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Research on safety management of Maritime Autonomous Surface Ships

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RESEARCH ON SAFETY MANAGEMENT OF MARITIME AUTONOMOUS SURFACE SHIPS

By

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Declaration

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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(Date):

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Professor of Dalian Maritime University

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ABSTRACT

Title of Dissertation: **Research on Safety Management of Maritime Autonomous Surface Ships**

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Abstract

Representing potential to be a safer, greener and more energy efficient ship, the development of Maritime autonomous surface ship (MASS) has become the consensus of the shipping industry. The MASS is expected to come in the near decades. Although a large quantity of researches have been conducted to verify the economic, technology and legal feasibility of MASS, the safety management of MASS has been frequently questioned because of the accompanying uncertain and risks. This dissertation tries to uncover the potential safety management challenges and risks of MASS, and puts forward corresponding recommended measures and strategies for safety management improvement.

In the beginning of this dissertation, the author tries to illustrate a whole picture of the MASS, including what is a MASS and the how it will significantly revolutionise the landscape of shipping industry, as well as the various development process of MASS in China and abroad. MASS is aiming contribute to a more sustainable maritime transport industry. Through a comprehensive analysis, it can be seen that the MASS represent an opportunity to reshape the maritime industry bringing benefits such as increased operational efficiency, human error reduction, emission reduction, increased safety, and operational cost reduction. However, from the perspective of safety management, the MASS bring a large number of challenges and risks on safety regulatory frameworks, maritime legal frameworks, maritime liability frameworks, reliability of safety critical equipment, cyber security, crew job losses and skill degradation, etc. Overall, the author concluded that the development of MASS is feasible, but series of further improvement actions should be taken out.

KEY WORDS: Autonomous ship; unmanned ship; remote control; safety management

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAWA	Smart Ship Application Project
AIS	Automatic Identification System
ASV	Autonomous Surface Vehicles
CCS	China Classification Society
COLREGS	International Regulation for the preventing Collision at Sea
DNV	DET NORSKE VERITAS
DTU	Technical University of Denmark
EDICS	Electronic Chart Display and Information System
EU	European Union
GPS	Global Positioning System
ILO	International Labor Organization
IMO	International Maritime Organization
ISO/TC	International Organization for Standardization's Technical Committees
ISM	International Management Code for the Safe Operation of Ships and for Pollution Prevention
LOA	level of autonomy
LR	Lloyd's Register
MSC	Maritime Safety Committee

	Seafarers
MASS	Maritime Autonomous Surface Ships
MARPOL	International Convention for the Prevention of Pollution From. Ships, 1973 as modified by the Protocol of 1978
MLC	Maritime Labor Convention
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks project
MSA	Maritime Safety Administration
NK	NIPPON KAIJI KYOKAI
RR	Rolls-Royce
SCC	Shore Control Centre
STCW	Standards of Training, Certification and Watch-keeping for
SOLAS	International Convention for the Safety of Life At Sea
SSAP	Smart Ship Application Platform Development Project
USV	Unmanned Surface Vehicles
UUV	Unmanned Underwater Vehicles
UNCLOS	United Nations Convention on the Law of the Sea
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 Background

Shipping is the lifeblood of international trade. It is often the least costly way to transport large volumes of goods between countries. About 90 percent of world trade, 95 percent of the total crude oil and 99 percent of the total iron ore are transported by sea (Yan, 2016). With the advantages of large transport capacity and low cost, shipment plays an irreplaceable role in the transportation, and it may be considered to be one of the main driving forces of today's global economy. However, with the rising fuel costs, crew costs, operation costs, increasing maritime accidents related to human errors and the more and more rigid environment policies, the green, efficient and safe ships are urgent needed. Maritime autonomous surface ships (MASS) could be the answer (Liu & Zhang, 2016).

MASS is a new concept that will change the conventional methods for ship designing, testing and approving their systems. In recent years, the development of MASS has become the consensus of the shipping industry, and Autonomous shipping is the future of the maritime industry. MASS represent an opportunity to reshape the maritime industry bringing benefits such as increased operational efficiency, human error reduction, emission reduction, increased safety, and operational cost reduction.

With the development of science and technology, various levels of autonomy for transportation industry are really starting to gain ground. For example, on the roads, autonomous cars have started to operate in recent years. On the railways, unmanned trains can be monitored and remote controlled from a control centre. The development of MASS has become technically feasible. However, the existing regulations, engineering and culture all present challenges as significant as the development of technology itself.

1.2 Objective of the study

The objective of this research is to demonstrate the potential of MASS to reshape the ship design, building and operation with its benefits in economic sustainability, environmental sustainability and social sustainability. A comprehensive analysis of MASS is carried out to uncover the potential safety management challenges and risks in the way towards fully autonomous navigation though MASS is theoretical feasible. Recognizing those challenges and risks, numbers of safety management recommendations, including adjustment in regulatory frameworks and legal framework, basic ship design concepts and critical technologies, are put forward to make full prepare for the coming maritime revolution. Overall, this research introduces the about coming autonomous ships era with its potential benefits and widely public concerns, then puts forward possible preparedness.

1.3 Methodology

The methods applied in this research are mainly literature review, quantitative analysis, field research, telephone and face to face interviews. Firstly, the relevant literature was widely reviewed, including appropriate International Maritime Organization (IMO) documents, international conventions, related program research achievements, articles from contemporary journals, books and information from websites. Secondly, a secondary resources and statistical figures were used to carry out a qualitative analysis on the feasibility of MASS. Furthermore, considering there is no practical experience available on merchant MASS and their safety in everyday use, an extensive field research, telephone and face to face interviews was conducted by visiting various shipping entities to figure out the potential safety management challenges and risks. Lastly, the possible safety management improvement advice was presented by shipping experts and senior Maritime Safety Administration (MSA) officers through opinions exchange.

1.4 Structure of dissertation

This dissertation divides into eight chapters. Chapter one gives a brief introduction, including general background information, objective and methodology of this study. Chapter two illustrates what is MASS, and gives relevant definitions and classifications of the MASS. Chapter three demonstrates widely development progress of the MASS, and a development comparison between home and abroad. Chapter four comprehensively analyzes the feasibility of MASS, and the accompanying potential benefits. Chapter five structures a general autonomous ship system context in terms of technology, manning, operation and navigation. Chapter six reveals the potential maritime safety management challenges and risks of MASS which are public concerned. Chapter seven puts forward corresponding recommended measures and strategies for safety management improvement. Finally, a last chapter discourses conclusions.

Chapter 2 What is a maritime autonomous surface ship

2.1 Definitions

In recent years, governments and research institutes have carried out a large number of researches on MASS and have given many definitions for MASS. However, the merchant MASS is still in the research and testing phase, and there is no a unified definition of MASS so far. According to different levels of autonomous, there are many alternative names for autonomous ships, such as unmanned ships, crewless ships, smart ships, and Maritime Autonomous Surface Ship (MASS) was widely used as a general term for autonomous ships (Rødseth & Nordahl, 2017). Among the numerous MASS studies, the European Union (EU), DET NORSKE VERITAS (DNV), Lloyd's Register (LR), and China Classification Society (CCS) give representative definition of the MASS.

The DNV defines a MASS as:

> *A vessel that has some level of automation and self-governance (Rødseth & Nordahl, 2017).*

The EU Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project defines a MASS as:

> *A vessel with next generation modular control systems and communications technology that will enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control (Fraunhofer, 2015).*

The CCS defines a MASS as:

> *A vessel which use of sensors, communications, Internet of things, Internet and other technical means to automatically perceive and obtain information and*

data of ships themselves, marine environment, logistics, port and other aspects, and based on computer technology, automatic control technology and large data processing and analysis technology (CCS, 2015).

Based on the above definitions, A MASS refers to a ship with sensors, automated navigation, propulsion and auxiliary systems, with the necessary decision logic to follow mission plans, sense the environment, adjust mission execution according to the environment, and potentially operate without human intervention.

2.2 Levels of Operational Autonomy

2.2.1 Sheridan Levels of Autonomy for Machine

There are many definitions of autonomy for machine. The level of autonomy (LOA) is often used to describe the degree to which a machine can act independently, and the most famous definitions of LOA are developed by Thomas Sheridan. The Sheridan scale describes a 10-level of autonomy from human control a machine completely without computer assistance through the machine does everything autonomously without human interference (RR,2016).

Table1.Sheridan levels of autonomy

Level	Description
10	The computer does everything autonomously, ignores human
9	The computer informes human only if it (the computer) decides so
8	The computer informes human only if asked
7	The computer executes automatically, when neccssary informing human
6	The computer allows human a restricted time to veto before automatic execution
5	The computer executes the suggested action if human approves
4	Computer suggests single alternative
3	Computer narrows aleternatives down to a few
2	The computer offers a complete set of decision alternatives
1	The computer offers no assistance, human in charge of all decisions and actions

Source: AAWA White Paper

2.2.2 Lloyds Register Levels of Autonomy for MASS

It is expected that the MASS will be operated widely in the near decades. Before fully autonomous navigation, there will be a picture that different levels of autonomous ships will navigate with conventional manned ships side by side. Therefore, the technology transition would be gradually and the operational autonomy should be "adjustable" or "dynamic". The Lloyds Register defines an AL0-AL6 level of autonomy concern navigation-related aspect for MASS, with detailed autonomy level descriptions and operator roles listed in table 2 (Lloyds Register, 2016).

Table 2. Lloyds Register Autonomy levels (AL) of MASS

AL	Description	Operator role
AL 0:	Manual steering. Steering controls or set points for course, etc. are operated manually.	The operator is on board or performs remote control via radio link.
AL 1:	Decision-support on board. Automatic steering of course and speed in accordance with the references and route plan given. The course and speed are measured by sensors on board.	The operator inserts the route in the form of "way points" and the desired speed. The operator monitors and changes the course and speed, if necessary.
AL 2:	On-board or shore-based decision support. Steering of route through a	Monitoring operation and surroundings. Changing course

	sequence of desired positions. The route is calculated so as to observe a wanted plan. An external system is capable of uploading a new route plan.	and speed if a situation necessitates this. Proposals for interventions can be given by algorithms.
AL 3:	Execution with human being who monitors and approves. Navigation decisions are proposed by the system based on sensor information from the vessel and its surroundings.	Monitoring the system's function and approving actions before they are executed.
AL 4:	Execution with human being who monitors and can intervene. Decisions on navigation and operational actions are calculated by the system which executes what has been calculated according to the operator's approval.	An operator monitors the system's functioning and intervenes if considered necessary. Monitoring can be shore-based.
AL 5:	Monitored autonomy. Overall decisions on navigation and operation are calculated by the system. The consequences and risks are countered insofar as possible. Sensors detect relevant elements in the surroundings and the system interprets the situation. The system calculates its own actions and performs these. The operator is contacted in case of uncertainty about the interpretation of the situation.	The system executes the actions calculated by itself. The operator is contacted unless the system is very certain of its interpretation of the surroundings and of its own condition and of the thus calculated actions. Overall goals have been determined by an operator. Monitoring may be shore-based.
AL 6:	Full autonomy. Overall decisions on navigation and operation are calculated by the system. Consequences and risks are calculated. The system acts based on its analyses and calculations of its own capability and the surroundings' reaction. Knowledge about the surroundings and previous and typical events are included at a "machine intelligent" level.	The system makes its own decisions and decides on its own actions. Calculations of own capability and prediction of surrounding traffic's expected reaction. The operator is involved in decisions if the system is uncertain. Overall goals may have been established by the system. Shore-based monitoring.

Source: (Lloyds Register, 2016)

2.2.3 Operational Levels of Autonomy for MASS

The autonomy levels of Thomas Sheridan and Lloyds Register have widely covered a range of operational condition and roles. However, before fully autonomy, we have to considerate an important factor-the manning levels. Therefore, based on the autonomy levels proposed in the other texts referenced above, the author proposes the operational levels (OL) of autonomy concerning manning levels.

Table 3. Operational Levels of MASS

	OL	Description
1	Decision support	This corresponds to today's and tomorrow's advanced ship types with relatively advanced anti-collision radars (ARPA), electronic chart systems and common automation systems like autopilot or track pilots. The crew is still in direct command of ship operations and continuously supervises all operations. This level normally corresponds to "no autonomy".
2	Automatic	The ship has more advanced automation systems that can complete certain demanding operations without human interaction, e.g. dynamic positioning or automatic berthing. The operation follows a pre-programmed sequence and will request human intervention if any unexpected events occur or when the operation completes. The shore control centre (SCC) or the bridge crew is always available to intervene and initiate remote or direct control when needed.
3	Constrained autonomous	The ship can operate fully automatic in most situations and has a predefined selection of options for solving commonly encountered problems, e.g. collision avoidance. It has defined limits to the options it can use to solve problems, e.g. maximum deviation from planned track or arrival time. It will call on human operators to intervene if the problems cannot be solved within these constraints. The SCC or bridge personnel continuously supervises the operations and will take immediate control when requested to by the system.
4	Fully autonomous	The ship handles all situations by itself. This implies that one will not have an SCC or any bridge personnel at all. This may be a realistic alternative for operations over short distances and in very controlled environments.

Source: Complied by the author

2.3 Manning Levels of MASS

With the development of autonomous technologies, more and more human labor will be replaced by machines. Over past decades, we have achieved periodically unmanned engine room, and it is only a matter of time to achieve unmanned bridge. According to different levels of autonomy, the manning levels of MASS can be classified into four levels.

Table 4.Manning Levels of MASS

	Manning level	Description
1	Continuously manned bridge	The ship bridge is always manned and the crew can immediately intervene in ongoing functions.
2	Periodically Unmanned Bridge	The ship can operate without crew on the bridge for limited periods, e.g. in open sea and good weather. Crew is on board ship and can be called to the bridge in case of problems.
3	Periodically Unmanned Ship	The ship operates without bridge crew on board for extended periods, e.g. during open sea passage. A on-board control team to control the ship, e.g. berthing operation and the port arriving/depart phase.
4	Continuously Unmanned Ship	The ship is designed for unmanned operation of the bridge at all times, except perhaps during special emergencies. This implies that there are no one on the ship that are authorized to take control of the bridge. There may still be persons on the ship, e.g. passenger or maintenance crew.

Source: Complied by the author

2.4 Classification of Autonomous Ship

A classification of different autonomous maritime vehicles is shown in Figure 1. Autonomous maritime vehicles can be divides into Unmanned Underwater Vehicles (UUV) and Autonomous Surface Vehicles (ASV). The UUV which is operated remotely or autonomous have been widely used for purposes of underwater scientific research or military use, while the ASV is in concept and research stage. Some of the small Unmanned Surface Vehicles (USV) has been developed and put in service (Campbell & Naeem, 2012).

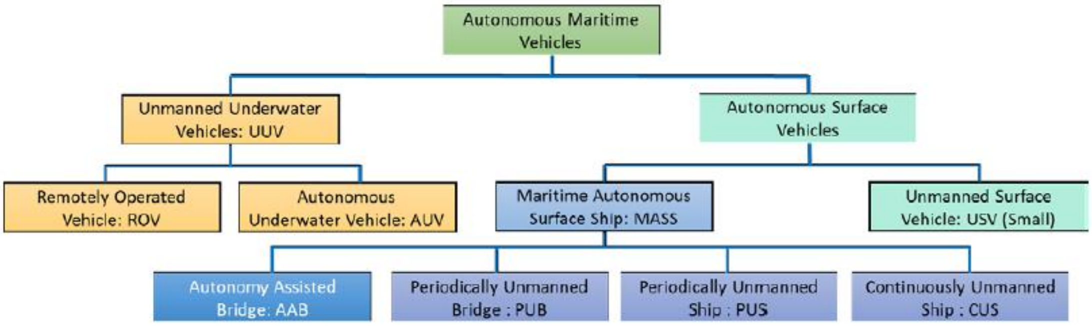
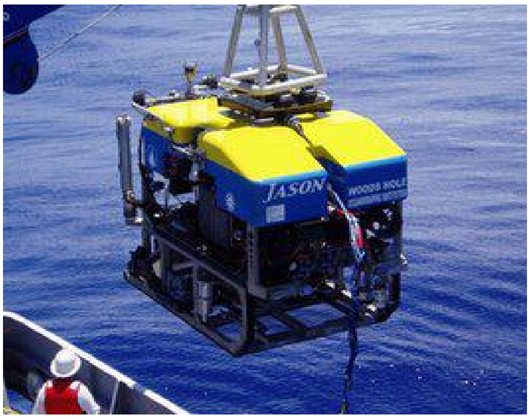


Figure 1. Classification of autonomous maritime vehicles

Source: Complied by the author



Remotely Operate Vehicle

Autonomous Underwater Vehicle

Unmanned Surface Vehicles

Maritime Autonomous Surface Ship

Figure 2. Images of Autonomous ships

Source: Goolge pictures

Chapter 3 MASS is all about to happen in the near future

3.1 The Initial Concept of MASS: e-Navigation

Advanced modern technologies have promoted navigation safety effectively. With the applications of radar, Automatic Identification System (AIS), Global Positioning System (GPS), and Electronic Chart Display and Information System (EDICS), the navigation operations have undergone tremendous changes. These advanced navigational equipment can help the sailor to better understand the surrounding and the ship's condition. Furthermore, the new generation of shore-based navigation aid facilities, such as Vessel Traffic Service (VTS), have facilitated the navigation greatly.

However, we cannot ignore the negative impacts of modern navigational technologies. The independence of existing navigation equipment has increased workload for duty crews. In addition, the increasing complexity and inconsistency of equipment have affected user efficiency, such as increasing the information change workload between ships, companies and maritime authorities (Burmeister & Bruhn, 2014). Furthermore, the increasing complexity of ships will require more diversified capabilities for crew, and degrade seldom used navigation skills.

Therefore, in 2005, the IMO proposed the e-Navigation concept and aims to improve the safety of navigation through modern technologies. In 2008, the IMO Sub-committee on Navigation Safety adopted a strategy proposal and proposed an execution plan that includes concepts such as user needs, system structure, gap analysis, cost-benefit analysis, and risk analysis. In 2012, this plan had been implemented.

E-navigation is the initial concept of MASS. The scope of the e-Navigation project is defined as:

> *"the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment" (IMO MSC, 2009).*

3.2 IMO Process of MASS

Recognizing MASS represents the potential to reshape ship's design, building and operation, the IMO's Maritime Safety Committee (MSC) had started considering regulatory scoping exercise for the use of MASS. In 2017, the MSC considered a proposal on how IMO instruments might be revised to address the complex issue to ensure safe, secure and environmentally sound operation of MASS, including interactions with ports, pilotage, responses to incidents and marine pollution. It was considered essential to maintain the reliability, robustness, resiliency and redundancy of underlying communications, software and engineering systems. As a starting point, the Committee agreed to start a regulatory scoping exercise over the four sessions of the Committee, until 2020, which would take into account the different levels of automation, including semi-autonomous and unmanned ships (ABS, 2017).

3.3 Great Market Potential and Widely Researches on MASS

3.3.1 Japan MASS Research and Development

In Japan, MASS research and development become the focus of attention for the shipping industry in the next five years. In 2012, 29 companies including the Japan

Shipbuilding Association and the NIPPON KAIJI KYOKAI (NK) jointly launched the Smart Ship Application Platform Development Project (SSAP), which is mainly to solve the problem of smart navigation. So far, the SSAP has developed a variety of smart ship systems, through which the most suitable route and speed can be selected to achieve collision avoidance and navigation efficiency (Fan & Xu, 2015). What is more, these systems have completed real ship testing on two ships.

In 2015, DNV and Nippon Yusen jointly created the “Digital Twins” project which is maritime smart data center. In the same year, two international standards for "Shipborne Sea Condition Data Server" and "Standard Data for Shipborne Machinery and Equipment" initiated by Japan were approved by the International Organization for Standardization’s Technical Committees (ISO/TC).

In 2017, a technology concept of ocean-going autonomous system jointly developed by the Mitsui River, Port and Aerospace Technology Association of Japan, etc. had been promoted in Japan. In addition, Japan’s shipyards and shipping companies are planning to jointly develop a large unmanned fleet in 2025 (Wu, 2017).

According to the statistics of the China Ship Information Center, from 2013 to 2015, Japan has led and published about 15 international standards in ISO/TC, of which 9 standards relate to ship navigation and letter transmission. There are a total of 10 standards under research that are led by Japan, among which five standards involving ship navigation, heading control, and navigation recorders. It can be clearly seen that the development focus of the international standardization strategy in Japan over the past two years and the next five years has been centered on the field of "smart ships."

3.3.2 Korea MASS Research and Development

MASS is an important strategy of Korea maritime industry. In Korea, the research of MASS is mainly implemented by the Hyundai Heavy Industries, the Daewoo Shipbuilding Marine, and the Samsung Heavy Industries. Among them, the Hyundai Heavy Industries has made great progress in the area of smart ship research and development. The Hyundai Heavy Industries focus on practical applications of MASS and have made substantial headway. In 2009, the Hyundai Heavy Industries began working with the Korea Electronic Testing & Research Institute (ETRI) to apply information technology to ships to jointly develop "Smart Ships 1.0". In 2011, Korea had built the world's first "smart ship". Since then, the Hyundai Heavy Industries has received a large number of building orders for smart ships. Hyundai Heavy Industries had received more than 70 orders for smart vessels in 2011, of which more than 40 orders for smart boats came from the Danish Muller-Maersk Group. Then, the Hyundai Heavy Industries cooperated with the Korea's Ministry of Energy, and many IT technology companies to establish an IT innovation center for the shipbuilding industry and jointly developed an upgraded version of "Smart Ship 2.0". In 2013, the Hyundai Heavy Industries released the research results and promoted the plan of "Smart Ship 2.0".

In 2015, the Hyundai Heavy Industries collaborated with the Accenture to develop smart ships and launched the Ocean Link smart ship systems. In 2016, the Korean government released the "Strengthening Scheme for Shipbuilding Industry Competitiveness", which proposed to invest 35 billion won to support the development of core technologies related to smart ships, and subsequently announced to invest other 7 trillion won to support new industries such as smart ships. In the same year, Korea's Marine Fisheries Department launched the "Smart Navigation" project with a total investment of US$114 million.

3.3.3 European Union MASS Research and Development

European Union is the leader of MASS research and development. So far, the European Union has carried out a large number of forward-looking MASS studies with a high level of research and development. The development of MASS in Europe was first begun in 2006 with the development of the Inland River Navigation Integrated Information System. This system was the first to integrate information technology, communications technology, electronic control technology, and computer processing technologies into the traditional inland river system. It provides eight major information service functions such as traffic management, logistics information and emergency rescue for inland shipping, achieving efficient, safe, and environmentally friendly inland shipping, and has aroused the attention of shipping industry to smart ships(Liu & Shan, 2017). Since then, Finland and the European Union have successively launched the COAST WATCH national water traffic management platform and the MONALISA project to explore the development of smart ships.

In 2012, the EU launched the MUNIN project. The MUNIN program verifies the feasibility of merchant MASS, and demonstrates the relevant frontier technologies and standards (Fraunhofer, 2015). In addition, a further analysis on laws and regulations revision is carried out in the MUNIN. The EU plans to complete research on the development of unmanned ships and the possibility of autonomous navigation by 2034.

In 2014, the Rolls-Royce launched a Smart Ship Application Project (AAWA). This project aims to realize autonomous navigation in the coming decades. It is expected to achieve remote support and operation of ships by 2020, then realize remote control of ships in the near sea area by 2025. By 2030, remote control of ships in the far sea area will be realized, and fully autonomous navigation will be realized by 2035. In addition, Finland is also launching a smart ship program that aims to create a “smart ship transportation eco-environment”, then create a completely intelligent shipping system in the Baltic Sea by 2025.

The Danish Maritime Bureau is also preparing for the about building of MASS. The Danish Maritime Bureau has cooperated with the Technical University of Denmark to launch an unmanned ship research, aiming to increase the knowledge base of the technology and establish a preliminary framework for the plan, thus ensuring the successful construction of unmanned ships.

3.3.4 China MASS Research and Development

In recent years, China regards MASS as a national manufacturing strategy. China tries to draft and amend relevant regulations related to MASS with fully consideration of China's shipping industry development level, and promote the orderly and healthy development of MASS. In 2013, China Ship Systems Research Institute and America National Science Foundation Center jointly established the "Smart Marine Equipment Information Intelligent Management and Application Technology Innovation Center" to promote the development of related core technologies and products. In 2015 and 2016, the Ministry of Industry and Information Technology of China organized the “Intelligent Ship Top Planning” and “Smart Ship 1.0” scientific research projects respectively.

In 2015, China issued the “Made in China 2025” and made key explanations for smart ship. In the same year, China Classification Society (CCS) released the “Smart Ship Code”. This code is the world's first smart ship code and sets specific requirements for functions that smart ships should possess. In 2017, the Joint Key Laboratory of Unmanned Ship Technologies and Systems was established in China to study not only the design and construction technologies of unmanned ships, but also the study of relevant regulations and standards.

3.4 Levels of Development Comparison between Home and Abroad

The levels of development vary from country to country. The technological levels of MASS development can be measured by many comparing factors, such as levels of autonomy, autonomous navigation systems, critical equipment, and remote control. The earliest research on MASS was conducted by Europe, and Europe is a leader in the development of smart ship safety, feasibility and related regulations. Japan is a pioneer who has developed series of technical standards for MASS. With abundant shipbuilding experience, Korea's MASS are being industrialized, and the main application is the development of a large number of autonomous systems and communications networks. In contrast, China's development level of MASS is at an early stage in terms of technology research (Bo & Zhang, 2017). However, at present, domestic research and exploration in the field of MASS are actively being carried out.

Chapter 4 Comprehensive analysis of MASS

MASS has the potential to contribute to a sustainable maritime industry. Although it seems hard to realize fully autonomous operation in the short term, MASS is feasible in terms of economic, safety, security, legal and technology. MASS has the potential to reshape the maritime industry by bringing benefits such as human error reduction, increased operational efficiency, fuel reduction, emission reduction, and operational costs reduction (Rødseth & Burmeister, 2015). In addition, The MASS can also mitigate the crisis of shortage in the supply of seafarer.

4.1Feasibility Study of the MASS

4.1.1Cost-benefit Analysis

Ship-owners always give priority to profit. A cost-benefit analysis which was carried out by the MUNIN project showed that autonomous bulk carrier is profitable for the shipping companies. While comparing with a reference conventional bulker, the autonomous bulk carrier is commercially feasible under certain circumstances. According to the MUNIN project, the autonomous bulker can improve more seven Million US Dollar (mUSD) expected present value than a conventional bulker over a 25-year lifetime (RR, 2016). Firstly, crewless MASS can save a lot of crew costs, which represent about half of the operation costs. Secondly, there will be a higher efficiency of land-based services in port and the Shore Control Centre (SCC). Lastly, perfect autonomous ship design ensures better fuel efficiency, larger cargo carrying capacity and lighter ship weight (Wróbel & Montewka, 2017). Although MASS will cost higher building costs, overall, MASS represent an opportunity to make more profit than conventional ships.

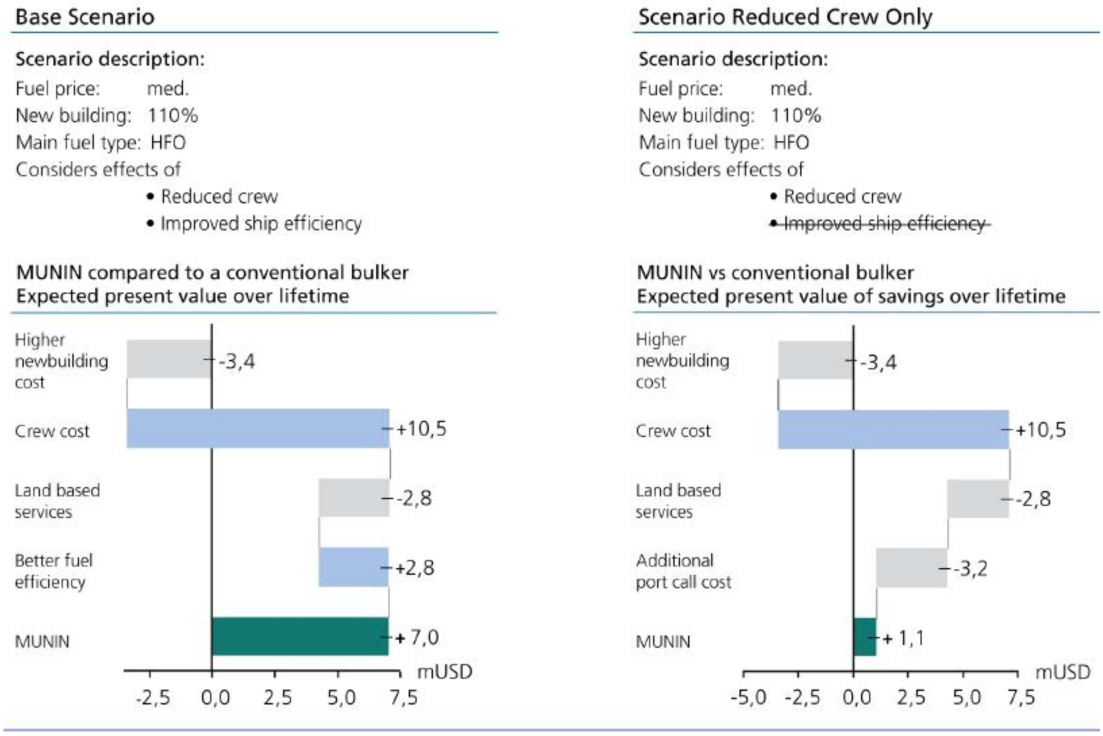


Figure 3.the MUNIN financial analysis of an autonomous bulker

Source: (RR, 2016)

4.1.2 Safety and Security Analysis

In addition to profitability, safety and security are also important factors affecting the implementation of MASS. Between 2005 and 2014, collision and foundering are the two highest probability incident categories, and they represented almost half of total loss accidents. Furthermore, most maritime accident root causes are human errors. Based on an analysis of collision and foundering accident models, after a proper operational and robustness testing, the accident rates of collision and foundering of a MUNIN concept MASS are ten times less than conventional manned shipping. Further analysis showed that the reduction of accident rate is mainly due to the elimination of fatigue issues. In addition, risks of engine and other system failures for MASS are expected to be lower because of redundancy ship design. In terms of fire and explosion accidents, MASS are likely to be much less risky than manned ships due to more efficient extinguishing systems in fully enclosed spaces. Finally, cyber security and piracy are widespread concern issues. However, the MASS can be designed and built to provide very high resilience against digital and physical attacks.

4.1.3 Legal and Liability Analysis

The design, building, and operation of MASS would present significant challenges to the entire international maritime legal framework and liability framework. However, generally speaking, the MASS does not seem to present any unsurmountable obstacle in terms of laws and liability. Many shipping experts have reservations about MASS, and they think MASS is incompatible with the existing international regulations. For example, Peter Hinchcliffe, secretary-general of the International Chamber of Shipping, publicly stated that he was not optimistic about MASS. However, we should bear in mind that maritime revolutions are never easy. When the containerization was introduced in the shipping industry, it needed a change in thinking and the industry became more capital intensive which provoked social resistance and more contractual negotiations (Tom, 2015). Any novel innovation process in an industry such as shipping may follow a similar trend.

Rules and standards reflect the social opinion. Judging from the historical trajectory, laws follow the development of science and technology, instead of constraining the development of society. If the MASS can operate at least as safe as conventional manned ships, and they can offer benefits as well, the rules shall change gradually. The legal framework and liability framework should not impede the development of MASS in maritime transport, but a number of aspects related to the legal responsibility of using autonomous vessels need to be clarified.

4.1.4 Technical Analysis

Today, technically speaking, full vehicular autonomy is indeed feasible. Driven by the global need for increased traffic safety, emission reduction, and the large mass-market potential, the development of autonomous vehicles, including autonomous land vehicles, aviation and also marine vessels, have been through great progress over the past decade. The general technologies needed to make MASS a reality laying in them. The most convincing progress has been demonstrated by the autonomous land vehicles. Thanks to continuous advancing autonomous technologies, vehicles can perceive the surrounding environment then plan the path independently, or be remotely controlled by operators. In fact, many autonomous land vehicles, aviation and also marine vessels have put into military applications, such as small patrol and attack boats. The Rolls-Royce recently successfully demonstrated their achievement of MASS- a small Shore Control Center: operators monitor and control a global fleet in real time through interactive smart screens, voice recognition systems, holograms and drone monitoring.

Figure 4.The Rolls-Royce remote control autonomous innovation

Source:Rolls-Royce touts remote-controlled cargo ship as "future of the maritime industry"

4.2 Benefits of MASS

4.2.1More safer and less life losses

MASS has the potential to reduce the occurrence of erroneous operations, avoid casualties and reduce ship risks. Today, the vast majority of marine deaths and injuries occur on board the sailors' own ships (Ai & Zhang, 2015). MASS use a large amount of advanced equipment instead of human labor, and the operators normally plays an auxiliary role in monitoring or remotely control under emergency. As a result of crewless, most on-board crew members' deaths and injuries can be avoided. In addition, human error is a dominant cause of many casualties at sea. According to the Allianz insurance report of Munich, Germany, 75% to 96% of marine accidents are caused by human errors, e.g. personnel decision-making and operating errors, improper emergency response, or fatigue. MASS could be the answer. Autonomous look-out, navigation and collision avoidance will provide significant safety benefits with regard to that. It is estimated that the probability of accidents of MASS will be reduced by more than half compared with traditional ships.

4.2.2 Economic sustainability

The biggest driven factors of MASS will be economic sustainable. While adding a higher building cost which is acceptable, the MASS represents an opportunity to save a large amount of operational costs. Crew costs on-board are one of the main operational costs. With the development of society, the labor costs are expected to increase year by year. In 2011, the Drewry Report on Ship Operating Costs showed that an average between 31 and 36% of the total ship operation costs are the labor costs on-board (see table 5). When considering the additional crew necessities, purchase, installation and maintenance of service facilities, the costs related to crew may up to 44% of the total cost (Ødseth & Burmeister, 2014). Furthermore, because there is no need for crews and their facilities such as deck houses, dormitories, life-savings, fire-fighting and ventilation, heating, and sewerage systems, this will make the vessels lighter and smoother for the purpose of full loading, thereby reducing fuel consumption and carbon emissions (Qin & Di, 2017). According to calculations, an unmanned ship can save at least 12% to 15% of fuel cost (Kretschmann & Burmeister, 2017).

Table 5.Costs for dry bulker

	Daily operating costs in US$ per day						
	Handysize	Handymax	Supramax	Panamax	Post Pmax	Capesize	VLCC
#Ships (2010)	2963	2124	n/a	1412	387	921	197
#Crew	18	18	18	19	20	20	22
Manning	1.779	1.779	2.247	2.359	2.366	2.648	2.662
Insurance	655	720	770	785	790	1.030	1.190
Stores/Lubes	610	625	650	770	780	875	1.010
M&R	1.590	1.634	1.837	2.099	2.370	2.622	2.765
Admin	651	651	700	749	793	837	833
Total OPEX	5.285	5.409	6.204	6.762	7.099	8.012	8.460
Man/OPEX	34%	33%	36%	35%	33%	33%	31%
Trip rates Past	18.640	36.840	n/a	32.760	n/a	65.660	n/a
Trip rates FC	17.700	30.950	n/a	16.283	n/a	19.300	n/a
Man/TR Past	10%	5%	n/a	7%	n/a	4%	n/a
Man/TR FC	10%	6%	n/a	14%	n/a	14%	n/a
Past:= Average 2006-2010		FC:= Average forecast until 2016			TR:= Trip rates		

Source: Secondary data based on "Ship Operating Costs 2011-2012: Annual Review and Forecast" and "Dry Bulk Forecaster 3Q11: Quarterly Forecasts of Dry Bulk Market"

4.2.3 Ecologic sustainability

Through energy saving and emission reduction, the MASS will contribute to the green shipping greatly. The shipping industry represents about 3% of global greenhouse gas emissions, and the industry has acknowledged that it also needs to contribute to future reductions so as to synchronize with land based greenhouse gas emissions (Veronika & Ivar, 2009). Today, slow steaming is a decent choice to realize energy saving and emission reduction. Looking at an exemplary route from Porto de Tubarao to Hamburg, a transit speed reduction from 16 to 11 knots should reduce fuel consumption by about 54% and thus avoid about 1.000 tons of carbon dioxide emissions (see table 6). However, while slow steaming will reduce fuel costs and greenhouse gas emissions, it will entail higher costs due to longer sailing times which in turn have an impact on crew cost, ship hire and the probability of technical faults and related off-hire penalties (Ødseth & Burmeister, 2014). Slow steaming also increases the societal challenge of providing attractive working conditions on long and slow intercontinental voyage. If the MASS is widely used, these problems will be solved. Furthermore, it was also stipulated that an unmanned ship can be operated more efficiently with more advanced automatic energy management systems and improved routing and navigation. Thereby, MASS would provide a possibility to foster ecological sustainability.

Table 6.Exemplary costs calculation to show slow steaming benefits

Route	Porto de Tubarao -> Hamburg (Charter = average 2006-2010)		Change due to slow steaming	Porto de Tubarao -> Hamburg (Charter = forecast until 2016)		Change due to slow steaming
Distance [nm]	5446			5446		
Speed [kn]	16	11	-31%	16	11	-31%
Time [d]	14,2	20,6	45%	14,2	20,6	45%
Fuel [t]	624,0	288,8	-54%	624,0	288,8	-54%
CO2 [t]	1.978,1	915,5	-54%	1.978,1	915,5	-54%
Charter [US$]	464.611,9	675.799,1	45%	230.935,0	335.905,4	45%
Bunker [US$]	405.613,5	187.722,0	-54%	405.613,5	187.722,0	-54%
Total [US$]	**870.225,4**	**863.521,1**	-1%	**636.548,5**	**523.627,4**	-18%
Manning [US$]	33.456,0	48.663,3	45%	33.456,0	48.663,3	45%
Manning/Total	3,84%	5,64%		5,26%	9,29%	

Source: Secondary data based on "Maritime economics, 3rd ed., Routledge, London, New York".

4.2.4 Social sustainability

The MASS represents a way out of the impasse of a shortage in the supply of seafarer due to the job's perceived unattractiveness and a growing demand for seafarer caused by slow steaming and increasing transport volumes. In recent years, as ships have become more complex, the quality of crew members has become increasingly demanding. However, due to the boring life at sea, which is far away from family and land, and full of hidden dangers, the seafarer career gradually becomes unattractive. Many seafarers choose to quit this profession, and many international shipping companies face the dilemma of difficult recruitment of seafarers (Qin & Di, 2017). Although the supply and demand of the crew market is affected by the market price, in the long run, especially in Europe, most parties agree that there will be a factual shortage. A current market pool in Germany shows that 80% of the maritime stakeholders already claim a lack of nautical and technical officers (Jahn&Bosse, 2011). If MASS are widely used, it could reduce the expected pressure on the labor market for seafarer as it would enable, at least partly, to reduce the labor intensity of ship operation. MASS can reduce labor intensity of ship operation and release crew for more demanding and interesting work, to attract and retain seagoing professionals.

MASS will also open new professional perspectives for seafarers. The boring on-board routine tasks would be automated, and the demanding but interesting navigational and technical jobs will transfer from ship to Shore Control Center, which will make seafarer career more attractive and family friendly than today.

4.2.5 Mitigate the Pirate crisis

The piracy problem has plagued governments and the entire shipping industry for long time, MASS might be a solution. Today, Pirates are getting more and more rampant in places like Somalia. So far, Somali pirates have still hijacked nearly 50 hostages. The design of MASS will make it very difficult for pirates to get on board the ship. Even if the pirates get on board, it is difficult to for them to control the MASS. The SCC can stop or slow down the MASS, so that the navy and the policy can take back the ship. Moreover, it is easier to recapture the ship. Because without the crew being held hostage, pirates do not have any high-priced chips. Therefore, for the pirates, there is no way to obtain a high ransom and there is a huge risk of robbery.

Chapter 5 the Autonomous Ship System Context

There will be a new maritime ecological chain in the autonomous era. As a new player of the shipping sector, the MASS needs to be supported by advanced technologies, new operator teams and new maritime entities.

5.1 Technologies for MASS

5.1.1 Shore Control Centre

The Shore Control Centre (SCC) would will a necessary part of MASS. On the one hand, the SCC is a backup in case the MASS encounters unexpected events. On the other hand, it needs the SCC to build substantial connection between the owners and MASS so as to satisfy legal requirements that someone is in control of the ship. The SCC will provide continuous monitoring on the MASS operation. Firstly, the SCC can offer additional safety supportive information. For example, the on-board sensor systems can only perceive the navigation environment within a small area, so it needs further information, such as tropical cyclone paths, severe sea conditions and tides of berths in the destination, to ensure safety navigation. Secondly, in case of any unexpected events which cannot be handled by the autonomous program, the operators of SCC will take control the ships until problems solved. Finally, when the SCC is in charge of the MASS, in terms of liability, the responsibility of the ship's crew members will transfer to the SCC.

Figure 5. the Shore Control Center

Source: Research in maritime autonomous systems project Results and technology potentials

5.1.2 On-board Sensor Systems

The on-board sensor systems can replace the lookout crew members by constantly collecting and processing data. The sensor information can be divided into internal environmental information and surrounding environment information. On the one hand, the on-board sensor systems can collect information from existing sensors of pressure, temperature, rotational speed and cargo hold, etc., so as to monitor and process internal environmental information, such as the working status of navigation equipment, engine and cargo information. On the other hand, the on-board sensor systems can use radar, AIS, ECDIS, infrared and visible light cameras to detect external objects and then analyze whether they pose a danger to ships. The collected sensor information is not only used for the autonomous navigation system, but also can also be displayed in the SCC for operators to learn the real situation.

Another key technology is sensor fusion. The collected sensor information could be overload, even contradict each other. Therefore, sensor fusion can be used to further analyze the real situation then to take corresponding actions.

Figure 6. The on-board sensor system

Source: Research in maritime autonomous systems project Results and technology potentials

5.1.3 Autonomous Navigation System

Through utilizing the sensor information and shore-based information, the Autonomous Navigation System is a smart system which is programmed to operate fully autonomously or be controlled by the SCC according to relevant regulations, such as IMO regulations and regional laws. This system can ensure MASS to follow its planned route within certain deviations to adjust the planned voyage. Deviations can be caused by unexpected encounter situations, such as heavy sea, severe weather conditions and complex ship traffic. On the one hand, this system can operate the MASS safely in both normal and emergency conditions. On the other hand, basing on loading condition, ship draft, wing speed and wave angle, etc., it can also optimize the voyage plans by adjusting its speeds and courses to achieve energy efficiency and emission reduction. A general context of autonomous navigation system is shown in figure 7.

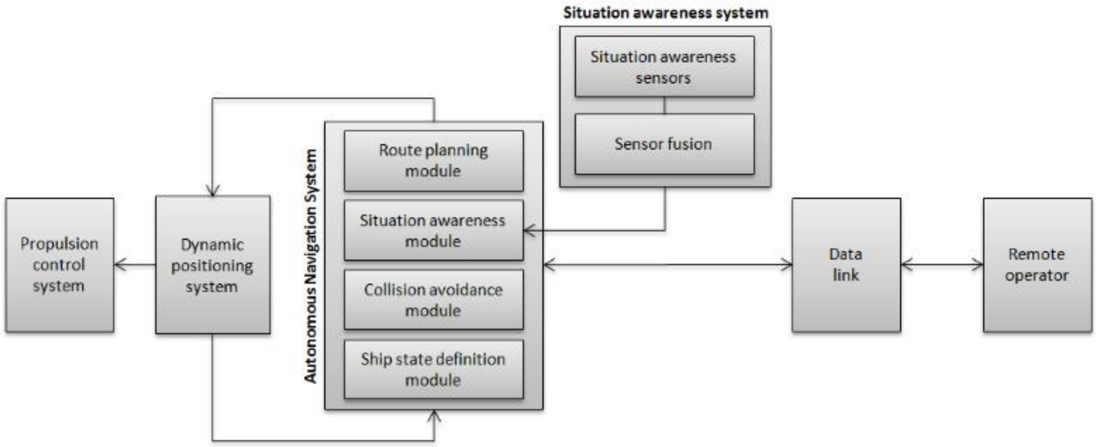


Figure 7. the context of autonomous navigation system
Source: Complied by the author

5.1.4 Smart Engine Monitoring and Control System

The Smart Engine Monitoring and Control System can be regard as an enhancement to conventional ship engine systems. With the development of MASS, the periodical unmanned engine room will evolve into a continuous unmanned. Therefore, it needs to increase additional advanced condition monitoring functionalities to make up human absent. In order to operate the engine systems autonomously or tele-control, it needs to add increased digital interfaces to the autonomous navigation systems and the SCC. Careful diagnostics are critical to ship's normal function and better maintenance planning, and the continuous monitoring contributes to the prevention of malfunctions and breakdowns of ship's systems. Such a monitoring and control diagnostic system for MASS has been developed with robust detection abilities for e.g. broken, burned-on or missing piston rings or for radial wear (RR, 2016). This system also detects thermal overloads of the cylinder liner. Technical condition indicator is an important developed concept for MASS.

5.1.5 Maritime Communication Systems

The maritime communication systems are bridges connecting the autonomous navigation system and the shore-based support system. Because it needs to timely send the on-board collected sensor information to SCC, and receive remote control directions from the SCC, there should be a high-bandwidth, low-latency and low-cost maritime communication system. Since it needs to transmit a large amount of sensor information, equipment status information, radar images, sensor video, etc., the transition volume is very large. Therefore, the data needs to be compressed before transmission, so as to achieve the purpose of cost savings. In order to ensure smooth communications in different weather and sea conditions, it is necessary to equip multiple communication systems, such as Maritime Satellite Systems, Very Small Aperture Terminal (VSAT), Comet, Public mobile communications, etc. In different situations, the communication system should be able to automatically select the appropriate data transmission route to improve the overall performance of the maritime communication system and reduce delay and cost. When only one communication path is available, the systems should ensure that high-priority data is sent first. For example, in the case of a collision emergency, priority should be given to sending the collision avoidance remote control commands, and then secondary information such as weather information should be sent (Gao, 2017).

5.1.6 Smart Maintenance System

Today, most shipboard systems are designed in consideration of the crew's availability. Without crew members on board, any significant technical failure could breakdown the MASS while sailing at sea. To ensure the ship will not run into problems when operating at sea, the crewless MASS must be designed with high redundancy and easy maintenance. Thus, a smart maintenance system needs to be developed to fill the gap. The user interface of the system will be integrated in the SCC to gain sufficient monitoring and support so as to diagnosis the abnormal, then to take further corrective actions. In addition, artificial intelligence is a crucial part of this system. It needs on-board robots to replace crews to conduct tasks automatically (RL, 2015). Robots can be programmed to assemble, inspect, manipulate and explore, or remote controlled by the SCC to perform their duty.

5.1.7 Smart Cargo Management System

The Smart Cargo Management System refers to autonomous monitoring and control of cargoes and cargo holds through the use of sensors and control systems (Gong & Ji, 2016). Based on the monitored data, during ships' loading / unloading, this system can optimize the loading / unloading plan, thus realizing the intelligent management of ship cargo. During the voyage, the system can continue to observe the status of the goods, such as possible movement of goods, flooding, Self-heating or fire, then take further emergency measures.

5.2 Operators of MASS

5.2.1 Operate team of SCC

The operate team of Shore Control Centre provides sufficient safety supportive information, as well as continuous monitoring and remote control of the MASS. The operational team of control center consists of experienced officers, engineers and the company managers, who conduct on-line monitoring of the navigational status, equipment working status and cargo status. Most of the time, the ships are under the control of Autonomous Navigation System without any human intervention. In case of any complicated problems which cannot be safely handled by the computer, the operators will assist to take control the ships until problems solved.

5.2.2 On-board Control Team

The On-board Control Team is a mobile team that may enter the MASS. On one hand, considering the complicated traffic condition in port, and the key operations of berthing or leaving berthing, most MASS will be designed for pilot station to pilot station. Thus, it needs an On-board Control team who will take over the MASS when entering the port or leaving the port. On the other hand, if there is any emergency or accident, such as a critical breakdown of some ship systems or collision accident, the On-board Control team will direct control the MASS until the problem solves. The On-board Control team consists of experienced officers, engineers, maintenance personnel and electronic personnel, etc.

5.3 General maritime entities

The common maritime entities that any MASS may relate to are shown in table 7

Table 7. the general maritime entities

	entities	Description
1	VTS/Ship reporting	Vessel Traffic Services or Ship Reporting Areas where the ship needs to contact a shore operator for guidance or reporting.
2	Aids to Navigation and AIS	Systems that provide the ship with real-time information about the fairways or other ships. Aids to Navigation are normally visible only, but may include radar reflectors. Virtual Aids to Navigation can be transmitted as AIS messages.
3	Maritime Rescue Coordination Centre and Global Maritime Distress and Safety System	These are radio services that are used for ships in distress or emergencies. The autonomous ship may need to use these services and are also required to respond to them.
4	Other ships	The VHF data communication system as well as AIS can be used to communicate with other passing ships.
5	Pilots, tugs and linesmen	will also communicate with the ship to provide mandatory or requested services.
6	Port Services	Logistic and supply services in port will also have to be arranged. This includes any automatic mooring systems as well as electrical connections.

Source: Complied by the author

Chapter 6 Potential Challenges and Risks on Safety of MASS

Safety of MASS is the most widely public concern which has been questioned frequently. Safety imposes essential constraining requirements for the MASS's design and implementation. In principle, the operation of MASS shall be at least as safe as the conventional ships with fully consideration of uncertainties and potential risks. When the levels of autonomy move higher, the target level of safety should be higher than the existing ships.

Compared with the manned conventional ships, the MASS has been questioned due to challenges and risks on safety regulatory frameworks, maritime legal frameworks, maritime liability frameworks, reliability of safety critical equipment, cyber security, crew job losses and skill degradation, etc.

6.1 Maritime Safety Regulatory Frameworks

MASS is a new player in the shipping industry. Over past centuries, the maritime regulatory framework has not anticipated MASS, and many features of MASS are incompatible with the existing international regulations. From a regulatory perspective, the shipping industry is not designed for the digital revolution. From a historical point of view, the formation of a maritime regulatory framework takes a long time and follows the development of science and technology rather than driving the development of science and technology. Therefore, the maritime regulatory framework should not be an obstacle to MASS. However, we should clearly recognize that the maritime regulatory framework needs to be adjusted accordingly to accommodate the operations of the MASS. For example, we need to change the concept of supervision from seafarers to autonomous systems. In addition, expert committees/panels will be created, and international bodies will need to provide legislative support for the technical developments.

6.2 Maritime Legal Frameworks

Maritime law is a functional term used for describing a whole range of laws and other legal sources that govern the legal framework related to ships and their operation. It includes a variety of different legal systems, ranging from international law to regional and national rules and down to local rules. It covers issues of public concerns, such as safety, security and environmental protection as well as civil law matters, such as contracts of carriage, liability and compensation for damage, salvage and rules related to marine risks and insurance, to name but a few.

One of the main obstacles to the MASS is the revision of conflict maritime legal frameworks. In general, there is no insurmountable obstacle in the application of MASS. However, of course, there is still a long way to go before the legal amendments on the use of MASS. First of all, the conventions and domestic laws governing the supervision of MASS are not yet sound. Due to the lagging nature of international conventions and domestic legislation, all aspects related to MASS are not comprehensive yet, and some characteristics of MASS are even deviating from the conventions (Xu & Zhang, 2017). For example, the terms of the International Convention for the Safety of Life at Sea (SOLAS) stipulate that "each flag state must provide qualified crew for the ship according to its own minimum manning regulations". Obviously, an unmanned ship does not meet this clause. In order to adapt to the development trend of MASS, it is extremely necessary to strengthen the revision and improvement of maritime conventions and laws.

Table 8. Summary of different maritime laws.

	Jurisdictional Rules (main target: states)	Technical requirements and Standards (main target: flag states)	Private law issues (shipowner and other commercial partners)
Global (UN)	UNCLOS		
Global (IMO&ILO		SOLAS, MARPOL, STCW, COLREGS,MLC	
Global (IMO, UNCITRAL, CMI etc.)			Private law conventions on e.g. liability, limitation, arrest, carriage of goods, salvage, etc
National (China)		National implementing legislation, discretion of flag state administration	other specified acts on liability, insurance etc.

Source: Complied by the author

At present, the IMO has established more than 50 effective conventions and rules for the world's contracting parties (Cai & Ma, 2017). These conventions and rules are mandatory for the States parties to adhere to. At the same time, these conventions and rules will also be converted into the regulations of the shipping industry of each State Party. The development of MASS must be supported by conventions and rules. The revision of conventions and rules of MASS will be a complex and large and even subversive work.

6.3 Maritime Liability Frameworks

The existing maritime liability rules may need to be interpreted, amended, and possibly supplemented by dedicated rules to supplement the traditional maritime liability framework. Even if it is not necessary to immediately change the basis of MASS's liability, we should clearly recognize that technological development of high level of autonomy may pose challenges to the current liability framework. While errors committed by SCC operators controlling remotely-operated ships are probably to be treated in the same way as errors committed by on-board crew members, autonomous technology may generate new types of errors and causal relationships. For example, damages cause by equipment or software failure of the autonomous system. In this case, the operator would probably be liable, at least in part, if he fail to override the autonomous system.

However, the inclusion of human intervention is even more complicated. If the connection between the MASS and the controller is cut off, the MASS will have to rely entirely on its autonomous system. For example, if damages caused by failures in the autonomous system, such as wrongful programming etc., it is controversial that the operators carry the liability under a strictly fault-based liability scheme. With the development of highly automated systems, such a fault-based liability scheme may be out of season. Therefore, the liability framework should take manufacturer's responsibilities into consideration.

6.4 Human Factors Issues in Remote Operation and Monitoring

While MASS represents an opportunity to reduce human based errors, there are a number of potential human factors issues related to operation and monitoring of MASS with safety implications. Firstly, there would not be bodily feeling of the ship rocking or ship sense when the SCC operators remote control the MASS. The sensor systems may not help the SCC operators to fully understand all the real situations. In practice, steering of small-size ships can be adjusted in accordance with the wave formation through bodily sense of the ship. Secondly, due to the complicated sensor systems, the SCC operators could be exposed to information overload and therefore no longer able to make sense of the situation. The problem would be even graver if one person would monitor several vessels as steering the overview from one vessel to another could be a potential point for mishaps (Osga & Williams, 2015). Additionally, boredom and vigilance maintenance have to be considered. The SCC operators work in a safe and comfortable environment, as a nature they may reduce safety alertness (Wahlström & Hakulinen, 2015). For example, in a previous study, 92% of unmanned aircraft system operators have reported “moderate” to “total” boredom. Boredom could results as a loss of vigilance and is therefore a risk factor.

6.5 Cyber Security

With further development of autonomy level, cyber security has been questioned frequently. In 2015, the remote hijacking of the Jeep car led to the recall of millions of Cherokee events for the first time to make everyone realize that autonomous technologies will also be a threat to hackers. Researchers at the University of Washington and the University of California, San Diego, conducted an intrusion test and declared that it is possible that millions of cars and trucks using their computer systems could not be braked. The exposing loopholes and flaws of autonomous systems may become a hard-hit area for cyber attacks. It can be foreseen that hacking attacks against driverless cars will increase, and large-scale car attacks will Bring cities and even threaten the lives of drivers and pedestrians. Likewise, remotely transmitting of ship operation and management also introduces cyber security risks.

Generally, anyone skilful and capable to attain access into the autonomous system could take control of the ship and change its operation according to hackers’ objectives. Compared with driverless cars, the consequences of cyber attacks aiming at MASS will be much more disastrous. If an unmanned full load oil tanker is hijacked by the terrorists, they may use it to attack a city.

6.6 Cargo Management

In existing ships, the chief mate and captain are in charge of cargo management. When in loading/unloading operation, the chief mate should be on site to ensure the operations are in accordance with relevant work procedures and the ship specific cargo manual. However, lacking well cargo management by the permanent crew on-board the MASS, the shipper and consigner may be unwilling to entrust such high value cargo to a crewless ship. The responsibility for cargo management may transit from the crew members to port operators. On-board cargo management is systematic professional job which needs well training and strong sense of responsibility, the existing dockers may be not capable for such work. Compared with the longshoremen, on-board crew members have a much deeper personal interest to ensure that cargo loading condition and ship equipments are on position. This may increase cargo related incidents.

Furthermore, when sailing at deep sea, crewless MASS only can take limit actions to take any cargo related measures. The sensor systems can help to monitor cargo condition, but there is no extra equipment facilitating additional measures so far. It needs further research to identify useful actions to cure cargo related problems ,such as cargo shift, leaks, problems with moisture, fire and flooding.

6.7 Managing Emergencies

With decreased crew size or even crewless on-board, the MASS may fail to manage emergencies which need specific prompt response actions. While dealing with never met emergencies, it will beyond the MASS limit which is programmed in advance. Flexibility, self-learning and innovation thinking are critical human nature to manage emergencies, it is doubtful that MASS can be designed with such characteristics.

Due to the limitations of currently available technologies, another problem is that how a MASS can assist in emergency situations related to other ships. Helping each other is an excellent maritime tradition, and helping the distress vessels and persons at sea is an obligation under international law. While facing emergency situations that need immediately hands-on help, the MASS can offer few help but only emergencies report. For example, though the MASS can transmit video and sensor data to search and rescue entities, it is impossible for a merchant crewless MASS which is designed without life saving appliances to get the help-seeker out of water.

6.8 Integration with Existing Transport System

Another challenge is the difficulty in communicating and interacting between the MASS and conventional manned ships (Ødseth & Burmeister, 2014). For a long time, there will be a situation that MASS navigates with conventional manned ships side by side. This puts particularly pressure on MASS to communicate and take coordinated collision avoidance actions. For example, MASS has difficulty in detecting small targets, and how to tell a very small fishing boat without modern technology from a rock or waves, then takes further collision avoidance actions. There is also concern about participation of a MASS in a search and rescue operation (SAR). This includes detection of emergency situations, e.g., identifying life boats or rafts and reporting this to the appropriate SAR authority. A distinguish from distress help-seekers and hostile pirate is another problems for MASS.

6.9 Job Losses and Skill Degradation

There is also a widely concern about seafarer job losses, navigational skill shortage, and skill degradation with the further application of MASS. At present, there are about 1.5 million seafarers worldwide. While a little part of them will transfer to SCC, most part of them will lose their job. In addition, this kind of unmanned ship is not likely to provide onboard training vacancies for deck and engine ratings and cadets. As a result of autonomous navigation, it is difficult to maintain skills needed in varying maritime activities. There will be skill degradation when a large number of seafarers quit their sea career. Rich navigation experience and skills are critical for abnormal situations. Furthermore, each ship is different in its own designed factors and operational condition, a good captain know his ship characteristics well and perceive the different in operation. However, without the body feeling and a Long-term focus, the CCS operators could have to learn the practical differences of each of the ships and could easily forget or fail to recognize relevant issues when switching the operation from one ship to another.

Chapter 7 Safety Improvement Suggestions for MASS

7.1 Draft or Revise International Standards and Guidelines for MASS

It is highly recommended that policymakers draft new policies and laws for MASS, and revise the existing international standards to clear the obstacle in the way towards autonomous shipping. The development of MASS faces challenges on design, construction, collision avoidance, marine environmental protection, crew training, legal liability and insurance, etc. Firstly, the policymakers should learn about the public concerns and needs before carry out legislative work. Secondly, successful legislation experiences of driverless cars and drones are good examples for MASS. In 2015, California has established legal regulations for fully autonomous cars, including regulations for operation, manufacturing and safety testing for them. In terms of drones, the United States, France, the United Kingdom, and Sweden have successively formulated regulations concerning safe management. The advancement of technology can always promote the improvement of various rules and laws. Lastly, co-operative actions are needed to develop international standards and guidelines for MASS. Widely co-operation between the national administrations, classification societies and other relevant bodies with interest in the field of MASS is recommended for the further development. Co-operation is necessary to be able to create a common ground for a coherent, safe approach when laying out the first sketches of principles to be followed in the procedures to be used guiding and controlling the technical and operational safety of MASS.

7.2 Basic Safety Concepts

A principle ship design concept of MASS is that they shall be made at least as safe as conventional manned vessels. It is no doubt that the new born MASS will affect the shipping markets with uncertainty and risk on financial, and the existing safety state and eco-system will be disturbed, e.g. significant fluctuation in accident rate at the beginning. Furthermore, with the increasing of autonomous levels, the corresponding ship design level of safety must be higher than the existing manned vessels. While with the potential to reduce human errors, the MASS also increases risk and uncertainty in autonomous system failures, emergency management and cyber security. When the levels of autonomy move higher, the target level of safety should be higher than the existing ships.

7.3 Qualification of New Technologies and Autonomous Systems

The new technologies and autonomous systems should be approved before widely commercial used. MASS represent a major technological and operational revolution which without relevant field supportive data currently available. At present, the international conventions, e.g. SOLAS, COLREG, ISM and STCW etc., specify the minimum standards for the design, construction, equipment, manning and operation of ships considered to enable safe operation together. Each individual ship should meet the specified requirements on structural design, specific equipment, size and qualifications of crew, etc. Any deviation from the specified requirements, the new type of ship needs to be proofed at least as safe as the existing requirements with sufficient evidence. For the purpose of development of new technologies, basing on such evidence, the Flag state can then issue an exemption permit for the deviant solution in a particular ship and service.

Generally, MASS is a deviation from the existing international agreed regulations. Thus the new technologies, autonomous systems, equipments required to be qualified and approved by the recognized organization.

7.4 Risks Management during Technology Transition

It needs fully prepareness in advance for the unknown risks and unexpected hazards. From a historical point of view, new emerging things of shipping industry are always accompanied by uncertain and risks. The transition of autonomous shipping is expected to take place gradually, and has been claimed to require at least a couple of decades. For a long time, there will be a picture that different levels of autonomous ships navigate with conventional ships side by side, alongside unknown risks and unexpected hazards. To make sure these new emerging risks and hazards under control, during technology transition, a continuous improvement of autonomous technologies is needed. One important aspect in the technology transition is the management of maintenance and repair of systems, and ensuring only as-planned interactions between e.g. subsequent software generations. The well-performed management with standardized routines of up-to-date documentation is an important part and feature of the systemic approach.

7.5 Improved System Robustness

Today, ship systems are designed and built to utilize a combination of maintenance strategies to provide a sufficient safety and reliability level for the complete system (Ødseth & Burmeister, 2014). This includes the use of technical and operational redundancy, periodic maintenance intervals and the possibility to repair or replace components by the crew. Obviously, crew repair/ replacement are not available for unmanned ships. Operational redundancy will also be problematic when this involves use of crew intervention. Therefore, it is a major challenge for MASS to improve the system robustness to ensure the ship will not fail during the voyage.

7.6 Update Operator Training Regime

The operators are critical factors contribute to safety navigation, and an updated training regime of STCW will be need. Firstly, to meet the new requirement, involve maritime universities should create new course curriculum for future maritime professionals. Secondly, it is recommended to convert existing seafarers to MASS operators, so as to utilize and preserve their skills. However, before any crew reduction or transfer to MASS operators, the crew members need to be trained in any case to fulfill all functional tasks. Thirdly, it is recommended to adjust the STCW training regime to ensure MASS operator competence. The operators of SCC team and on-board control team are required to have a sufficient amount of experience related to similar ships, i.e. with regard to dimensions, deadweight and power and their relations. Furthermore, it is critical to maintain operator good skills. Good skills are needed in safety critical and challenging situations. Manual skills weaken when they are not used, that is, it could be problematic if the operator usually only monitors the ships and at times takes control. Thus, well designed simulator training would be needed for practicing challenging safety critical situations.

7.7 Protect Against Cyber Security

They are many factors concerning cyber security, including technology implementation, education and the organizational culture guiding performance. Technical speaking, protection against cyber threats requires eliminating vulnerabilities in autonomous system facilities, and implementing effective measures of intrusion prevention, and intrusion detection, damage control and security recovery in case of system failures. With the advancing of technology, the potential cyber attackers may become more proficient, thus the oversight on cyber security needs to be dynamic and proactive introducing updates in the systems accordingly. In addition, data classification, data encryption, user identification, authentication and authorization, prevention of unauthorized use of data, data integrity protection, connection protection, logging and auditing are also common methods to protect against security attacks. Furthermore, shipping companies should foster a security culture and enhances the security awareness of operators greatly.

7.8 Improve Supporting Facilities of MASS

While developing and applying the MASS, it is recommended to improve the supporting facilities of MASS as well. For example, autonomous service vessel with combined underwater and drone can be used to inspect and maintain the MASS, instead of labor work. During the maintenance phase of MASS, autonomous service vessels with combined underwater and drone can carry out effective regular inspections without crew on-board. Besides, supporting facilities such as fully or semi-automatic mooring systems at port are highly needed. This kind of fully or semi-automatic mooring systems require some modifications to the dockside infrastructure (RR, 2016). Large number of supporting facilities will be needed to meet the high efficient operation of MASS.

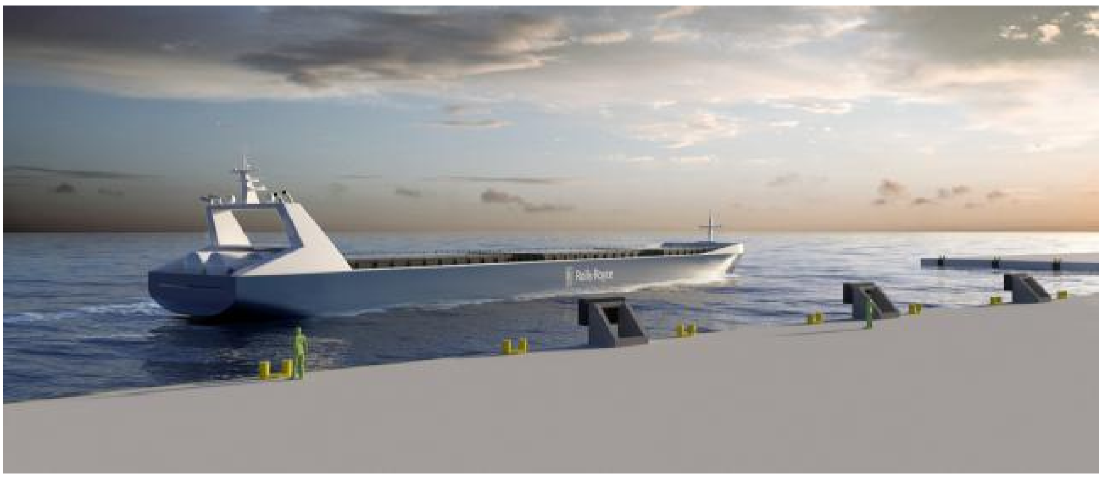


Figure 8. Semi-automated mooring system concept.
Source: AAWA white paper

Chapter 8 Conclusion

The MASS provides an important pathway for a sustainable development for maritime industry. Although it is difficult to realize fully autonomous operation in the short term, MASS revolution has begun, and autonomous navigation era is about to come in the near future. In the present development phase, the way towards autonomous navigation is full of uncertain and challenges on technical, economical, legal, liability and safety management aspects.

The conclusions are:

• There are not insurmountable obstacles in terms of laws. The international regulations and domestic laws can be amended if there is a political will. Recognizing the existing maritime legal frameworks does not anticipate MASS, a wide range of regulations need to be drafted or amended. A starting point is that the MASS should be subject to the same rights and obligations as the conventional manned ships.

• Maritime liability frameworks are also likely to undergo significant changes with the coming MASS. The MASS will reshape a new maritime liability system due to the new risks and new players. The existing liability rules should be reinterpreted and amended.

• The technologies of MASS are indeed feasible. Today, the development of autonomous vehicles, including autonomous land vehicles, aviation and also marine vessels, have been through great progress over the past decade. The general technologies needed to make MASS a reality laying in them.

• In terms of safety, the operation of MASS shall be at least as safe as the conventional ships. While there is potential to reduce human error and increase overall safety, at the same time, we should realize the new risks and challenges which need to be identified and addressed.

• In terms of economy, MASS has the potential to reshape the maritime industry bringing benefits such as increased operational efficiency, fuel reduction, emission reduction, and operational costs reduction. In addition, The MASS can also mitigate the crisis of shortage in the supply of seafarer.

The next steps are:

• Widely cooperation is needed to adjust the maritime safety management regulatory framework, legal framework and liability framework. Corresponding international regulations and guidelines should be drafted or amended for MASS.

• At the beginning, the operation of MASS shall be at least as safe as the conventional ships with fully consideration of uncertainties and potential risks. When the levels of autonomy move higher, the target level of safety should be higher than the existing ships.

• The transition of autonomous shipping should by small and cautious steps, so as to make sure those new emerging risks and hazards under control. During technology transition, a systematic approach in risk management and continuous improvement of autonomous technologies is needed.

The safety management of MASS is a very wide and deep domain, including ship safety, cargo safety, maritime traffic safety, environmental safety, occupational safety and security, etc. Due to the author's limited capabilities, this dissertation presents only the tip of the iceberg for MASS safety management, and it needs further research and exploration.

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