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Legal issues relating to the maritime autonomous surface ships' development and introduction to services

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LEGAL ISSUES RELATING TO THE MARITIME AUTONOMOUS SURFACE SHIPS' DEVELOPMENT AND INTRODUCTION TO SERVICES

By

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Declaration

I certify that all the material in this dissertation 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 dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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(Date): 24 Sep, 2019

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Abstract

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MASS technological development has close relationships with legal issues because the regulation enacted has tended to reflect an understanding of yesterday's technologies, and it is important that all stakeholders should understand the limitations of technology and reflect them on the regulation through IMO discussion. However, there is no comprehensive legal and technological MASS development roadmap.

MASS technological development cannot be achieved at once. There are several degrees of automation; the operation task, operation design domain and automation level, and they should be expanded correspondingly to the degrees. There are several projects developing MASS, and each of them defines the degree of automation including IMO. These projects are investigated and summarised with IMO´s definition of the degree of automation. Further, it is examined "what legal issues may relate to MASS depending on the degree of automation, and how will MASS be put into practical services".

It is understood that legal amendments will be needed, corresponding to the MASS development; and there are several characteristics of the amendments such that the difficulty of them and when to amend them vary. However, all amendments should be incorporated into the MASS development and the development should not be disturbed by the amendments.

In this respect, the concluding chapter suggests the legal and technological development roadmap to put MASS into practical services.
Furthermore, it is suggested that what should be considered in the legal and technological MASS development.

KEYWORDS: Autonomous vessel, remotely controlled vessel, MASS, legal and technological MASS development roadmap, SOLAS convention

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AAWA	Advanced Autonomous. Waterborne Applications Initiative
AIS	Automatic identification systems
BIMCO	Baltic and International Maritime Council
CLC	International Convention on Civil Liability for Oil Pollution Damage, 1992
COLREG	The International Regulation for Preventing Collisions at Sea, 1972
COSCO	China Ocean Shipping Company Limited
ECDIS	Electronic chart display and information system
EEDI	Energy Efficiency Design Index
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNSS	Global Navigation Satellite System
ICS	International Chamber of Shipping
IGF	International Code of safety for ships using gases or other low-flashpoint fuels
IMO	International Maritime Organization
IS	International Code on intact stability, 2008
ISM	The International Safety Management Code
ISPS	The International Ship and Port Facility Security Code
LIDAR	Light Detection and Ranging
LLMC	Convention on Limitation of Liability for Maritime Claims, 1976
MARPOL	International Convention for the Prevention of Pollution from Ships, 73/78
MARPOR	The International Convention for the Prevention of Pollution from Ships
MASS	Maritime Autonomous Surface Ship
MLC	Maritime Labour Convention
MOL	Mitsui O.S.K. Lines

RADAR	Radio Detection and Ranging
SEEMP	Ship Energy Efficiency Management Plan
SOLAS	The International Convention for the Safety of Life at Sea, 1974
STCW	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
SVAN	Safer Vessel with Autonomous Navigation
UNCTAD	United Nations Conference on Trade and Development
VHF	Very High Frequency

1. Introduction

1.1 The prospect of MASS

1.1.1. Trends of trading

International trades rely heavily on shipping. Based on the criterion of weight, roughly 90% of international trade has been served by sea-going vessels. In 2017, it was estimated that about 10.7 billion tons of cargo were transferred by seaborne means, according to UNCTAD [REVIEW OF MARITIME 2018, 2019]. The annual seaborne trade growth rate, globally, was 4% in 2017 and 10.7 billion tons in 2017 was 4 times more than what it was 50 years ago. In addition, that between 2018 and 2023 is predicted to be 3.8% [REVIEW OF MARITIME 2018, 2019].

One of the reasons causing the seaborne trade boom is the global GDP growth, especially in Asia. For example, Chinese GDP growth rate was 6.2% in 2018, the East Asian region being 5.2% and the South Asian region being 4.4% [World Economic Situation and Prospects 2019, 2019]

In fact, the rapid GDP growth in Asia has contributed to the seaborne trade boom all over the world such that 42 % of loading and 61% of unloading around the world was related to Asia in 2017. Further, trans-pacific container trade in 2018 was 4 times as much as what it was in 1995; and Europe-Asia container trade in 2018 was also 6 times as much as what it was in 1995 [REVIEW OF MARITIME 2018, 2019].

Economics in the rest of the world is also growing. For example, GDP growth rate in most African States was more than 3%, as well as that in South American States in 2018 [Real GDP growth Annual percent change, 2019]. In the future, not only East-West trade, but also the North-South trade, will be enhanced. DNV-GL forecasts it will reach to 16 billion tons in the 2030s [Endresen, 2018].

Indeed, shipping and trade are interrelated to each other. However, the increase of shipping activities is also associated with certain significant rises of collisions and groundings which stand out.

1.1.2. Safety of shipping

Although the number of a total loss of vessels has decreased over time due to equipment preparedness on board and capacity building of seafarers based on international conventions, the number of reported marine casualties and incidents has been stable or increased since 2011 [ANNUAL OVERVIEW OF MARINE CASUALTIES AND INCIDENTS 2018, 2019].

One of the factors influencing their outcome can be considered the increasing average age of vessels. The average age of world fleets has increased since 2000, and it is indicative of the fact that it was 25 years old in 2016. In the statistics of Lloyd's, around 30 years old, it has the highest rate to cause serious casualty incidents between 2006 and 2010 [Graham, 2016] [Mandryk, 2011].

Another cause of accidents is human erroneous action. In the EMSA statistics, there were about 3,300 maritime casualties and incidents in 2017. 60% of 781 incidents related to cargo ships were attributed to human erroneous actions [ANNUAL OVERVIEW OF MARINE CASUALTIES AND INCIDENTS 2018, 2019]. Also, according to an Allianz report, it is estimated that 75% to 96% of marine accidents can be related to human error [Shipping Safety - Human error comes in many forms, 2019].

The lack of safety in shipping makes seafaring an unpopular job. In the United Kingdom, the fatal accident rate per 100 thousand workers year of merchant seafarers was the second worst following fishermen in 1980.

1.1.3. Number of seafarers

In these 20 years, the demand of seafarers has been higher than the supply. Now, the number of seafarers on board internationally trading merchant vessels is estimated at 1,647,500 [Global Supply and Demand for Seafarers, n.d.]. It is forecasted that an additional 147,500 officers will be required by 2025, depending on increasing seaborne trades [Aron Sørensen, 2016].

In some developed countries, not only for shipping but also the whole of society, the population is shrinking, which has a significant impact on the economy and society [KATO, 2018]. Therefore, each industry has to compete to hire competent human resources, and shipping companies also have to provide an attractive work environment to hire them.

However, there are several negative views of working on board seagoing vessels these days. Although there have been positive opinions on seafarers in terms of their salaries and long holidays, in a survey conducted to maritime university students, they feel negatively because they will be isolated from society, suffer from hard work, and have disadvantages regarding getting married [the result of survey about maritime university students' consideration, 2010]. To hire competent human resources and keep sustainable growth in the maritime industry, an improvement of the working environment must be one of the prerequisites [Cahoon, 2014].

Not only the working environment but also the maritime industry depression, affects students' awareness negatively.

1.1.4. Profitability of shipping industry

The shipping industry has suffered from economic depression after the end of seaborne trade boom in the 2000s. According to Clarkson Research services, the price of a five year old Panamax dropped to one third in 2015 because the annual world tonnage on orders between 2008 and 2011 had tripled compared to what it was in 2007 while the demand of fleets fell by 4% in 2009 [How Predictable Are Ships Prices, 2014]. As a result, the Baltic Index, which is one of the freight rates, had dropped from more than 10,000 in 2008 to less than 1,000 in 2009 and the low Baltic Index has kept that level until now [Baltic Exchange Dry Index, 2019]. Also, the daily earnings of bulk carriers of Panamax size had decreased down to one seventh of what it was in 2010, according to UNCTAD [REVIEW OF MARITIME 2018, 2019]. Furthermore, in 2016, most of the shipping companies were in deficit as shown in Table 1, thus demonstrating companies such as Maersk, CMA CGM, Hapag-Lloyd and COSCO that they could not make a profit [Matsuda T. , 2017].

Table 1.

Financial Report of the Major Shipping Company

	Maersk		CMA CGM		Hapag-Lloyd		COSCO	
	2015	2016	2015	2016	2015	2016	2015	2016
Gross sales	40,308	35,464	15,674	15,977	9,811	8,563	8,778	10,517
Gross profit	522	-1,897	587	-427	126	-103	193	-898

Compiled from [Matsuda T. , 2017]

Apart from the profitability issue, the increase of the shipping activities also has a significant influence on the environment.

1.1.5. Greenhouse Gas Emissions from shipping

IMO estimated that international shipping emitted 2.2% of the total CO_2 emission in 2012 equivalent to 796 million tons of CO_2 and that emissions from international shipping could grow by between 50% and 250% by 2050 [Third IMO GHG Study 2014, 2015].

Although IMO had already introduced two mandatory mechanisms which are the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) to MARPOL Annex 6 to ensure an energy efficiency standard for ships, IMO adopted the resolution of Initial IMO Strategy on Reduction of GHG Emissions from Ships in 2018 [Josefin Madjidian, 2018]. It was decided that the total annual GHG emissions from international shipping will be reduced by at least 50% by 2050 compared to 2008 and will be pursued to be phased out; and the carbon intensity of international shipping will be declined by 40% by 2030 and will be pursued to be declined by 70% by 2050 compared to 2008. In the strategy, one of the short-term and mid-termed measures to accomplish the value is to improve operational energy efficiency [RESOLUTION MEPC.304(72) INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS, 2018].

1.2. What is Maritime Autonomous Surface Ship?

1.2.1. Maritime Autonomous Surface Ship System

In the framework for the regulatory scoping exercise of IMO, MASS means Maritime Autonomous Surface Ship and is defined as a ship which, to varying degree, can operate independently of human interaction. Technically, it is considered as a conventional vessel with a Manoeuvre Control System, Autonomous System and Monitoring System as Figure 1 explains in the related concepts [HIRAYAMA, 2018].

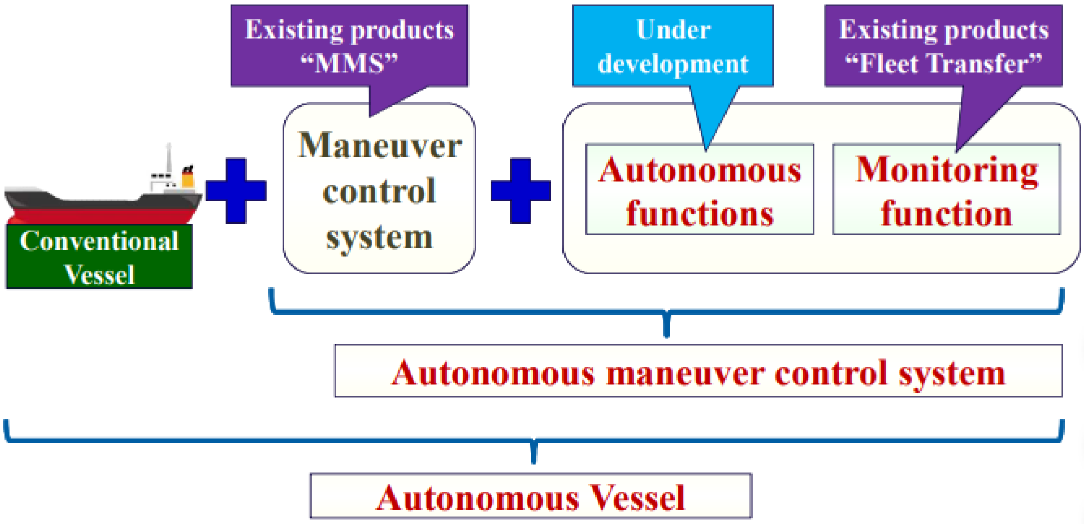

Figure 1. The image of MASS system. Copied from [HIRAYAMA, 2018]

1.2.1.1.Manoeuver control System

"Manoeuver Control System" enables auto tracking, dynamic positioning, auto heading and joystick operations. For those control, the function automatically needs to perform a complicated manoeuvre with its engine, thruster, and rudder at the same time [DYNAMIC POSITIONING SYSTEM MODES AND FUNCTIONS, n.d.].

1.2.1.2. Monitoring System

"Monitoring System" means collecting and monitoring the operation data of vessels in service. The data about its navigation and equipment are processed on board and processed further in remote centres if needed corresponding to the degree of automation. The processed data like its surroundings, equipment abnormalities and oil consumption are used to support its navigation and equipment maintenance simultaneously or strategically for the future [HIRAYAMA, 2018].

1.2.1.3. Autonomous System

"Autonomous System" is accomplished with autonomous elemental technologies like auto collision avoidance system to suggest a safe course depending on its surroundings and auto berthing system to automatically control berthing speed and heading. These systems receive input data from human or the Monitoring System depending on the degree of automation, and process it further to output commands to the Manoeuver Control System [Remote and Autonomous Ship The next step, 2016].

1.2.2. The degree of automation

In this sector, concretely, the degree of automation will be introduced. It will be explained through what operational tasks will be automated, under what situation they will be automated, and "how much" they will be automated [MLIT, 2016].

In this thesis, Figure 2 illustrates the coordinate system with three axes, (X) Operation task for automation; (Y) Operational design domain; and (Z) Autonomous level, which will be used to illustrate the degree of automation. A combination of the level of each axis indicates a particular degree of automation. In the following chapters, each axis will be explained in detail.

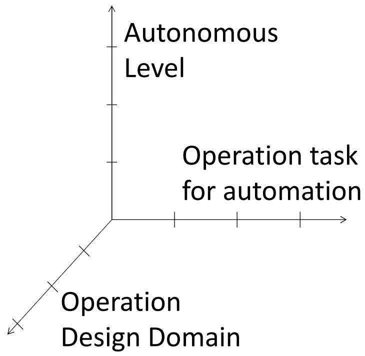

Figure 2. The degree of automation. Adapted from [MLIT, 2016]

1.2.2.1. Operation task for automation

The operation task for automation describes what tasks on board can be automated. Shipping operation tasks can be classified into several tasks such as navigation, communication, maintenance, fire protection, cargo handling, berthing and de-berthing [International Network for Autonomous Ships, n.d.].

For example, navigation can be sorted further into lookout and information acquisition with RADAR, AIS and ECDIS; manoeuver with steering; record; report and emergency response.

Corresponding to the degree of automation, these tasks can be automated. However, a regular operation in the high seas is different from an operation in the rough sea at night to automate operation tasks.

1.2.2.2. Operation design domain

Operation design domain is the condition possible to automate operation tasks such as particular weather, hydrographic condition, clock time and congestion. Most of them are heavily dependent on the ability of sensors [Rødseth, 2017].

For example, there are several kinds of visible sensor. A camera has advantages of object classification, object-edge precision and lane tracking in regular daytime operation compared to other sensors such as RADAR and LIDAR. However, they cannot work in the night or bad weather. RADAR is workable in even the night or bad weather. On the other hand, the capability of object classification, object-edge precision and lane tracking is limited. LIDAR is also workable in the night or bad weather and the capability is not poor. However, it is expensive. Each sensor has advantages and disadvantages. Therefore, a good and effective sensor fusion should be developed [Marks, 2018].

Network connectivity also influences the operation design domain for remotely controlled vessels, especially because they require significant data exchange with remote centres. For them, congestion of vessels can be the limitation for the operation design domain depending on the capacity of satellite network at that time.

The limitation of each equipment influences operation design domain for MASS.

Under a particular operation design domain, how much the operation tasks can be automated is the autonomous level.

1.2.2.3. Autonomous level

A classification of the autonomous level is the following, partial autonomous, remote control and fully autonomous. This specific topic has been discussed since MSC 98 and member States defined the autonomous level exactly in the framework for the regulatory scoping exercise as shown below:

A 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 a seafarer on board ready to take control

A 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 system and function.

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

A fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself [REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS), 2018].

In this thesis, the ship with automated processes and decision support will be defined as a partial autonomous vessel, the remotely controlled ship with seafarers on board will be defined as a manned remotely controlled vessel, the remotely controlled ship without seafarers on board will be defined as an unmanned remotely controlled vessel and the fully autonomous ship will be defined as a fully autonomous vessel. Moreover, a partial autonomous vessel and manned remotely controlled vessel are collectively called a manned autonomous vessel, an unmanned remotely controlled vessel and fully autonomous vessel are collectively called unmanned autonomous vessel, and a manned remotely controlled vessel and unmanned remotely controlled vessel are collectively called a remotely controlled vessel.

The detailed definition will be explained in the following sections.

1.2.3. Detailed definition of Maritime Autonomous Surface Ship

To understand MASS further, the detail definition of the concept should be illustrated because it is supposed that the system configuration varies depending on the degree of automation and companies developing the system.

While the automated tasks and domains for fully autonomous vessels will be extensive, those for manned remotely controlled vessels will be limited. Autonomous level correlates with the automated tasks and domains as Figure 3 illustrates that MASS development expands the degree of automation; autonomous tasks, domains and levels together [Twomey, 2018]

For example, at the beginning of the development of manned remotely controlled vessels, some of the operation tasks like maintenance of equipment and response to emergencies will be handled by seafarers on board with assists from a remote control centre [Kinthaert, 2017].

Also, the Manoeuver Control System will be equipped with on board. The input will be fully automated and put from the Autonomous System for fully autonomous vessels, although it will be put from humans at remote centres for manned remotely controlled vessels [Class Guideline Autonomous and remotely operated ships, 2018]

Name	Definition (Proposed Maritime Autonomy Framework)	Who is in Control? Sustained operational task	Who takes over control? Fail Safe Operational Task	System Capability
No Autonomy	All aspects of operational tasks perform by human operator even when enhanced with warning or intervention system. Human operator safely operates the system at all time. (e.g. Select pumps)	Manual		n/a
Partial Autonomy	The targeted operational tasks perform by human operator but can transfer control of specific sub-tasks to the system. The human operator has overall control of the system and safely operates the system at all time. (e.g. start engine sequence)	Automation		Some Operational Tasks
Conditional Autonomy	The targeted operational tasks perform by automated system without human interaction and human operator perform remaining tasks. Human operator is responsible for its safe operation.	Semi-Autonomous		Majority of Operational Tasks
High Autonomy	The targeted operational tasks perform by automated system without human interaction and human operator perform remaining tasks. System is responsible for its safe operation. (e.g. PMS, DP)	Semi-Autonomous		Majority of Operational Tasks
Full Autonomy	All operational tasks perform by an automated system under all defined conditions.	Full Autonomous		All Operational Tasks

Figure 3. Relationship between MASS development and the degree of automation. Copied from [Twomey, 2018]

Therefore, in this thesis, the degree of automation will also be referred to with the classification of autonomous level introduced in 1.2.2.3.

To expand the degree of automation, it will be needed to establish how to judge an abnormality of equipment in advance to maintain MASS automatically with the Monitoring System; how to avoid collisions with the Autonomous System; and how the network connectivity even on the high seas work well.

At least, until the task is justified to be automated equivalent or safer than conventional vessels, equipment and crews on board will still be needed to satisfy the present conventions.

After partial tasks under particular domains are justified to be automated, the tasks with equipment and crews for them will be removed from on board. In the degree of automation, the amendment of conventions enabling to remove them should be discussed simultaneously at IMO. Then, unmanned remotely controlled vessels will be put into practical use.

Moreover, if tasks are automated further and even remote controllers are not needed, fully autonomous vessels will be put into practical use. It will take a long time to establish a reliable system without remote controllers. For example, to develop algorithms to avoid collisions among more than two vessels needs to collect a lot of related data, analyse them and let the algorithm do self-learning about how to avoid collisions with others [In Artificial Intelligence Breakthrough, Google Computers Teach Themselves To Spot Cats on YouTube, 2012].

One of the biggest challenges to establish the algorithms are controlling at a congested area, detecting abnormality and failure of equipment and controlling in case of emergencies. The regulatory requirements for algorithms to replace remote operators should be discussed further in IMO [Marr, The Incredible Autonomous Ships Of The Future: Run By Artificial Intelligence Rather Than A Crew, 2019].

In the following sections, to make it possible to discuss technological and legal MASS development, “navigation” out of operation tasks for automation introduced in paragraph 1.2.2.1 will be illustrated as one of the examples.

1.2.3.1.Element of navigation system

Crew members carry out specific tasks to navigate their ships safely. First, they need to “detect its condition” with data from RADAR, AIS, ECDIS, CAMERA, LIDAR, other equipment and their five senses. They detect their position, their machinery condition and the object around the ship with the sensor fusion and “analyse its condition”. Then, they “plan actions” like avoiding bad weather and other vessels and establishing the maintenance plan for its equipment. Finally, they “control the actions” to follow the shipping plan as diagrammed in Figure 4 [Class Guideline Autonomous and remotely operated ships, 2018].

In the MASS system introduced in section 1.2.1, the Monitoring System detects and analyses the condition, the Autonomous System plans actions and the Manoeuver Control System controls actions.

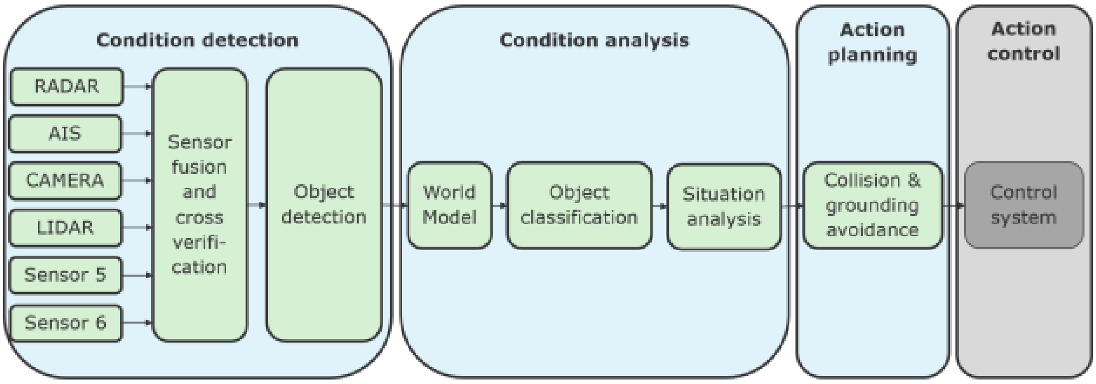

Figure 4. Element of Navigation. Copied from [Class Guideline Autonomous and remotely operated ships, 2018]

According to DNV-GL, each task can be performed by not only human but also by systems on board or even the combination of them as shown in Figure 5. Navigational officers on board conventional vessels must be present to carry out all of the condition detections, condition analyses, action planning and action control and the engineer also must be on board to ensure the reliability of the equipment. [Class Guideline Autonomous and remotely operated ships, 2018]

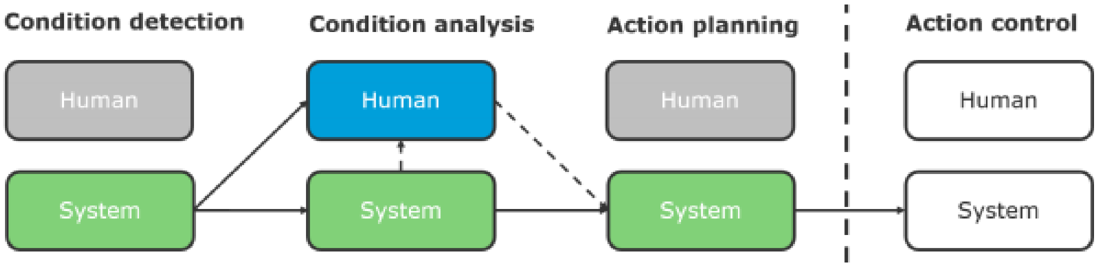

Figure 5. Sequence to Navigation

1.2.3.2.Condition detection

Most important issues in this task is to detect geography, bathymetry, fixed objects, floating objects, weather and conditions of equipment which may potentially affect the ship’s manoeuvrability, in an accurate and timely manner [Vartda, 2018].

Today, condition detection depends on information in advance, information from sensors and the human´s five senses. For example, SOLAS regulates coastal States to collect and provide meteorological data; and ship owners to equip AIS and ECDIS, to satisfy manning level of seafarers who look out and read the input from equipment, and to maintain equipment periodically [The International Convention for the Safety of Life at Sea, 1974]. The sensors and a central control centre, for its engine, are to reduce tasks for crews which are also introduced on board.

One of the keywords of condition detection for MASS is “redundancy”. Unlike conventional ships with crews, if the Monitoring System fails, it results in the loss of condition detection. Therefore, MASS needs to be redundant enough to safely adjust in case of failure [Technology Assessment :Autonomous Ships, 2018].

Information about a vessel´s position is also a crucial factor for its condition detection. Except for people, GPS has a significant role for it. However, vessels need to have alternative position detecting methods like another GNSS and gyro sensor to be automated, because even GPS can fail, or be jammed [Top 3 Positioning Challenges in Autonomous Marine Navigation, n.d.].

Sensors for not only its surroundings but also for its equipment are also crucial and need to be redundant because engineers might be also moved to onshore and they can only maintain its equipment at ports or in case of emergency if needed. This means that essential navigation function like propulsion and manoeuvrability will not be allowed to fail and be left to fail as it is [Komianos, 2018]. Sensors are required to assess the equipment and to report it if it detects its abnormality.

For MASS, the condition detection is the prerequisite of sound navigations as input for the whole tasks, and it is considered to be automated first [Class Guideline Autonomous and remotely operated ships, 2018].

1.2.3.3.Condition analysis

When relevant information has been detected, this information must be analysed for its situational awareness by crews or automatically. Adequate situational awareness requires that all detected conditions have to be classified, and any changes in each state have to be established such that feasible future states can be determined.

However, it is not easy to classify the objects. One indication example of algorithms to classify objects is Google AI enabling to distinguish cats from pictures developed in 2012. In the experiment, a thousand computers had been used to let the AI enable to distinguish cats for days [Oremus, 2012].

On the sea, there are many kinds of objects like other vessels, glaciers, sea creatures, fishing instruments and garbage under various situations where vessels are controlled such as night, heavy rain and dense fog. It will take time to develop the system enabling classify all of possible objects under every situation, and it should be prioritised.

In addition, the ability to analyse the equipment condition is also crucial. For example, how to judge abnormalities of its equipment in advance has to be established to maintain its shipping without catastrophic failure. For example, SOLAS regulation II-2/24 requires to maintain fire-fighting systems based on the IMO guidelines [The International Convention for the Safety of Life at Sea, 1974]. It will be required to incorporate the measures of the guideline to the algorithms to find the abnormality.

1.2.3.3.1. Condition analysis of remotely controlled vessel

Data shown to remote controllers might be different depending on the degree of automation from just showing the row data like the vision from the bridge, AIS and ECDIS to showing processed data. Besides, there will be several tasks not fully automated on board the unmanned remotely controlled vessels. Remote controllers have to understand their tasks and process the transferred data.

Condition analysis will depend on the remote controllers' skills as well as the seafarers. Therefore, corresponding to the responsibility between crews and remote controllers, the necessity of certification for them should also be considered. As long as they can understand it, the conditions are correctly analysed [Maritime autonomous surface ships, 2018].

Also, it should be considered how the data will be presented. One research item suggests that an operator needs a condensed and focused view with top-level indicators, but they should have a right to access detailed information to judge the situation correctly if they are desired to do so [Updated requirements to Bridge Alert

Management (BAM) in the Marine Equipment Directive (MED), 2017]. Remote controllers might process the transferred condition data and take action. Therefore, what information they can look at has a significant meaning and developers have to consider them taking action carefully but immediately in case of emergency.

Another issue is network connectivity. If the network connectivity is reliable and infinity, they can replicate all the information available on board at remote centres, and remote controllers can navigate vessels with them. The network connectivity required to transfer the information for one autonomous vessel might be as much as several tens of megabits per second depending on the sensors on board [Remote and Autonomous Ship The next step, 2016]. Although capacity through satellite network is already better than that, it is difficult to correspond to an incense of autonomous vessels. In addition to the technology revolution of satellites, it should be considered that not all data but needed data should be transferred after being processed on board to make the amount of data small.

On the whole, if the tasks will be remotely controlled, remote operators will have the responsibility for them principally. Therefore, the reliability of the Monitoring Systems has to be assured at a minimum.

1.2.3.3.2. Condition analysis of fully autonomous vessels

Unlike remotely controlled vessels, fully autonomous vessels have no remote controller who can process the condition analysis. Therefore, the Monitoring System has to analyse the data good enough to let the Autonomous System plan the journey [Class Guideline Autonomous and remotely operated ships, 2018].

One difficulty is that fully autonomous vessels cannot communicate with vessels around them and analyse their condition as remote controllers can do. An alternative measure is to require MASS system to change their programmed routes electronically. However, even if it is possible technically, there will still be problems to analyse the objects that do not share the information electronically like conventional vessels. Obstacles like glaciers, sea creatures, fishing instruments should also be considered.

Even now, some of the vessels like fishing boats turn off their AIS not to let others know their significant information like good fishery location and smaller vessels not equipped with AIS [Taconet, 2019]. Fully autonomous vessels should detect them and differentiate what they should avoid.

Thus, the remote controllers analysing condition will be also incorporated in the Monitoring System and the remote controllers will be removed for fully autonomous vessels, although some of the tasks, such as response to emergency, might be kept in remote centres [Class Guideline Autonomous and remotely operated ships, 2018]. The Monitoring System for fully autonomous vessels should be more reliable because the failure of condition analysis might result in incidents.

1.2.3.4.Action planning

Once the condition around the ship is detected and analysed, the course of action must be decided based on the Autonomous System as introduced at paragraph 1.2.1.3.

1.2.3.4.1. Action planning of remotely controlled vessel

The action planning will be carried out by the designated remote controllers. They can make decisions or approve decisions made by autonomous system based on analysed condition. Regardless of the degree of automation, the final decision will be approved by remote controllers for remotely controlled vessels, although there might be some crews on board.

In one project, remote controllers are required to have the competence and skills equivalent of those of traditional navigational officers [Class Guideline Autonomous and remotely operated ships, 2018]. Corresponding to the responsibility among crews and remote controllers, the necessity of certification should be considered.

1.2.3.4.2. Action planning of fully autonomous vessels

The action planning must be carried out by the Autonomous System based on the COLREG. CORLEG is established to prevent collisions at sea as rules of the road. However, COLREG does not cover every possible navigational situation. For example, rule 13 regulates overtaking among two vessels and rule 14 regulates head-on two vessels [Convention on the International Regulations for Preventing Collisions at Sea, 1972, 1972]. Specific traffic requirements for more than two vessels and concrete requirements such that how far vessels should initiate their collision avoidance are not stipulated in COLREG.

Today, they are conducted based on the good seamanship referred to in rule 2. However, it is difficult to spell out the good seamanship into the Autonomous System. Therefore, it might take a time until the degree of automation can proceed to full automation.

A measure to shorten the development is self-learning which can be based on programmed situations. Systems looking for hazards at sea have already been trained by millions of people using them, such as finding pictures of objects or hazards that ships might encounter at sea. In addition, real traffic cases while the vessels will be remotely controlled can also be contributed to the development [Marr, Rolls-Royce And Google Partner To Create Smarter, Autonomous Ships Based On AI And Machine Learning, 2017].

1.2.3.5. Action control

When the action is planned by remote controllers or the Autonomous System on board, this plan must be sent to the Manoeuver Control System.

The maintenance of its equipment is essential to control its action. EMSA concluded one fourth of incidents between 2011 and 2017 happened in its engine room [ANNUAL OVERVIEW OF MARINE CASUALTIES AND INCIDENTS 2018, 2019]. If there is no crew in attendance to carry out maintenance, it must be carried out at ports.

Although the engine powered by oil has been used for more than decades, there are still many incidents caused at the engine room because it has mechanical movements causing to abrade equipment. It is not easy to remove abnormalities from its engine. In addition, the mechanical structure needs maintenance periodically. A vessel with its engine needs to heat the pipes not to let oil cool down and solidified, to maintain motors to generate electricity for its accommodation, and to supply lubricating oil to maintain the mechanical structure.

Therefore, the possibility to replace its engine needing more efforts to batteries should be considered. One of the difficulties is the capacity of batteries. YARA Birkeland already plans to make their coastal autonomous vessel powered by batteries. However, its operation is for about 70 km, and it will be planned to put batteries storing 7 MWh on board [Tuman, 2018]. In this project, it was not revealed how long it takes to charge the vessel. To equip with batteries on board ocean-going vessels, a relation between the number of batteries and how long they need to be charged at ports still causes problems. The batteries must be much more efficient.

The cost of batteries is another challenge. Electricity cars, the leading battery powered vehicle, cost more than 1,000 USD per kWh to manufacture lithium-ion batteries in 2010, it has now fallen to less than 200USD per kWh in 2018 [Goldie-Scot, 2019]. However, it is not sufficiently cheap yet to replace gasoline-powered cars. Although the price of batteries depends on the characteristics and number of batteries on board, further cost reduction will be required for sea-going battery-powered vessels needing many batteries.

These are the reasons why battery-powered vessels are introduced in limited areas such as coastal shipping and domestic shipping [Why ships of the future will run on electricity, n.d.].

This is one of the examples to replace the equipment since it needs much maintenance. Not only ships' engines, but also all equipment should be subjects for maintenance free between ports at a minimum.

As a summary of sections 1.2.3, Figure 6 is an example of the remotely controlled vessels when navigating. Both vessels and remote centres have roles for its navigation and interact with each other.

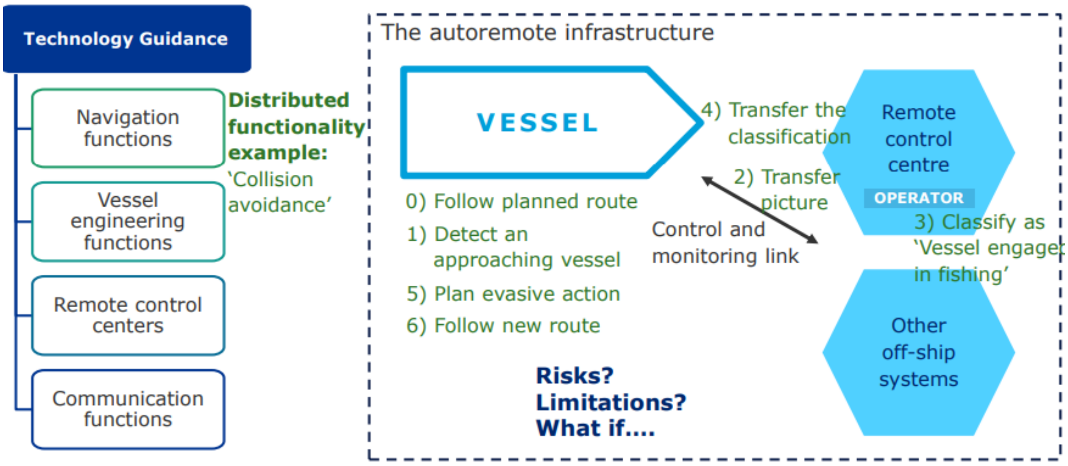

Figure 6. Example of automated navigation. Copied from [Andersen, 2018]

1.3. Why Maritime Autonomous Surface Ship is being needed

MASS has been considered as one of solutions for problems written between paragraphs 1.1.2 and 1.1.5. It can prevent or deter the humans´ erroneous actions and detect machinery errors in advance.

Seafarers might be moved to onshore, or even replaced by MASS, with the result that they can contribute to the growing demand of seafarers and making seafaring a more attractive occupation.

The replacement of seafarers is beneficial for ship owners from the perspective to cut the cost for seafarers' salary, as well as to reduce the opportunity losses because of diminishing ship incidents. If the Monitoring System can detect the abnormities of its equipment, and they can be fixed in advance, the possibility to be detained by port state control officers will also be minimized, which can also contribute to the benefits of shipowners. Also, the Monitoring System can also optimise the shipping operation in terms of shipping routes.

Notably, the monetary benefit can encourage shipowners to introduce it. Therefore, the benefits shall be analysed further in the following section.

1.3.1. Economic benefits of Maritime Autonomous Surface Ship

Costs for ships consist of personnel, port charges, banker consumption, lubricants, repairs, maintenance and insurance, mainly [Costs, Revenue and Cashflow, n.d.]. As a typical ship operating cost distribution, fuel costs account for 40%, port charges 20%, personnel 10%, and repair 10% [Maersk and digital revolution in shipping industry, 2017].

One of the measures to cut ship operating costs was the gigantism of ships, historically. Increased capacity of cargo ships can reduce the costs per unit. Gigantism of container ships started when the first container ship named “Gateway City”, which sailed from port Newark to Miami in 1957 for the first time, was built [CUDAHY, 2006]. The tonnage of the biggest container ship grew five times as big as what it was 30 years ago, and this gigantism has contributed to cut costs for shipping [Maritime gigantism, a risky turning point for insurers, 2018].

On the other hand, some researchers insist that it is not easy to build ships which can be loaded with more containers because major canals have depth limitations, and the height, outreach and movable range of the cranes equipped in terminals are limited [Pursuing economimc efficiency by gigantism and strategy of MOL, n.d.]. It is not impossible to enhance the capacity of the facilities; but it needs many additional investments. In addition to the monetary investments for the port facilities, there are many stakeholders at ports and it tends to take a long time to make an agreement among them, put it on the port plan and build the facilities [Natsuhiko Otsuka, 2015].

If shipping can be automated, it will be possible to decrease the number of seafarers and stevedores, to remove equipment on board like accommodations and life-saving appliances, and to decrease the number of incidents. Rolls-Royce calculated it and estimated up to 20 % operation cost saving [Eloranta, 2018]. The total cost efficiency depends on many factors such as type, size and technology of the ship. However, one of the researches illustrates the expected present cost of owning and operating an autonomous bulker over 25 years is 4.3 million USD cheaper than a conventionally manned ship [Kretschmann, 2017]. How to build a cost effective MASS system should be further discussed in the following IMO meeting.

The cheaper shipping will be beneficial not only for shipowners suffering from their depression but also consumers, because some products like a part of agricultural products which are not affordable enough to be transported from production areas and consumed might be transferred in the future.

1.4. Why legal issues relating to the Maritime Autonomous Surface Ship development and introduction to service is important

MASS technological development has close relations with legal issues because the regulations enacted tend to reflect an understanding of yesterday's technologies [Eggers, 2018].

The accidents of Boeing 737 MAX 8 happened in Indonesia in 2018 and Ethiopia in 2019, killing more than 300 people [Ellis, 2019]. It was said that the accidents were caused by the "Manoeuvring Characteristics Augmentation System (MCAS)". The failure of the pitot tubes calculating the aircraft's speed influenced MCAS, and it pushed the nose of the planes down sharply [TRAVIS, 2019]. At that time, the fact that the Boeing regulation trusts pilots, rather than the system, is different from Airbus. However, the Boeing system did not allow itself to be overridden by pilots unlike the conventional Boeing systems, and the nose of the plane kept going down.

It is not easy to decide whether humans or the system should be trusted. Also, although remotely controlled vessels will rely on the crews or remote operators, fully autonomous vessels will rely on the "system". It is important that all stakeholders should understand the limitations of technology and reflect them on their regulation through the IMO discussion.

Figure 7. Boeing 737 MAX 8. Retrieved from [Young, 2019]

Furthermore, MASS technological development cannot be achieved at once. There are several degrees of automation; the operation task, operation design domain and automation level, and they should be expanded correspondingly to the degrees.

Considering that MSC 98 decided to discuss intensively regulatory scoping exercise to make it possible to develop MASS technology with applicable regulations, it is important to amend regulations corresponding to the degree. Otherwise, for example, unmanned remotely controlled vessels have to equip with accommodation facilities, and there is no requirement for remote centres.

1.5. Research question and the methodology of this thesis

There are several projects to develop MASS, and each of them defines the degree of automation. Although IMO also defined it in 2018, there is no uniform MASS development roadmap.

In this thesis, the MASS system and IMO´s definition of the degree of automation were already introduced, and each MASS development project will be scrutinised and summarised against the IMO definition of the degree of automation. The discussion is then "what legal issue relating to MASS will be caused depending on the degree of automation and how MASS will be put into practical service".

In chapter 2, the MASS development until now will be introduced. The MASS project explaining how to develop MASS will also be introduced. Several projects have published guidelines, and the press releases will be examined. Then, based on the development plans, the roadmap of MASS development will be illustrated.

In chapter 3, the legal discussion about MASS was held at IMO until now and will be summarised. Then, the IMO regulation will be reviewed. First, some requirements from SOLAS and COLREG will be reviewed to show how to review the regulations. The amendment will be classified into:

(1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated

(2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated

(3) About information which should be informed to a Master or crew on board conventional vessels

Then, SOLAS chapter II-1 will also be examined. Based on the result of the examination, it will be revealed what legal issues related to MASS will be caused depending on the degree of automation and how MASS will be put into practical service.

In chapter 4, as a conclusion, the legal MASS development incorporating in the roadmap of the technological MASS development will be suggested.

In chapter 5, suggestions against the present IMO discussion will be introduced, and the topics which cannot be introduced in this thesis will also be introduced.

2. Technological development of MASS

2.1. History of development of Maritime Autonomous Surface Ship

The development of MASS started in Japan in the 1960s. At the beginning of the project, they intended to decrease the number of crews down to nine. Then, they intensified the focus on MASS in the 1980s. The concepts of the route optimising system, autonomous berthing system and collision avoidance system were developed at that time. However, the degree of accuracy of sensors and the network connectivity were limited, and the crews also had negative opinions on MASS under the fear of losing their jobs, which made it difficult to put MASS into practical use [FUKUTO, 2017].

Recently, following the development of self-driving cars and the growth of IoT and ICT technology, accurate sensors and extensive network connectivity have been developed. As well as other kinds of vehicle, the MASS development was resumed in especially the Northern Europe and East Asia [MLIT, 2016].

2.2. Recent developments of Maritime Autonomous Surface Ship

“Partially autonomous vessels have already been put into practical use. For example, SOLAS chapter IV/19 stipulates that “All ships of 10,000 gross tonnage and upwards shall have a heading or track control system, or other means, to automatically control and keep to a heading and/or straight track” [Convention on the International Regulations for Preventing Collisions at Sea, 1972, 1972]. Although a Master is still responsible for controlling ships all, there is equipment to support controlling vessels.

Even now, the degree of automation is uneven depending on the tasks, domains, types and size of ships. In the United Kingdom and Japan, remote controlled survey ships were already put into practical use as well as warships for naval missions in the United States, as shown in Figure 8 [DuffieJr, 2017].

In addition, there are several MASS development projects between coastal autonomous vessels, local autonomous vessels and ocean-going autonomous vessels.

In the following sections, several continuing projects, especially focusing on their MASS development plans, will be introduced.

Figure 8. Sea Hunter. Copied from [DuffieJr, 2017]

2.2.1. Yara Birkeland project

The dimension of this autonomous vessel is 79.5 meters length, 14.8 meters width and 6 meters draught. Also, it is battery powered, and all operations between Heroya, Brevik and Larvik among the Norwegian coastal area are automated including loading, unloading, berthing and manoeuvring to replace cargo trucks.

Kongsberg leads this project with Yara international, SINTEF, and Marine Teknikk. They planed that the design was finalized and testing model ship was constructed in 2017, the shipyard for construction was decided on the beginning of 2018, and it has currently been constructed. They will start its operation gradually with a minimum manning and the transition from manned to unmanned will be planned by 2022 [Rustand, 2018] [Yara International, 2018].

2.2.2. Advanced Autonomous Waterborne Applications initiative project (AAWA)

This project aims to complete a basic design and basic specification for unmanned vessels as shown in Figure 9. Many participants around Rolls-Royce from shipbuilding companies to universities have discussed not only the sensors, systems and network elementally, but also a roadmap to put MASS into practical use. This project divides the MASS development and roadmap into two fields, coastal waters and international waters.

In the beginning, they tried to make the domestic ferry automated. Following AAWA, Rolls-Royce and Finferries successfully demonstrated the world's first fully autonomous local ferry in Finland. The car ferry Falco was equipped with the combination of Rolls-Royce Ship Intelligence technologies on board and the remote operating centre, it has successfully been navigated autonomously between Parainen and Nauvo. The return journey was navigated under its remote control as a part of a new project called SVAN [Rolls-Royce and Finferries demonstrate world' s first Fully Autonomous Ferry, 2018].

They plan to develop autonomous ocean-going vessels until 2035 and its roadmap is shown in Figure 10 [Autonomous ships The next step, 2016].

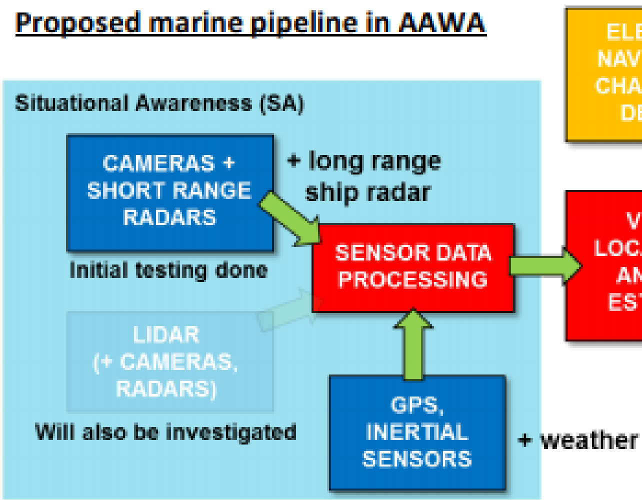

Figure 9. System of AAWA. Copied from [Remote and Autonomous Ship The next step, 2016]

Figure 10, Roadmap of AAWA. Copied from [Autonomous ships The next step, 2016]

2.2.3. DNV-GL project

In addition to the ReVolt project for short sea shipping and the AAWA project lead by Rolls-Royce and DNV-GL being involved with it, this classification society also established a class guideline called “Autonomous and remotely operated ships” containing methods, technical requirements, principles and acceptance criteria [Class Guideline Autonomous and remotely operated ships, 2018]. This is not a MASS development project but summarizes the MASS system. They explicitly separate remotely controlled vessels, and fully autonomous vessels as illustrated in Figure 11.

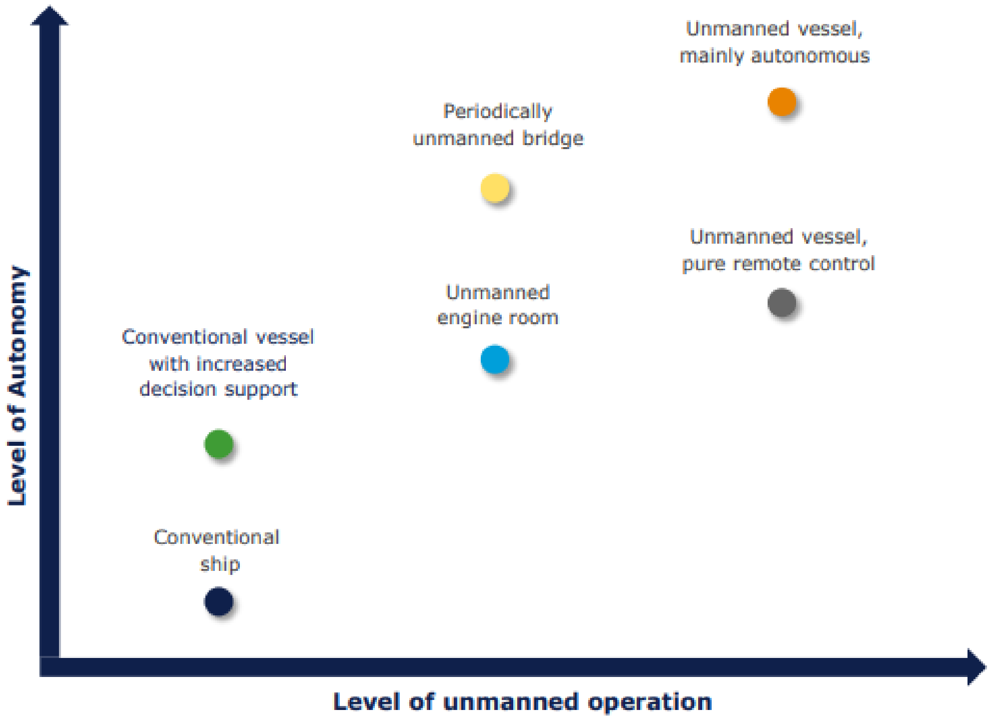

Figure 11. The degree of automation by DNV. Copied from [Andersen, 2018]

Basically, they consider it will be possible to establish classification rules through close cooperation with the MASS developers, but not alone. Therefore, the roadmap is also abstract relatively, such as in Figure 12.

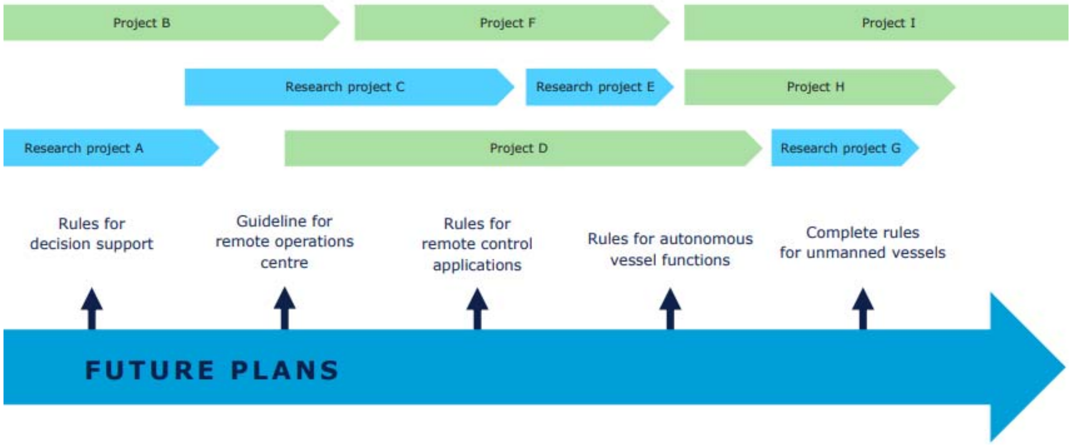

Figure 12. Roadmap of DNV. Copied from [Andersen, 2018]

2.2.4. Japanese Maritime Administration

The Japanese Maritime Administration divides the beginning part of MASS development in detail. Automation phase one is to collect data from sensors, analyse it, propose optimum routing, detect abnormalities of its engine and inform them with crews. However, it will cover partial tasks on board. Automation phase two is to analyse it further, to integrate equipment, propose optimum operation and present information visually to choose preferred options. It will cover more parts of tasks on board. Remotely controlled vessels can also be considered as a part of this phase. However, the final decision will still be made by humans.

Automation phase three is to develop an appropriately functioning system under any traffic circumstances, weather condition and in berthing or de-berthing. The final decision is to be made without seafarers.

They plan to develop phase one until 2020, phase two until 2025 and then proceed to phase three [International Network for Autonomous Ships, n.d.].

2.2.5. Stakeholders' intended purpose of Maritime Autonomous Surface Ship development

Until today, there are many projects not only introduced above. The stakeholders intended purpose depends on their perspective. Shippers, ship building companies and equipment suppliers purely aim at “technology improvement” and “boost confidence”. For classification societies, they contribute to ship building companies and aim at standardising new technology. For administrations, they aim at optimising the whole development of new technology with R&D funding and rule-making. Every stakeholder contributes to MASS development, and the combination of each stakeholders’ plans creates the roadmap of MASS development.

2.3. Roadmap of development of Maritime Autonomous Surface Ships

The budget of MASS projects, including projects introduced in paragraph 2.2, reached 6.1 billion USD and is predicted to reach 13.8 billion USD in 2030. The factors expected to fuel the growth of MASS development are an increase of seaborne trades, compliance with maritime safety regulations and the growth in maritime tourism [Singh, 2019].

Based on the recent MASS development plans introduced in chapter 2.2, the MASS development can be summarised as in Figure 13. The degree of automation should be expanded correspondingly to development and reliability of the technology, and it will proceed step by step.

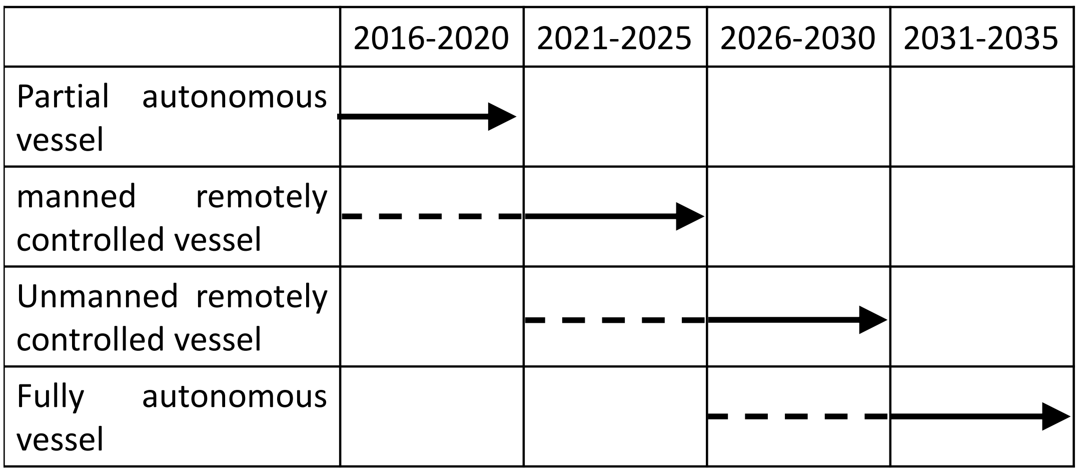

Figure 13. Future MASS development. Compiled by Author.

2.4. Procedure of Maritime Autonomous Surface Ship development

On the way of MASS development, first, all tasks of condition detection, condition analysis, action planning and action control, will be developed to be automated for each element. Some of them are put into practical use as auto tracking system and auto berthing system. However, these elemental developments work independently. For example, a present auto tracking system will not detect and avoid obstacles, and it just follows a programmed plan.

Then, each elemental development will be integrated and developed as one system. However, there will still be some tasks and domains which cannot be automated, such as repairs of equipment and emergency responses. Crews will still be needed on board.

Corresponding to the degree of automation, the tasks and domains automated will be expanded. When most of the tasks are automated under most domains, vessels can be controlled by remote controllers without seafarers on board [Xiao, 2019].

Meanwhile, it is supposed that algorithms for condition analysis and action planning independently from remote controllers will be developed. For example, while vessels will be controlled remotely under remote controller's surveillance, the algorithm of action planning can do self-learning through realistic examples. When the algorithm is reliable enough to replace remote controllers, the vessels will be fully automated [Schubert, 2018]. This procedure is illustrated in Figure 14.

Today, the elemental development for MASS is already established. However, further developments, for example, batteries and the artificial intelligence to manoeuver at a congested area, are still needed. On the basis of those elemental developments, the technological integration to work as a system for MASS will also be needed. Finally, the reliability of the system should be improved further because there will be no crew on board to cope with the troubles.

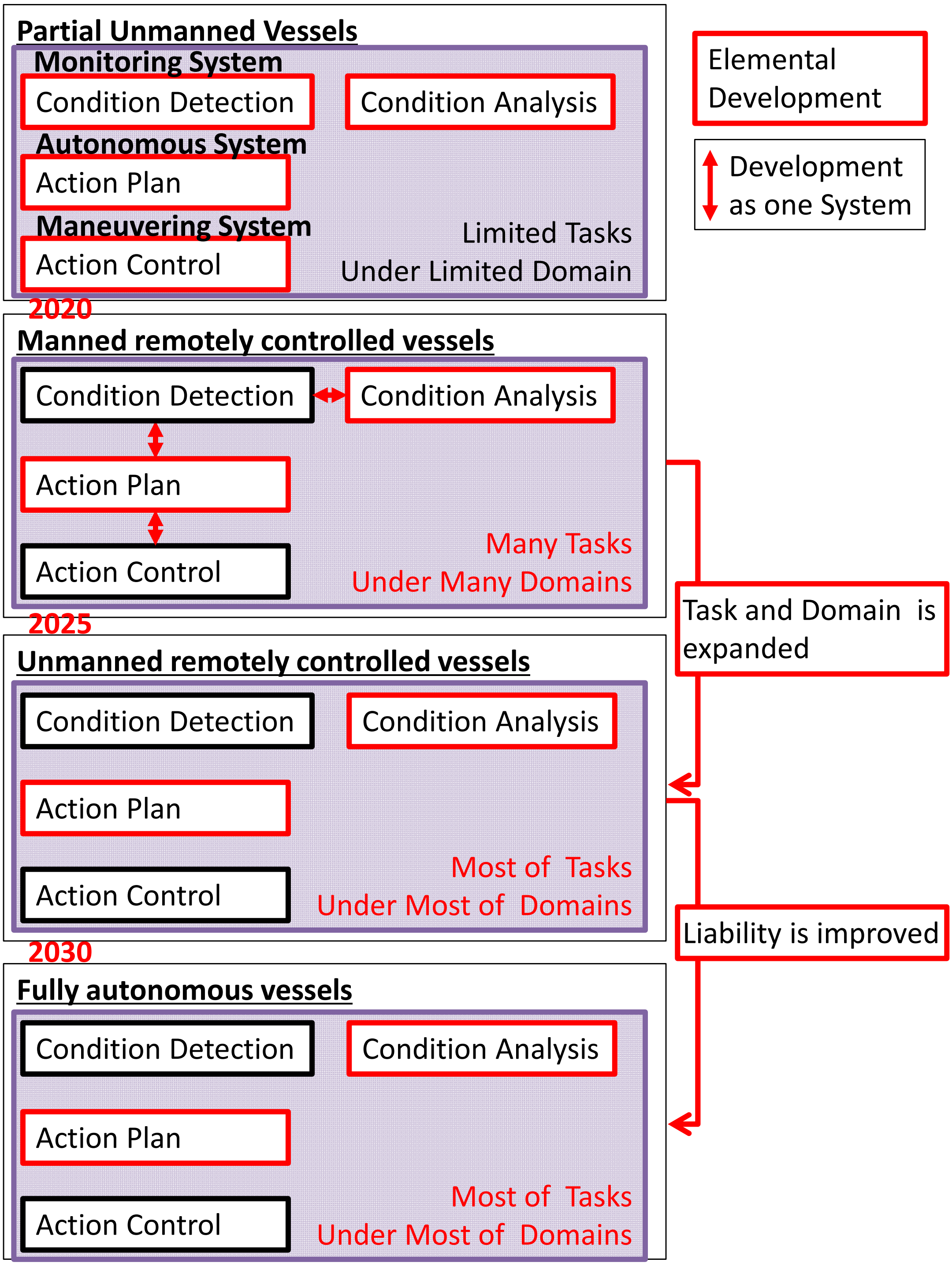

Figure 14. The procedure of MASS development. Compiled by Author.

Also, as introduced in paragraph 1.2.2, there are three axes to illustrate the degree of automation. The degree of automation will expand following this procedure, as also shown in Figure 15.

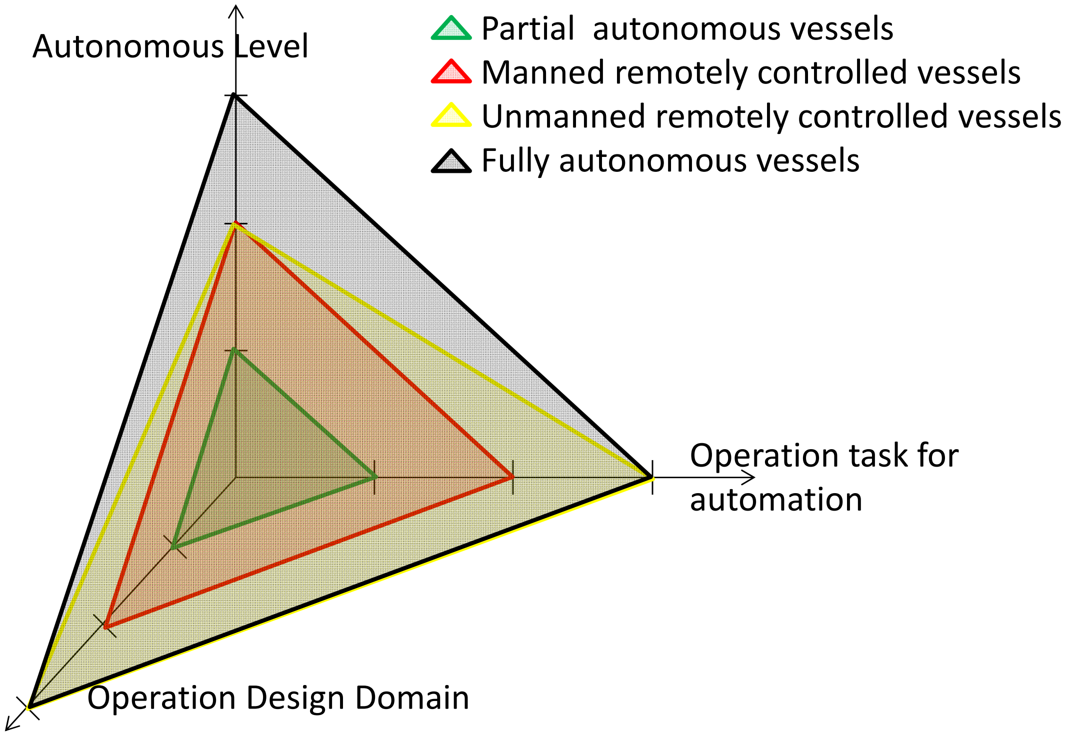

Figure 15. The degree of automation. Made by Author.

As introduced in chapter 1.4, it is important to make it possible to develop MASS technology with applicable regulations corresponding to the degree and to understand the technology among all stakeholders through the IMO discussion. In the following sections, the legal developments will also be introduced.

3. Legal development of Maritime Autonomous Surface Ship

3.1. International conventions related to Maritime Autonomous Surface Ship

MASS relates to international conventions such as SOLAS including ISPS and ISM, MARPOL, STCW, MLC and COLREG. At the beginning of MASS development, when partial autonomous vessels are developed, it is not considered to need to amend conventions so much such that IMO encouraged member States to consider remotely controlled vessels rather than partial autonomous vessels in regulatory scoping exercise for the use of MASS [REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS), 2018].

In the latter part of MASS development, many of these conventions should be processed and amended so much. For example, it is considered that SOLAS should be amended to remove the visual and audible alarm from on board and to change framework of fire-fighting, ISPS should be amended for proper security measures without crews, STCW should be amended for the training and certificate for personnel in remote centres, and COLREG requiring a proper look-out by sight and hearing should be amended to consider the situation under autonomous operation.

Although some regulations such as SOLAS regulation I/5, II-1/55, II-2/17 and III/38 stipulate provisions relating to equivalents, which refers that “the administration may allow any other fitted or carried, or any other provisions to be made in that ship”. It needs to be communicated to IMO and takes a time. To put ocean-going MASS to practical use efficiently, it is important to amend concerned conventions at few times corresponding to the degree of automation. Furthermore, it should be minimum standards as the contemporary conventions specify minimum standards [Dalaklis, 2017].

3.2. Discussion at IMO

At MSC 98, the competent authorities decided to start a discussion about the framework for the regulatory scoping exercise. At MSC 99 and 100, they deepened the discussion about the framework. The latest document defines MASS with four types as introduced in paragraph 1.2.2.3. Also, they proceeded to classify the rules and regulations in IMO instruments into:

A Apply to MASS and prevent MASS operations.

B Apply to MASS and do not prevent MASS operations and require no actions.

C Apply to MASS and do not prevent MASS operations but may need to be amended or clarified, and/or may contain gaps.

D Have no application to MASS operations.

In this context, for example, the requirement so difficult to attain the equivalent or safer for MASS can be referred to as A; the requirements not influenced by automation like structural requirements or influenced by automation, but the technology is not developed enough for the degree of automation, can be referred to as B; the requirement influenced by automation, and the technology is developed enough for the degree of automation, can be referred to as C; and the requirements not regulating MASS such as the requirements for seafarers can be referred to as D.

Then, they will analyse each requirement for each degree of automation to determine the most appropriate amendments.

At both identifying and analysing phases, procedures consist of volunteer States initial reviews or analyses, the member States commenting on them, volunteer States considering the comments and the committee's final consideration, following the schedule shown in Figures 16 and 17 [REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS), 2018].

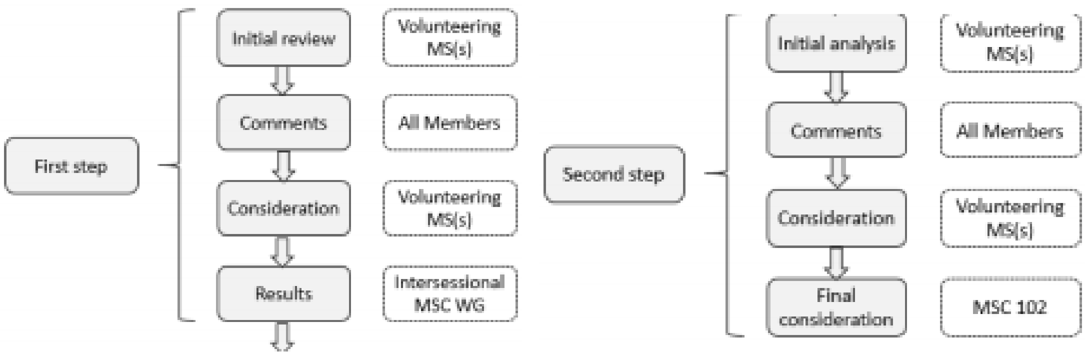

Figure 16. Regulatory discussion procedure at IMO. Copied from [REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS), 2018]

Action	Deadline	Who?
Upload of the initial review of IMO instruments	April 2019	Volunteering Member State(s)
Commenting stage related to the initial review	May/June 2019 (two months)	All IMO Members
Consideration of comments and presentation of results	July 2019 (one month)	Volunteering Member State(s)
Consideration of the results of the first step	[2 to 6 September 2019]	[Intersessional MSC working group]
Analysis of the most appropriate way of addressing MASS operations (second step)	September/October 2019 (two months)	Volunteering Member State(s)
Commenting stage related to the initial analysis	November 2019 (one month)	All IMO Members
Consideration of comments and presentation of results	December 2019/January 2020 (two months) – deadline for submissions to MSC 102	Volunteering Member State(s)
Final consideration	May 2020	MSC 102

Figure 17. Regulatory discussion schedule at IMO. Copied from [REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS), 2018]

Then, the IMO regulation will be reviewed in following sections. First, some requirements from SOLAS and COLREG will be reviewed to show how to review the regulations with the above classification.

3.3. Example of the amendment review

How to amend the regulation should be analysed from every perspective such that who has a responsibility to control the vessel, whether there are still crews on board, and what equipment is still on board or removed if deemed unnecessary.

In any case, the amendment needed will vary corresponding to the degree of automation.

3.3.1. SOLAS chapter III/17-1 Plans and procedures for recovery of persons from the water

For example, SOLAS III/17-1 regulates about the recovery of persons from the water. According to that, all ships must be in possession of plans and procedures for the recovery, taking into account the guidelines developed by IMO. These plans and procedures (which do not need to be approved by the Administration) are to identify the equipment intended to be used for the recovery purposes and measures to be taken to minimise the risk to shipboard personnel involved in recovery operations [The International Convention for the Safety of Life at Sea, 1974].

Basically, this regulation does not let it mandate to recover persons to the ship but consists of two factors, procedures for recovery identifying the equipment and the safety of shipboard personnel.

Although it is not clarified what type of crews will work on board manned autonomous vessels, the number of crews might decrease depending on the degree of automation. If there are still humans on board, they might be equipped with life-saving appliances and the procedures for the recovery can then be carried out sufficiently and this regulation will not prevent a MASS operation [Recovery of Persons from the Water, 2014].

From a different point of view, the autonomous equipment to recover persons might be developed and replace life-saving appliances with it while the remotely controlled vessels are operating. However, there is no crew on board the unmanned autonomous vessels. In this case, it might be also necessary to discuss how the distressed persons should be treated after being recovered.

3.3.1.1. Treatment for distressed persons

The fact that there is no crew on board causes an issue. A guideline for cold water survival is referred to in SOLAS chapter III/17-1, which requires the treatment of any human survivors in even case that there is no accommodation on board MASS [GUIDELINES FOR THE DEVELOPMENT OF PLANS AND PROCEDURES

FOR RECOVERY OF PERSONS FROM THE WATER, 2012]. As the accident of MV Titanic is remembered, the distressed persons in the cold water need rapid treatments.

Whatever measures MASS may introduce for recovery, treatments will be needed for them if the distressed persons are to be rescued on board MASS. Unless MASS operations are limited, every situation, including cold water, is predictable. It requires MASS to be equipped with treatments for them including accommodations, drinks and foodstuff.

For example, the AAWA project plans to repair the equipment on board at ports, and does not plan to arrange crews on board. It should be discussed what kind of treatments should be on board at least. From the perspective that MASS has to be as safe as conventional ships at least, it cannot be allowed to recover persons on board ship without enough arrangements for treatments.

If developers can invent the safe and affordable autonomous recovery system and provide treatments on board MASS, shipowners might be able to rely on the system, and SOLAS chapter III/17-1 has to be amended only not to consider the risk to shipboard personnel involved in the recovery operations.

If it is challenging to take care of distressed persons on board MASS, another measure should be considered.

3.3.1.2.New recovery scheme

MASS should be able to detect objects and also be good enough to distinguish persons in the water. Also, MASS has remote centres enabling it to send signals to search and rescue centres or ships around it. In response to the signal, it can dispatch vessels and recover people in need.

In this case, although the procedure for each shipping company has to be revised, SOLAS chapter III/17-1 might not be amended. However, this may worsen the risk because it will take time to rescue people in need.

It should be discussed how equivalent safety to conventional ships should be attained; for example, whether it is enough to dispatch a life-lift and dispatch vessels from search and rescue centres.

These types of issues will always be raised in the regulatory scope exercise, and every stakeholder has to conclude the optimal measure by factoring in the safe, feasible and economic points of view.

3.3.1.3.Discussion at IMO

In the IMO discussion, the voluntary States evaluated B among the classification introduced in paragraph 3.2 for manned remotely controlled vessels. Also, they evaluated C for unmanned autonomous vessels because they consider that "a principle discussion on whether SOLAS chapter III/17-1 should be applicable to MASS without persons on board is required." In other words, the necessity of this requirement for MASS is still under debate. One State insisted "trained personnel would be needed to be on board which prevents MASS when no seafarers are on board" [GISIS, 2019].

It is difficult to conclude the necessity among even IMO member States now. After the identifying phase, every possibility should be considered and reach to an agreement among stakeholders.

3.3.2. COLREG

Remote controllers and the Autonomous System for fully autonomous vessels have to fulfil the Masters' or crews' role relating to COLREG which regulates how to navigate and prevent collisions at sea through regulations for manoeuvring, look-out and navigation lights. In the following sections, the most important COLREG requirements in this case will be examined.

3.3.2.1.Collision avoidance

Under COLREG, how to avoid collisions between two ships is regulated in COLREG rule 13 for overtaking and rule 14 for head-on situation. On the other hand, there is no particular regulation to avoid collisions among more than two ships. As a general provision, COLREG rule 2 stipulates that "Nothing in these Rules shall exonerate any vessel, or the owner, Master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case". The traffic rule among more than two ships has to be based on this good seamanship [Convention on the International Regulations for Preventing Collisions at Sea, 1972, 1972].

Seamanship is considered as knowledge and skills pertaining to the operation, navigation, management, safety, and maintenance of vessels. According to the maritime accident tribunal, half of the maritime accidents relate to good seamanship [TAKEMOTO, 2015]. The good seamanship is raised by their experiences, and it is not the same exactly for every ship under every situation. Therefore, it is not easy to incorporate common good seamanship into the Autonomous System.

For real, in an experiment with one of the typical algorithms of the Autonomous System, two ships could avoid collisions each other but four vessels could not avoid collisions if each ship headed to the one point [Matsuda A. , 2017]. COLREG has to consider to avoid collisions among more than two vessels descriptively because there will be conventional vessels and MASS, and conventional vessels have to be included in the Autonomous System.

At the IMO discussion, the voluntary States evaluated C for rule 13 and rule 14 for every autonomous level to exclude the terms "assume" and "doubt" containing anomalies because it was noted these regulations seem clear enough to regulate MASS [Rule 13 Overtaking, 2019] [Rule 14 Head-on Situation, 2019]. The voluntary States also evaluated C for rule 2 and referred to "whether a system would be able to act by the ordinary practice of seaman" [Rule 2 Responsibility, 2019].

It takes a long time to conclude the regulation for the Autonomous System for more than two vessels. While the technology will be developed, it should be discussed further, and the direction of the development should also be debated in detail.

3.3.2.2.Look-out

Furthermore, COLREG rule 5, stipulating that every vessel shall at all times maintain a proper look-out by sight and 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 of the risk of collision, will also be controversial [Convention on the International Regulations for Preventing Collisions at Sea, 1972, 1972].

Cameras, RADAR and LIDAR are being developed to replace look-out crews. However, this provision requires human sight and hearing for look-out.

It is considered that the insight of high vision camera has 0.5 vision, which is an almost minimum in-service eyesight standard for seafarers regulated in STCW Code table A-I/9 [International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, 1978].

The auditory instrument should also be equipped with on board MASS. SOLAS chapter V/19.2.1.8 stipulates that “when the ship's bridge is totally enclosed and unless the administration determines otherwise, a sound reception system, or other means, to enable the officer in charge of the navigational watch to hear sound signals and determine their direction” [The International Convention for the Safety of Life at Sea, 1974]. Even now, seafarers do not need to hear sounds outside directly such that the sound reception system can transfer the sound to seafarers.

In the IMO discussion, the voluntary States also evaluated C for rule 5 for unmanned autonomous vessels to replace the terms “by sight and hearing”. However, there are a few member States having concerns about whether MASS could maintain a proper look-out using sight and hearing devices. In other words, most of the member States suppose the sensor fusion will meet the equivalent standard for seafarers.

3.3.2.3. SOLAS chapter V/19.2 Carriage requirements for shipborne navigational systems and equipment

In this section, shipborne navigational equipment will be examined. Depending on the degree of automation, the equipment will also be installed in remote centres and provide the equivalent information to remote controllers [Weintrit, 2017]. However, the navigational equipment on board will still be kept because it needs interfaces for seafarers on board to take over the role to control the ships in case of emergencies. Therefore, a few regulations for navigational equipment on board manned remotely controlled vessels have to be amended, while regulations for navigational equipment in remote centres are established.

Then, after most of the navigational equipment will also be installed in remote centres and the regulations are amended not to need seafarers on board, an unmanned remotely controlled vessel will be operational and remote operators will have a responsibility for its navigation.

Moreover, if the action can be planned by non-remote controllers but rather the Autonomous System on board, the vessel will be a fully autonomous vessel and the navigational equipment in remote centres will not be necessary in regular operations.

However, tasks such as responding to emergencies might be kept in remote centres. It should then be discussed what tasks should not be fully automated and what navigational equipment should be kept in remote centres [Xiao, 2019] [Schubert, 2018].

In the IMO discussion, the voluntary States also evaluated C for manned remotely controlled vessels to establish requirements for remote centres but evaluated A for unmanned autonomous vessels. They consider that “the current carriage requirements are based upon the premise that seafarers operate on board the ship. For unmanned ship, the premise changes, and reconstruction of the regulation is required” [Regulation V/19 Carriage requirements for shipborne navigational systems and equipment, 2019]. Approximately, half of the States agree with the idea, and the remaining considered it possible to amend the present requirement. However, both sides do not refer to how to reconstruct the new requirements or amend the present requirements.

It will take more time to conclude the regulations about navigational equipment in remote centres. While the technology will be developed, it should be discussed further, and the direction of the development should also be discussed.

3.4. The amendment review of SOLAS

Most of the requirements introduced in section 3.3 need to be amended; they are classified into:

(1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated;

(2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated;

(3) About information which should be informed to a Master or crew on board conventional vessels.

Every classification of amendment seems to have its characteristics. To examine the characteristics further, in the following sections, SOLAS chapter II-1 will be looked into. SOLAS clearly holds a pivotal role for maritime safety issues and it will be one of the conventions which should be amended to put MASS into practical use [Dalaklis, 2017]. Also, to examine SOLAS chapter II-1 regulating ships' construction makes it possible to suppose the condition of its bridge and equipment and also to consider the role of crews to examine STCW; and to suppose the ability of the Manoeuver Control System, Monitoring System and Autonomous System and also to consider the amendment of COLREG [The International Convention for the Safety of Life at Sea, 1974].

The requirements in SOLAS chapter II-1 considered to apply for MASS and need to be amended in IMO discussions will be picked up; they will be classified into (1), (2) and (3). Simultaneously, it will be revealed what legal issue relating to MASS will be caused depending on the degree of automation.

3.4.1. Chapter II-1 Construction – Structure, subdivision and stability, machinery and electrical installations

Most of the provisions in SOLAS chapter II-1 relate to ship design like structure, subdivision, machinery installation and electrical installation. In detail, the Code such as the Code on noise levels on board ship, IS and IGF also stipulates further in addition to SOLAS.

3.4.1.1. Regulation 3-4 emergency towing arrangements on tankers

This regulation regulates tankers of not less than 20,000 tonnes deadweight to have an emergency towing arrangement [The International Convention for the Safety of Life at Sea, 1974].

For manned autonomous vessels, as long as there is enough equipment used by crews for the safety, they can decrease the risk. Therefore, this kind of regulation should not be amended.

However, for unmanned autonomous vessel, it should be discussed whether this is applicable because there is no seafarer to be saved in case of emergencies. However, it should still be considered a tankers draft has a significant risk in its surroundings. Therefore, this should be applicable even for unmanned autonomous vessels. SOLAS chapter II-1/3-4.2.2 stipulates about an emergency towing procedure, which needs a complex procedure to tow and to be towed. Therefore, it is not enough just to stipulate to be equipped with emergency towing arrangements on board. It should be considered how unmanned vessels should avoid drafting.

The AAWA project refers to options like just slowing down its speed, stopping or autonomously heading back to the safe area in case of emergencies [Remote and Autonomous Ship The next step, 2016]. If these measures are feasible, this requirement might be replaced with them. If they are not feasible, another measure not to draft should be discussed.

In the IMO discussion, the voluntary States also evaluated C for unmanned autonomous vessels to redraft this requirement to consider no crew on board to take emergency towing actions [Regulation II-1/3-4 Emergency towing arrangements and procedures, 2019]

Also, its classification should be (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated.

3.4.1.2.Regulation 3-9 Means of embarkation on and disembarkation from ships

This regulation regulates the embarkation on and disembarkation from ships, especially gangways and accommodation ladders to save the life of crews and inspectors [The International Convention for the Safety of Life at Sea, 1974].

In that kind of meaning, for manned autonomous vessels, as if the ship is automated, this regulation will be needed and will not need to be amended as long as there are crews on board.

For unmanned autonomous vessels, the accommodation will be removed as well as accommodation ladders. However, there will still be personnel on board to repair or to inspect its equipment, and it will be difficult to remove all of embarkation equipment such as gangway. Therefore, this regulation should be amended partially but still be applicable to unmanned autonomous vessels.

In the IMO discussion, the voluntary States also evaluated C for unmanned autonomous vessels [Regulation II-1/3-9 Means of embarkation on and disembarkation from ships, 2019].

Also, its classification should be (2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated.

3.4.1.3.Regulation 3-12 protection against noise

This regulation refers to machinery noise in machinery spaces, and its object is to protect engineers from noise [The International Convention for the Safety of Life at

Sea, 1974]. For manned autonomous vessels, the crews who will suffer from machinery noise have to be considered, and this regulation will not need to be amended.

However, for unmanned autonomous vessels, it is not needed to care for the crews under the operation. Therefore, it is considered this regulation will not be applicable to autonomous vessel.

In the IMO discussion, the voluntary States also evaluated D for unmanned autonomous vessels because there is no crew but one State insisted that “the requirements may be needed to protect people (not crew/seafarers) on board” [Regulation II-1/3-12 Protection against noise, 2019]. It might be considered this regulation will still be applicable to only personnel to maintain or repair its equipment at ports.

In addition, the guideline for the reduction of underwater noise was approved at MEPC 66. Although it is not mandatory yet, some of the member States suggested to discuss it further [Reducing underwater noise utilizing ship design and operational measures, 2018]. Depending on the progress of this discussion, regulation about noise from vessels might be kept even after the ship is fully automated.

Also, its classification should be (2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated.

3.4.1.4. Regulation 5-1 stability information to be supplied to the Master

This regulation refers to vessels’ stability information. Although ships’ stability itself is applicable to MASS, this regulation also refers to its Master being supplied with stability information [The International Convention for the Safety of Life at Sea, 1974].

In the definition of STCW, Master means the person having command of the ship. The general certificates and requirements are national certificate of competence; certificate of GMDSS and familiarization of basic safety training for personal survival techniques, fire prevention and firefighting, elementary first aid and personal safety, survival craft and rescue boats [International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, 1978].

The Master for MASS will vary depending on the degree of automation. For manned remotely controlled vessels, it will be controversial whether a remote controller or a crew on board should be a Master. As long as there are enough seafarers and equipment on board, the Master managing its seafarers and its equipment will be a basis of safe shipping. However, depending on the degree, crews on board a manned remotely controlled vessel might lose the responsibility for safe shipping or be removed.

For unmanned remotely controlled vessels, there is no crew, including a Master on board. Under a particular degree of automation when a remote controller has the responsibility for safe shipping even in case of emergencies, the role of a Master also has to be handed over to its remote controller. At that time, the requirements related to a Master should be amended.

Regulation 5-1 is one of the examples. Stability information should be supplied to enable the Master to obtain accurate guidance as to the stability of the ship. Therefore, for remotely controlled vessels whose remote controller has the responsibility, this regulation should be amended to enable remote controllers to get adequate information about its stability.

Furthermore, there is not even a remote controller for fully autonomous vessels. The person designated for its safety should be assigned, such as the designated person to ensure the safe operation of ships in ISM. The person should be supplied with adequate information [International Safety Management Code, 2010].

In the IMO discussion, the voluntary States also evaluated C for unmanned autonomous vessels to redraft that “the operating limits shall be managed by the MASS directly or by a shore-based support person that may be considered as the Master to be clarified”

Also, its classification should be (3) About information which should be informed to a Master or crew on board conventional vessels.

3.4.1.5. Regulation 8-1 system capabilities and operational information after a flooding casualty on a passenger ship

This regulation stipulates the availability of essential systems in case of flooding damage such as the propulsion, steering system and navigation system required in SOLAS chapter II-2/21 and the stability computer on board to provide operational information to its Master for a safe return to port [The International Convention for the Safety of Life at Sea, 1974].

The operation in case of emergencies varies among the degree of automation, and it is difficult that the equipment and seafarers being in charge of emergencies will be removed because the emergency operation will be one of the most complex tasks and will rely on the crews [Schubert, 2018]. Therefore, this regulation will be kept until the end.

After removing all of the crews and putting unmanned remotely controlled vessel into practical use, this regulation might be amended to remove stability computer on board because the role to calculate the stability in case of emergencies will not need to be carried out on board.

For fully autonomous vessels, it might need to be amended to incorporate the stability calculation into the Monitoring System on board and maintain its operation in case of flooding damage.

In the IMO discussion, the voluntary States also evaluated C for unmanned autonomous vessels to redraft that “stability after flooding casualty shall be managed by the MASS itself or by a shore-based support Person”. It takes more time to conclude the regulations about emergencies; while the technology will be developed, it should be discussed further, and the direction of the development should also be discussed

Also, its classification should be (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated.

3.4.1.6.Regulation 19 damage control information

This regulation requires supplying the information about damage control to the officers of the ship for managing damage and flooding water [The International Convention for the Safety of Life at Sea, 1974].

As well as chapter 3.4.1.4, corresponding to the degree of automation, the subject responding to emergencies varies among crews on board, its remote controller and its designated person.

In the IMO discussion, the voluntary States also evaluated C for unmanned autonomous vessels to redraft considering no crew on board. Also, its classification should be (3) About information which should be informed to a Master or crew on board conventional vessels.

3.4.1.7.Regulation 20 Loading of passenger ships

This regulation requires a Master in charge of passenger ships to calculate its stability with the computer or equivalent means [The International Convention for the Safety of Life at Sea, 1974].

For even conventional ships, a computer is already used to calculate the passenger ship’s stability. For manned remote controlled vessels, this kind of tasks might be moved to a remote centre first. Therefore, this regulation will need to be amended to change the subject calculating stability and establish the requirements of equipment in remote centres.

For fully autonomous vessels, there will be no remote controller always checking the Monitoring System on board. Therefore, the Monitoring System itself should calculate the stability, and it should be discussed what extent of the Monitoring System reliability should be required to replace remote controllers.

In the IMO discussion, the voluntary States also evaluated C for MASS to redraft considering stability check performed remotely.

Also, its classification should be (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated.

3.4.1.8. Regulation 21 Periodical operation and inspection of watertight doors, etc., in passenger ships

This regulation requires conducting place drills for the operation of watertight doors weekly and in ships [The International Convention for the Safety of Life at Sea, 1974]. In addition to this drill, SOLAS requires a set of drills such as fire-extinguishing systems, life-saving appliances, mustering passengers and abandoning ship drill [The International Convention for the Safety of Life at Sea, 1974].

For manned remotely controlled vessels, corresponding to the degree of automation, some drills will also be automated. For example, drills for the operation of watertight doors already take place from the doors and its bridge now. Depending on the liability of the system, the operation of watertight doors might be automated, which make it possible to conduct drills for the operation of watertight doors from remote centres. On the other hand, it is difficult to automate the response to emergencies from only remote centres. The response and drills will require to take place on board for the time being.

For unmanned remotely controlled vessels, tasks will be automated, and drills will take place from remote control centres. For fully autonomous vessels, there will be no even remote controller. Designated persons might be assigned to respond to emergencies.

As long as the drills take place correctly, it should be approved to conduct drill remotely and the requirement should be amended for it.

In the IMO discussion, the voluntary States also evaluated C for MASS to redraft considering the periodical check of the doors and other devices performed and recorded “remotely” [Regulation II-1/21 Periodical operation and inspection of watertight doors, etc. in passenger ships, 2019].

Also, its classification should be (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated.

3.4.1.9.Regulation 26 General

This regulation stipulates the general regulation for machinery installation about design, maintenance and arrangement. One of the controversial requirements is that “means shall be provided to ensure that the machinery can be brought into operation from the dead ship condition without external aid”. The definition of dead ship condition is “the condition under which the main propulsion plant, boilers and auxiliaries are not in corporation due to the absence of power” in SOLAS, and the dead ship condition needs aids at least [The International Convention for the Safety of Life at Sea, 1974].

Although there are crews on board conventional vessels, unmanned autonomous vessels need external aids to recover from dead ship condition. Therefore, this requirement cannot be compatible with MASS. For manned remotely controlled vessels, one of the crews’ tasks might be to respond to the dead ship, and this regulation will not need to be amended.

However, for unmanned remote controlled vessels, supposing that there is no equipment without failure risk, it should be discussed external aids such as personnel outside should be approved, MASS just should rely on emergency towing, and unmanned autonomous vessels should not be approved.

In the IMO discussion, the voluntary States also evaluated A for unmanned autonomous vessels. Further discussion will be needed to put unmanned autonomous vessels to practical use.

Also, its classification should be (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated.

3.4.2. Characteristics of classified amendment

In addition to the review in section 3.3, the review in section 3.4.1 illustrates the characteristics of amendments. As Table 2 illustrates, the requirements (2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated and (3) About information which should be informed to a Master or crew on board conventional vessels can be just removed or moved to the remote centres. On the other hand, requirement (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated, has various degrees of difficulty to be amended as introduced in section 3.3 and 3.4.1.

Table 2.

Characteristics of Classified Amendment

(1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated		
	Difficult to be automated and rely on another measure	
		SOLAS 2-1/3-4 Emergency towing arrangements SOLAS 2-1/26 General(dead ship) SOLAS 3/17-1 Plans and procedures for recovery of persons from the water SOLAS 5/19.2 Carriage requirements for shipborne navigational systems and equipment COLREG Rule 2 Responsibility(Good Seamanship) COLREG Rule 5 Look-out COLREG Rule 13 Overtaking COLREG Rule 14 Head-on situation
	Not difficult to be automated and just established in remote centres	
		SOLAS 2-1/8-1 System capabilities and operational information after a flooding SOLAS 2-1/20 Loading of passenger ships SOLAS 2-1/21 Periodical operation and inspection of watertight doors
(2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated		
		SOLAS 2-1/3-9 Means of embarkation on and disembarkation from ships SOLAS 2-1/3-12 Protection against noise
(3) About information which should be informed to a Master or crew on board conventional vessels		
		SOLAS 2-1/5-1 Stability information to be supplied to the Master SOLAS 2-1/19 Damage control information

3.5. The non-amendment review of SOLAS

In section 3.3 and 3.4, the amendment was reviewed. However, there are several requirements applying to MASS and not preventing MASS operations and requiring “no actions”. One kind of them is the basic requirements such as structural requirement. Another is requirements for the equipment which is not automated enough for the degree of automation like emergency towing arrangement for manned remotely controlled vessel. The latter was already introduced in chapter 3.4. In the following section, the former will be reviewed.

3.5.1.1. SOLAS chapter II-1/3-1 structural and electrical requirement for ships

This regulation stipulates that “ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society” [The International Convention for the Safety of Life at Sea, 1974].

Today, many classification societies have already developed guidelines for developing MASS like DNV-GL, Bureau Veritas and Class NK and are expected to lead the MASS development with other stakeholders [Class Guideline Autonomous and remotely operated ships, 2018].

As the flag States have relied on them in terms of structural, mechanical and electrical design and construction of conventional vessels, those of MASS might also be inspected by them. In that kind of meaning, this regulation does not need to be amended.

However, the requirements of classification societies must be approved in advance by competent authorities. It is necessary to have a common sense of the MASS system among them through discussions, such as at IMO.

4. Conclusion

Unlike other amendments discussed at IMO, MASS is still under technological development. Therefore, it is impossible to amend all of the concerned conventions at once. Corresponding to the progress of the degree of automation, requirements which should be amended at that time shall be considered at once.

There are several characteristics of classified amendments as introduced in Table 2. Although the difficulty of the amendment and when to be amended vary among each amendment, all of amendments should be incorporated into the MASS development and should not disturb it. The roadmap of MASS development with legal developments is introduced as Figure 18 and it could be “How MASS will be put into practical services”.

During the whole developing of MASS, the completed elemental technology, such as the auto track system, was or will be put into practical use along with the automated tasks and domains that will be expanded. The requirements (1) About equipment and the roles carried out on board conventional vessels for shipping, which will be automated should be considered corresponding to the developments at this stage. The discussion should be held intermittently at IMO and member States which can put the technology into practical use should suggest the amendments.

During developing manned remotely controlled vessels and unmanned remotely controlled vessels, the technology to expand automated tasks and domains, such as the computer to calculate its stability and measure to recover from dead ship, will also be developed. Corresponding to the expansion, the responsibility of the task will be moved from on board to remote centres and requirement for (1) should be considered at that time.

At the completion of the development of unmanned remotely controlled vessels, requirements (2) About equipment and the roles carried out on board conventional vessels for seafarer, which will be automated, and (3) About information which should be informed to a Master or crew on board conventional vessels should be considered. For example, the requirement of protection against noise should be included at that time.

Also, at the completion of development of fully autonomous vessels, requirements for (3) should be considered again to move its responsibilities to designated persons.

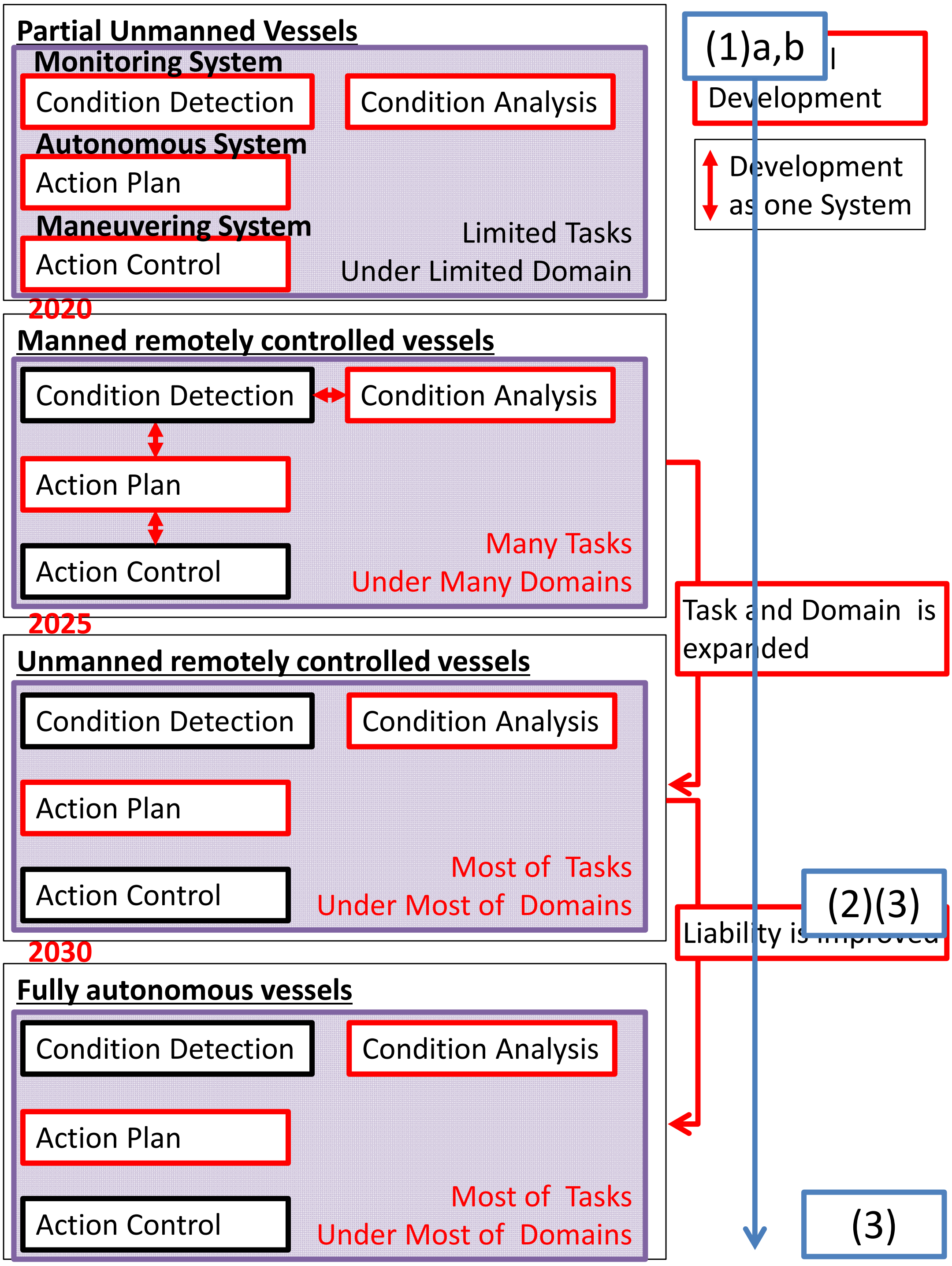

Figure 18. How MASS will be put into practical service.

5. Suggestions

One of the purposes of the IMO is "to encourage the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships" [Convention on the International Maritime Organization, n.d.]. In other words, technological developments should lead legal developments, not legal developments leads or deters technological developments.

In the case of SOLAS, generally, most of amendments are deemed to have been accepted tacitly at the end of two years unless the amendment is objected to by more than one third of Contracting Governments [The International Convention for the Safety of Life at Sea, 1974]. The amendments will then enter into force within 18 to 24 months and it will not be difficult compared to amendments in the past.

In addition, the working group was already organized under the MSC, and it should be held periodically to identify what developments are already matured and what amendments should be suggested in the MSC and its sub-committee. As introduced in chapter 3.3 and 3.4, there are requirements difficult to be automated and rely on other measures like emergency towing arrangements. These issues should also be discussed at the working group to conclude the solution to make it possible to develop the technology based on the discussion.

Apart from the technical issues, this thesis will suggest to add one more classification to the degree of automation introduced section in 1.2.2.3 in the following section.

5.1 Partial B0 navigation

For stakeholders, the recent discussion about MASS is not the first time to discuss the automation of ships. In 1970s, the automation of its engine room had been discussed as E0, and Resolution A.325 (1975) was published to amend SOLAS, enabling unattended machinery spaces partially [RECOMMENDATION CONCERNING REGULATIONS FOR MACHINERY AND ELECTRICAL INSTALLATIONS IN PASSENGER AND CARGO SHIPS, 1975].

In the present SOLAS, the requirements for unattended machinery spaces are stipulated in SOLAS chapter II-1/46-57. As stipulated on SOLAS chapter II-1/46, “the arrangement of unattended machinery spaces shall be such as to ensure that the safety of the ship is equivalent to that of a ship having the machinery spaces manned” [The International Convention for the Safety of Life at Sea, 1974]. Based on this idea, MASS shall also be safe equivalent to the conventional ships at least.

In addition, SOLAS chapter II-1/49, 50 and 51 require the control of propulsion machinery from its navigation bridge enabling to control its pitch of propeller; allow the control only from one location at a time; demand the communication between its main machinery control room; navigation bridge and even engineer officers' accommodation; and require the alarm system enabling to indicate any fault requiring attention, which is capable of sounding an audible alarm in its main machinery control room, navigating bridge and even engineer officers' accommodation [The International Convention for the Safety of Life at Sea, 1974]. There are engineers to maintain its machinery spaces on day time, and also in accommodation on board at least [IMAI, 1980].

From the perspective, the bridge might be periodically automated and unattended such as after passing through the congested area if the requirements for periodically automated bridge follow requirements for periodically unattended machinery spaces.

In the discussion at IMO, if the periodically unattended bridge is incorporated in the degree of automation, it could be a part of partial autonomous vessels. However, it is not taken into account, explicitly. If additional requirement will be discussed, it might be permitted and can be one of the feasible steps to MASS.

One company is developing the system enabling bridge unmanned periodically named B0. The typical number of crews on the bridge and the operating conditions are classified into B3 that there are an officer on watch, a lookout and a helmsman under special condition; B2 that an OOW and a lookout under night and good condition; and B1 that there is only an OOW under day and good condition. They contribute to monitoring the traffic situation, navigation equipment status, radios and equipment status. The company considers that the general B0 condition will be under

good weather, visibility clear, no technical problems and no objects visible in the forward sector. In addition to the good condition, it also considers requirements for the necessary equipment such as monitoring and diagnosing all navigation sensors and equipment, automatically recording radio message, and alarming to officers as well as for E0 systems [Eero Lehtovaara, 2018].
To take partial B0 navigation into account will encourage stakeholders more to introduce MASS for their benefits.

5.2 Others

This thesis focuses on MASS construction, not cyber security and training and education for the remote controllers.
However, the higher the degree of automation will be, the higher the risk of cyber-attack will also be. AIS is vulnerable today because it relies on VHF broadcasts on open frequency [Dimitrios, Vulnerabilities of the Automatic Identification System in the Era of, 2018]. However, which network MASS relies on will be more important than AIS because data manipulation, spoofing and hacking can result in its drafting easily.
Moreover, in one experiment conducted by M. Baldauf et al. [2018], even non-seafarers who had access solely to a synthetic ECDIS screen and had software-based handles to input rudder/engine revolution commands could avoid collision. Although it was not concluded who can be certified as remote controllers, it should be continuously discussed.
Moreover, for a particular period, there will be both conventional ships and MASS. These mixed traffic scenarios seem to be especially challenging in terms of safety because there will be the issue of confidence between human and system as discussed in section 1.4 [Dimitrios, Exploring the Issue of Technology Trends in the "Era of Digitalisation", 2018].
Thus, the transition from conventional ships to MASS will change shipping drastically. The legal developments in all genres must follow the technological developments to put MASS into practical use.

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