed, and numerical modelling is introduced, and the standards related to the ice breaking process are taught. This course does not cover automation in shipping industry.

3.1.12. Model Scale Testing in Ice:

The course covers scaling methods in ice properties and ice breaking ships, the measurement technologies to measure the properties of ice, basics of model ice physics, measurement methods in model scale testing for ship resistance in ice and the experiments of performance assessment of the ice and the ships in ice. The student is expected to understand the model ice preparation methods and the measurement technology, data processing methods and measurement system setup and the impact on the experimental outcomes. Also, the student is expected to understand the limitations of scaling the model tests and the challenges that come with model testing. Autonomous shipping is not covered in this course.

3.1.13. Fluid Dynamics:

This course focuses on increasing the depth of the knowledge of fluid flow phenomena both boundary layer and turbulent flow. The course focuses on understanding the Navier-Stokes equations and the fundamental physical process of fluid flow. The student is expected to understand, use and apply all the concepts and formulae taught. No automation technology is taught as this is a physics course.

3.1.14. Computational Fluid Dynamics:

This course covers a systematic approach to CFD where it touches upon the topics learnt in Fluid Dynamics and uses the concepts to model certain problems in the software OpenFOAM, and the theory is put to practise in MATLAB as well. Students learn the basics of discretization, mesh generation and simulation. The student must be able to work with the Navier-Stokes equation and compare simulation data with reference solutions in laminar flow regime and dynamic flow phenomena. It doesn't cover any automation studies.

3.1.15. Computational fluid modelling:

This course instructs the students to perform a complete CFD simulation project from definition of the research problem to the results of CFD simulations and inferences from those results. This will also familiarise the students with the main steps required to complete a simulation successfully and help in understanding the modelling approaches and techniques. The course relies on learning by doing approach and reading circles help in gaining knowledge of the concepts required for the modelling of the project. Students must present their projects in the final seminar. Doesn't cover automation as the course is entirely based on fluid simulations.

3.1.16. Computational Marine Hydrodynamics:

This course requires individual reading and computation analysis of a reference ship and a concept design. The topics covered are:

- General description and characteristics of free surface flow problems and the mathematics behind them.
- Numerical modelling of ship hydrodynamics with potential flow and RANS equations.
- Hull form improvement based on results and numerical predictions.

This reading is supported by meetings with the teaching staff. This course should be taken with Computational Fluid Modelling as the basic concepts of simulation are not taught in Computational Marine Hydrodynamics. The students are expected to use the knowledge and apply it to analyse the fluid flow and power requirements of a ship in calm water conditions using CFD software. No autonomous shipping is taught in this course.

3.1.17. Random Loads and Processes:

This course covers the general description of random variables of processes like loads due to wind and waves and their properties along with the continuous and discrete distributions of these variables. Techniques like Fourier transformation of the random variables are also taught. The single degree of freedom in frequency domain and the gaussian signal in time domain are covered. Random variables of beams and strings are covered along with the peak and extreme value statistics of the variables. The student is expected to apply the concept of probability and the distributions in mechanics and how these variables are connected. They should also be able to perform spectral analysis if these variables and estimate the probability of the extreme values and define the response of the variables for a linear system. The use of autonomy is not taught in this course

3.1.18. Finite Element Analysis:

This course covers topics like vibration, stability, non-linear and thermo-mechanical analyses of machines and structures using tools of Analysis and Finite Element Methods. The student should be able to analyse the vibration of beams structures, to find the critical load for buckling of a beam structure, to model of non-linear bar structure and perform thermo-mechanical analyses of bar and thin slab structures. Autonomous systems are not taught in this course.

3.1.19. Fatigue of Structures:

This course introduces of fatigue phenomena and loading. The theory covers the modelling principles and different approaches such as stress and strain-based approaches and fracture mechanics. These methods are applied to do fatigues assessment of a selected structure through a project. The course also covers the basics of residual stress effect, fatigue of welds and multiaxial stresses. The student should be able to use this knowledge to understand cyclic loading, identify the main factors of fatigue and main modelling principles and assumption used in fatigue approaches. Autonomous systems are not taught in this course.

3.1.20. Thin-walled Structures:

This course teaches design, load modelling, discretization of finite element models. Analyses of isotropic, orthotropic materials and sandwich structures is taught. Modelling of offset beams, equivalent plates and shells, sub models are covered. Static analysis, fatigue analysis buckling analysis, ultimate and accidental strength analysis is also covered. The student is expected to identify the requirements of analysis and modelling of thin-walled structures. Autonomous systems are not covered in this course.

3.1.21. Passenger Ships:

This course introduces the students to shipscapes, teaches how to creatively design a ship. It covers the design criteria, functions and features of a passenger ship. It covers the history of cruise ships, the design and architecture of cruise ships and how they are made. Modern technologies for the safety, design and comfort of the passengers and the rules and regulations for a passenger ship are taught along with what entails in the future of cruise shipping industry. The student is expected to be creative in the design of passenger ships in the project while understanding the current trends and developments in the industry. A student should be able to define the general arrangement while keeping the design user-centric design based on broad requirements of the ship. They also should be able to apply the safety and regulatory requirements and how to go beyond the requirements.

3.2. Official Description of courses and degree programs offered at other universities related to MASS.

These courses contents were described from the websites (referenced) of all the universities and were used to analyse what is being taught in courses that contain curricula of MASS. The analysis of this helps in probable development of courses for MASS analysed in Aalto University.

3.2.1. Master's Degree Program in Autonomous Maritime Operations

This program is offered by Åboa Mare – Maritime Academy and Training [15]. The program, which is in origin provided by Novia University of Applied Sciences, has a special focus on digitalization of maritime technology. It is basically aimed at educating engineers and seafaring personnel so that they can meet the expectations of the fourth industrial revolution related to the maritime industry. The program starts by giving an introduction to studies and introduction to Marine operations and moves on to cover subjects such as, Automation of Autonomous Vessels, Artificial Intelligence, Remote Operations, Cyber Security and Connectivity, Classification, Qualification and Safety Perspectives. These subjects are all connected to Digitalization of maritime technology.

3.2.2. Master's Degree Marine and Maritime Intelligent Robots

This course if offered by the Université de Toulon [16]. The Course is a combination of robotics and artificial intelligence using innovative ways with context to the progress of maritime and marine sciences related to their technological applications. The main aim is to shape skills for development in marine-related fields, with particular focus to the implementation of autonomous marine robots (both surface and underwater) with remote operating capability, and the use of artificial intelligence (AI) in these fields.

The MIR consortium has four main academic partners. the University of Toulon (UTLN, France) as coordinator, the Norwegian University of Science and Technology (NTNU), the Jaume I University (UJI, Spain) and the Instituto Superior Técnico (IST-UL, Portugal). It als is part of a network that has associates numbering more than fifty academic and industrial partners. All the partners specialize in marine sciences and/or robotics and artificial intelligence. First year of the master's degree gives the students the required base in marine sciences, robotics and AI. It is taken in France at UTLN. Specialized seminars in industry are also held during the first year.

For the second year Students get to choose a specialization with one of the other Consortuium Partners. Underwater Intervention is conducted at UJI, Spain, while Autonomous Underwater Operations are taught at NTNU. The third option Cooperative Robotics for Marine Vehicles at IST, Portugal.

3.2.3. The University of Strathclyde

Course Name: MSc Marine Engineering[17]

Elective Subject: Autonomous Marine Vehicles (AMV) and Digital twin

This is a full time Course of 12 Months duration split in 2 semesters. There is a prerequisite of a first or second-class honours degree in a relevant subject (International Equivalents are acceptable).

The following subjects are compulsory.

Semester 1:

Shipping Economics and Market Sector Analysis

Systems Availability & Maintenance

Inspection & Survey

Marine Engineering Simulation and Modelling

Onboard Energy Management & Marine Environment Protection.

Semester 2:

Advanced Marine Engineering

Maritime Safety & Risk.

Also, a group Project is compulsory during the second semester.

One of the Second semester's elective subject is Autonomous Marine Vehicles (AMV) and Digital Twin.

This module covers topics such as:

A: Introduction

1. An introduction to AMVs: capabilities and potential.
2. AMV Design parameters.
3. Overview of AMV Power and Propulsion.

B: Modelling and Dynamics of AMV

4. Hydrodynamic forces and moments.
5. Six degrees of freedom of equations of motions.
6. Models for wind waves and ocean currents.

C: Guidance, Navigation and Control

7. Reference models
8. Trajectory tracking and manoeuvring control
9. Control methods for AMV

D: Modelling of Power and Propulsion plant

10. Models for propellers and motors
11. Thrust and torque modelling

E: AMV Applications

12. Autopilot models
13. AMV Propulsion Plant Modelling and Simulation

3.2.4 University of Southampton

Subject Area: Civil and Maritime Engineering

Course Name: Ship Science (MEng)[18]

Elective Subject: Maritime Robotics [19]

This Course is of 4 years duration. During the first 2 years, the knowledge of fundamentals of Science, Mathematics and engineering is imparted upon the students. During the second-year students can choose from broader discipline specific subjects like, Advanced Computational Engineering, Marine Engineering and Autonomy, Naval Architecture, Ocean Energy and Offshore Engineering and Yacht and High-Performance Craft. As the students' progress into the third and fourth year, more elective Modules are introduced.

One of the Fourth year Elective Subject is Maritime Robotics. In the subject or module, introduction of theoretical and practical design of maritime robotics systems with special attention is given to autonomous surface and underwater vessels/vehicles (AUVs, ASVs). This module provides knowledge required to develop skills pertaining design, build and deploy simple robotic systems, Theoretical principles include aspects of navigation and control and Modelling and Simulation.

The subject as taught in the fourth year has certain prerequisites. The following Structure must be followed for a student to take up the subject of Maritime Robotics as an elective.

Third year elective prerequisite: Marine Engineering. This has a Second year Elective Prerequisite, namely Systems Design and Computing for Ships. This also has certain Frist year Prerequisites such as, Mechanics, Structures and Materials, Thermo fluids, Electrical and Electronics Systems among others.

3.3. Specific Technological Developments in the field of Autonomous Technologies

In this part of the analysis done various projects of MASS were identified and literature was identified to narrow down on specific aspects of the technology required to design and operate an Autonomous ship. This is particularly important as to classify them into the various courses we analysed and to establish supporting courses already available at Aalto University to formulate a plan and timeline to implement this with the teaching methods we established are useful for education in master's studies.

3.2.1. Hull and Deck design:

Usually, hulls are designed for efficiency and ability to handle loads that are put on the hull as they need to. This also applies to MASS because they will operate under similar loads from weight and weather. Development in the hull designs will affect both traditional and autonomous vessels. As the technology of sensors develop and they are installed on the hull form it will diverge from the tradition design of hull form example docking systems will have to be different. [2]

Deck design will be a different issue as for commercial MASS (cargo, bulker, etc) there is no need for a superstructure and crew supporting functions of the ship. Of course, this is for level 4 of autonomy. If the autonomy level is lower, it will be. This will affect the loads on the hull as well. [2]

3.2.2. Propulsion and Power Generation:

In the present-day engine rooms are unmanned and the engine and related systems are controlled from the bridge. But as is known conventional power generation have a lot of moving parts which is why complete autonomy isn't possible with convention engines[20]. We are also heading towards more environmentally friendly sources of power due to the climate crisis and hybrid and electric propulsion systems are a good way to move of the technology[2]

Carmen Kooij et al. analysed the applicability of diesel and hydrogen fuel cell propulsion systems and concluded that with diesel engines complete autonomy isn't possible and someone will have to be onboard to maintain the system. Whereas with hydrogen fuel cells there are no moving parts and will support full autonomy, but the technology is expensive and not ready for implementation commercially[20].

3.2.3. Navigation and Collision Avoidance

The navigation of a traditional ship is mainly done through the following methods. The list just states the technology available for navigation purposes [21]:

- The use of human resource (captain/first mate). Mainly them using situation awareness, their eyesight, and their sense of judgement.
- RADAR
- Gyro Compass
- Magnetic Compass
- Auto Pilot
- Automatic Radar Plotting System (ARPA)
- Automatic tracking Aid (ATA)
- Electronic Chart Display Information System (ECIDS)
- GPS
- Global Satellite Navigation System (GNSS)

These systems are fairly on the path of autonomy especially Auto Pilot which adjusts for weather and dynamic instability.

For MASS the trends are seen to be such that, the best of these technologies is used in the decision making of the autonomous navigation system. These systems need to be developed such that the unmanned ship or shore-controlled ship will be able to do docking manoeuvres and function in busy waters [21] We are far away from this technology and will need more development.

In the present Maritime sector Avoidance of Collisions at Sea or during harbouring manoeuvres, practices or regulations better known as COLREGs as defined by the IMO are used. These regulations are used to show the rules COLREGs has. They are mainly categorised in six main branches. Each Segment has a set of defined rules[22].

- General (Rules 1 to 3)
- Steering and sailing (Rules 4-19)
- Lights and shapes (Rules 20-31)
- Sound and light signals (Rules 32-37)
- Exemptions
- Verification of compliance with the provisions of the Convention (Rules 39-41)

Further COLREGs has four Annexes [22]. They are

- I. Positioning and technical details of lights and shapes
- II. Additional signals for fishing vessels fishing in close proximity
- III. Technical details of sounds signal appliances
- IV. Distress signals, which lists the signals indicating distress and need of assistance.

Application of COLREGs is mandatory to all Seafarers and is mainly related to Human Controlled Collision Avoidance (CA).

It may be noted that in recent years a vast number of vessels have Automated Radar Plotting Aids. (ARPA). The systems or regulations (COLREGs) and the current ARPA systems are fairly in use and can be used as a base to further develop the systems required for Collision Avoidance Systems in MASS[23] .

There could be conflict between some regulations such as "Every vessel shall at all times maintain a proper look-out by sight as well as by hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and the risk of collision." [24]. These types of regulations can be updated or modified to accommodate modern Sound and Vision technologies used in the electronic world. For example, Sight can be replaced by Digital Images or Vision. In modern times, Computer generated Vision or Images or even Laser techniques have been broadly used to measure a lot of parameters such as length or distance, tracking applications among others. Such technologies, among others, will be useful to develop CA Systems for MASS [25].

3.2.4. Fuel and power sources

The current trend in the Maritime industry is the usage of heavy fuel oil and will be continued to be used in the industry especially for big cargo vessels. In 2010 roughly 80% of big cargo ships used heavy fuel oil. This number will go down to roughly 47%-66% [26] . The use of LNG has been implemented in cargo ship and it will increase to about 11% by 2030. Using hybrid LNG-diesel engines with battery powered assistance during challenging situations with require extra power. This system also promotes fuel savings of about 30% as seen on the ship 'Viking Energy' [27]. This system will be good for partial automation during use of electric power as it is easier to control than mechanical engines. Electric propulsion used for MASS operations in ferries and short sea shipping is already in place as seen in the Yara Birkeland[5].

Hydrogen fuel is a viable option for MASS as it provides fewer moving parts in terms of engines and this will help in reducing breakdowns and also provide a clean fuel to support upcoming regulations of environment. This fuel will produce electric energy to propel the ship [2].

3.2.5. Auxiliary systems

The auxiliary systems of a ship are namely:

- Cargo Handling
- Mooring
- Ballast water management
- Gray water and sewage control systems
- Lighting
- Heating and Air Conditioning
- Winching
- Fire Management

Cargo Handling in MASS is a crucial task as traditionally uses lashings which can loosen during operations. This can be avoided in MASS by using cell guides which will ensure container stability[28]. There has been advancement in mooring systems such as AutoMoor [29] which use vacuum pads for mooring and reduces dependence on traditional methods like using ropes. This system will provide full autonomy to the ship as it will not need to be managed by crew. Some of these systems may be fully autonomous and these auxiliary systems need to be linked with one another to avoid discrepancies.

3.3. Risks of Autonomous Ships and cyber security

There are risks involved with all types of ships but where MASS is considered these risks must be analysed so when MASS are put to sea accidents and incidents don't happen. Certain risks to Autonomous Shipping are:

- Collision
- Grounding
- Failure of engine and propulsion systems
- Fire on board
- Cyber Attacks
- Piracy

The collision is a real threat as currently we have manned ships in the sea and for seafaring to be fully autonomous it is going to take quite a few years. Collision avoidance was discussed in section 3.2.3. The failure of engine and propulsion is a real threat to fully automated MASS in the middle of its voyage as someone would have to visit the ship and it could cause disruption in other vessels voyages. The best way to avoid this is regular maintenance of the systems in place and introducing redundancies in energy management systems. Fire is a real threat as for fully autonomous ships it must be detect early and mitigated or the ship may be lost at sea. This could be avoided by implementing systems that will detect and extinguish fires early and can be monitored from a SCC [30].

Cyber Attacks are a real threat to MASS. A cyber-attack could take control of the navigation system and would lead to loss of control and lead the ship to a different location or to a disaster which be a big monetary loss. Cyber security is an important aspect of protecting the ship as there are numerous cyber criminals worldwide. IMO has guidelines in place which recommend cyber security measures to be considered [2].

Piracy is a threat that actually can be mitigated in a fully autonomous ship because there is no threat of loss of life as the crew is not present on the ship. Preventive measures can be taken to avoid boarding of the vessel and if the ship is boarded then preventive measures of shut down of the ship or protection of the ship's material can be done.

3.4. Evaluation of Education techniques

Master studies programs are conducted, and, in the process, they provide viable opportunity through which the learners can be able to enhance their skills by gaining information and skills that can be used for different programs hence facilitating education provision. Master's program is conducted on different avenues including both in class and out of the class session. The essence of establishing these different education avenues is aimed at increasing learner's skills and also open up an individual learner's ability to study and gain information from different avenues.

The various methods that are used by learners to study in master's programs include evening class session, out of class activities, in class sitting session, field trips and online learning programs. These different methods of teaching and offering masters student education provides an opportunity through which the individuals are able to be provided with an avenue to gain knowledge, study real issues in life in the society and also stand an chance to apply knowledge gained in various exposure sessions to be able to gain knowledge and skills vital for education enhancement and skill realization. Students expect to learn about practical applications in the real world "Since theories and practice are inextricably linked, it is strongly suggested to adopt instructional methods that encourage this connection, for example, engaging guest speakers. In addition, a "guest speaker event" can help students make the connection between theory and practice "In addition to standard teaching, guest speaker events can expose students to the latest trends and new technologies and techniques.

There are concepts which are inherently difficult to solve especially when they relate to a technical concept which can only be accessed in an educational field study. In regards to studying concepts such as automation of ships, master students can explore and gain this education through organizing for an academic professional trip to the respective companies where they are conducting ship building and testing of vessels in order to study and be able to enhance their skills by studying and getting to interact directly with technicians in the field and in the process, they will be able to gain insight knowledge on how to build or establish an autonomous ship.

3.4.1. Importance of excursions in master's Education.

A lot of skills such as reflective thinking, knowledge of practical methods, application of the knowledge they have are developed in excursions as they see real world. Excursions are a type of learning where students interact with real world professionals who are working in the field, they are studying in. This interaction motivates students to engage in the studies even more as they see what they can achieve and what career paths they can possibly take, and the steps required to achieve the goals set. They also learn important skills like ethics, and practises in their field of study. This also helps them develop self-confidence. They also form links between the things they experience and the courses they study as they see real world applications[31].

3.4.2. Importance of Guest Lecture.

Guest lectures are beneficial because it helps student to see what is happening in the real world and away from their university. This facilitates formal and sometimes casual interactions in the world. These interactions create an opportunity for students to realise who these experts are and what is going on in the world. This can create an opportunity for students to find the connection between classroom and course learning and connect it with real world situations. These guest lectures can also be role models to students and will help them develop mentors in specific fields and they can learn from them. This can also help them think about projects they can do, their thesis or help them develop entrepreneurial endeavours. [32]

3.4.3. Importance of assignments in master's program.

There are several positive aspects associated with using a homework assignment as a form of assessment. Assignments provide another opportunity for students to demonstrate their ability to apply acquired information and abilities. It has the potential to act as a template for professional behaviour in the years to come. It is a device for determining how well a person's skills, attitudes, and knowledge are collaborating with one another (competences). When doing an analysis of the complete results, there are several procedures to follow. Amongst other topics, evaluation of the assignment consistently and fairly; check whether the student has done any malpractice; how the gradation of the assignment is done; and so on [33].

The assignment programs therefore provide an opportunity through which a learner can be able to compose their message by researching, understanding the concept and the come up with an assignment that contain all the necessary information which can provide an opportunity through which the information can enable the learner to understand the content that they are being asked to discuss about [33].

4. Discussion

In this section we will discuss if the inclusion of MASS is viable, and the implementation of the information and techniques are seen and what courses can include which technologies are evaluated.

4.1. Is the inclusion of MASS viable in the education of maritime engineering?

We have seen in that there is a lot of progress in the field of MASS and autonomous shipping and research has been developed such that education of students on this topic can start slowly at first and then can pick up speed. First a few supporting techniques can be implemented and then slowly these techniques can be included in the courses specific to the technologies and methods developed to educate students. There can also be a possibility where a course could be developed where MASS could be the sole focus.

4.2. Implementation of techniques in the education of Maritime education.

It has been realised that the techniques used namely excursions, guest lectures, and assignments are important. There are a few ways to implement these techniques. Firstly, professors could invite industry professionals and experts who are working on projects like Yara Birkeland, AAWA, MUNIN and others and professors to educate the students on the current developments in the field of MASS. This will help students understand and gain interest in the field and they can research more on these technologies.

Field excursions can be introduced which can be on ships like the Birkeland, and to companies developing such technologies because they will be helpful in networking and students interacting with these professionals, they can possibly do future research work on these projects. This will also give them hands on experience on the technology seen in the real world.

Assignments related to MASS and projects can be developed in courses like Principles of Naval Architecture and Ship design portfolio with the support of assignments in other courses can be assigned. This will challenge students to think out of the box and implement all the technologies that are available in concept ships.

4.3. Courses that can support the studies of MASS at Aalto.

The courses that are supporting the studies of MASS as these incorporate Automation technologies. These can be helpful to have as electives.

4.3.1 Autonomous Mobile Robots (School of Electrical Engineering):

This course expects the students to understand main concepts of Autonomous robots and vehicles, the kinematics of mobile robots and intelligent vehicles. The course teaches machine perception and sensors for mobile robots while studying the uncertainty and sensors used for outdoor use and positioning. The mapping and localization and mapping and different approaches of SLAM are also covered. Path and trajectory planning, navigation, reactive control obstacle avoidance and safety are also covered. The motion control of a vehicle, intelligent autonomous and heavy-duty work, machines and vehicles, fleet control and autonomous cars. These concepts can be useful in development and study of MASS as the concepts of fleet control, navigation, safety, sensors, positioning are all concepts that can be used for application on Marine Vessels.

4.3.2 Control and Automation (School of Electrical Engineering):

This course expects students to understand the principles and analysis of dynamic systems which are related to automation systems, the use of Programmable Logic Controllers and their design is covered. The course covers the representation of dynamical systems (transfer functions, state-space representation), simple modelling and parameter estimation, the control problem, negative feedback, stability, PID controller, state controllers, frequency domain techniques, compensators, introduction to digital controllers. The basic structures of automation systems, sensors and automation networks are covered. This can help students in understanding the systems that control the automation of any system and how they work so that students can use the technology to develop in the projects.

These courses can be offered as electives to support the studies of Naval Architecture. A minor in MASS can be developed where these courses are included.

4.4. Technologies that comply with the courses that already exist.

Hull technologies can be included in the courses of Hydrodynamics, Ship Dynamics, Principles of Naval Architecture, Ship Design Portfolio and Winter Navigation as the prediction of the hull technology is that the hull design for will diverge from traditional design due to technological advancements. This will warrant inclusion in the above courses as the hull form might be different and will warrant different resistance and propulsion needs. Deck technologies should also be included in Ship Stability and Construction along with Ship Dynamics because a completely autonomous ship has no requirement for a deck house as there is no crew onboard. This will affect the weight and loads on the ship and will warrant in different methods of design.

Propulsion and power generation technologies should be included in the courses of Principles of Naval Architecture and Ship Design Portfolio as this affects the general arrangement of the ship. Propulsion technologies can also be included in Ship Hydrodynamics to decide the power requirement and which technology to be used to attain this power requirement. Marine and Ship Systems engineering can also be included these technologies in the propulsion and plant management and the discussion of what type of power generation unit can be used for what ships.

Navigation and Collision Avoidance technologies can be introduced in courses Principles of Naval Architecture, Marine and Ship Systems Engineering and Ship Dynamics as this technology covers the Navigation equipment and how the ship adjusts for dynamic stability in different conditions of weather. The seakeeping of the vessel is also included in the technologies. The navigational technologies themselves are already included in the Ship Systems Engineering course so further applications on MASS can be discussed.

Fuel and power sources and usage of new types of fuel is covered here which is already covered in Marine and Ship Systems Engineering course. The applications of these fuels in MASS can be discussed during the lecture of this course.

Auxiliary systems are included in the Marine and Ship Systems Engineering course. The applications of these technologies with MASS can be discussed as in the firefighting, mooring, cargo handling and such other technologies. The ballast system can be discussed during Ship Dynamics.

The Risks of Autonomous Ships and Cyber Security can be discussed in the Marine Risks and Safety course. The risks of traditional ships are already discussed, and risk assessment is done, these concepts can also be applied to MASS operations. Risk analysis of MASS can also be as an assignment to see if students understand the concepts.

4.5. Possible timeline of inclusion of MASS in the education.

The development of Autonomous ships has gained tremendous speed in the last few years. This warrants the inclusion of MASS in the education of Naval Architecture. It can be introduced slowly at first and the interest of students can be evaluated to see how much traction it is gaining and what percentage of the students are interested in educating themselves in MASS.

In the first year of introduction of MASS, professors can invite respective guest lecturers in the area of expertise that is related to the course. In Principles of Naval Architecture experts from projects like AAWA and Yara Birkeland can be asked to lecture and show how the design process was done. Feedback of the lectures from students can be taken and then it can be evaluated how much interest it has generated. This will help in evaluating what students liked about the lectures and what they would like to get out of this. A questionnaire can also be generated to see if they would like to learn more about MASS and related technologies.

In the second year of courses teachers and school could arrange excursions to view autonomous vessels and Shore Control Centres. This will engage students as discussed in subsubsection 3.4.1. It will make them interested in these technologies and motivate them to research the technologies and develop concept projects in Maritime Engineering major using technology for MASS. Excursions could also be conducted to visit design firms that are working on new technology in the field of Autonomous Shipping.

Finally in the third year of studies MASS, its applications and technologies can be introduced, and further advancements will have been made in this field which could be included in the course material. Assignments can be given in such courses related to applications of MASS and this can be used to gauge how the students are understanding and grasping the concepts of MASS. This evaluation can be done by individual teachers and then the department of maritime engineering can introduce one or multiple courses.

This introduction of course can be done in the fourth year with a possibility of offering it as a minor with the supporting courses in the school of electric engineering which was mentioned in subsection 4.3. This course can be designed by analysing the courses from other universities seen in subsection 3.2.

5. Conclusion

This thesis analyses some of the literature about Maritime Autonomous Surface Ships (MASS) and its related technologies to see if MASS is a viable option to be included in the education of Naval Architects at Aalto University. The concept of MASS is discussed, and technologies related to MASS are analysed. Courses provided in the Marine Technology major at Aalto university are analysed to see if their syllabus included MASS. Some teaching methods were also studied and with all this information a plan was formed for the implementation of MASS in Marine Technology education at Aalto University.

MASS was seen as a viable option to be included in the education of Naval Architects and the plan formulated can be discussed and further implemented. Due to the rapid development in MASS and related technology in the world of Maritime Transport it is vital that this be introduced to students in a classroom setting and in the real world. This will promote further developments in the research and development of new technologies which will improve operations and viability of MASS in the open sea.

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