2016

Existing conventions and unmanned ships - need for changes?

Tomotsugu Noma
World Maritime University

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EXISTING CONVENTIONS AND UNMANNED SHIPS - NEED FOR CHANGES?

By

TOMOTSUGU NOMA

Japan

A dissertation submitted to the World Maritime University in partial Fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MARITIME AFFAIRS

(MSEA)

2016
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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Last but not least, I wish to extend my deepest appreciation to my parents and sister for their supports.

I hope you kindly accept my apology to anyone whom I have not mentioned but who has contributed to me directly or indirectly.
ABSTRACT

Title of Dissertation: Existing conventions and unmanned ships - need for changes?

Degree: MSc

Driven by ambitious technological developments in automation, statistical figures illustrating that up to ninety per cent of maritime accidents are caused directly or indirectly by Human Element and last but not least by the aspiration to make shipping cos-effective, there are numerous ongoing research and technological developments to realize unmanned ships.

In the light of those recent developments this dissertation studies if there is a necessity for changes of existing conventions when introducing unmanned ships into the current maritime transportation system. ‘Unmanned ships’ is a new trend and there are a lot of ongoing projects. However, there are still many topics to be solved. Among others, the dissertation focuses on survey schemes especially in respect to regulations of SOLAS Chapter V.

Firstly, for the studies a clarifying definition of unmanned ships is developed through literature survey. A selection of recent projects dealing with unmanned ships is summarized and explained to understand the current situation of unmanned ships. Challenges and problems are identified for three sectors: technical, administrative/regulatory and operational.

Secondly, the existing survey scheme is studied and challenges are identified through case studies. In particular, flag state survey, interval of surveys and PSC are analysed and potential solutions and approaches to overcome are developed and discussed.

Thirdly, the applicability of SOLAS Chapter V regulations is considered and challenges are identified using specific scenario studies. Especially, definition of master, officer and crew, requirement of minimum Manning and pilot services are discussed and potential solutions are drafted and explained.

Lastly, conclusion of the dissertation is provided and recommendations for technology, legislation and operational aspects are given.

KEYWORDS: unmanned ship, autonomous mode, remote control, survey, SOLAS Chapter V
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<tr>
<td>AAWA</td>
<td>Advanced Autonomous Waterborne Applications</td>
</tr>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>AIS</td>
<td>Automatic Identification System</td>
</tr>
<tr>
<td>AMOS</td>
<td>Centre for Autonomous Marine Operations and Systems</td>
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<tr>
<td>AUV</td>
<td>Autonomous Underwater Vehicle</td>
</tr>
<tr>
<td>CoE</td>
<td>Centre of Excellence</td>
</tr>
<tr>
<td>COLREG</td>
<td>Convention on the International Regulations for Preventing Collisions at Sea</td>
</tr>
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<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>DP</td>
<td>Dynamic Positioning</td>
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<td>DSMAC</td>
<td>Digital Scene Matching Area Correlation</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>ECDIS</td>
<td>Electronic Chart Display and Information System</td>
</tr>
<tr>
<td>ECT</td>
<td>Emergency Control Team</td>
</tr>
<tr>
<td>EOSP</td>
<td>End Of Sea Passage</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAOP</td>
<td>Full Ahead On Passage</td>
</tr>
<tr>
<td>FOC</td>
<td>Fleet Operation Center</td>
</tr>
<tr>
<td>FP7</td>
<td>Seventh Framework Programme</td>
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<td>GL</td>
<td>Germanischer Lloyd</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GT</td>
<td>Gross Tonnage</td>
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<tr>
<td>IACS</td>
<td>International Association of Classification Societies</td>
</tr>
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<td>IALA</td>
<td>International Association of Lighthouse Authorities</td>
</tr>
<tr>
<td>IAMSAR</td>
<td>International Aeronautical and Maritime Search and Rescue</td>
</tr>
<tr>
<td>IGS</td>
<td>Inertial Guidance System</td>
</tr>
<tr>
<td>III Code</td>
<td>IMO Instruments Implementation Code</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>IMSAS</td>
<td>IMO Member State Audit Scheme</td>
</tr>
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<td>ITF</td>
<td>International Transport Workers' Federation</td>
</tr>
<tr>
<td>KRISO</td>
<td>Korea Research Institute of Ship &amp; Ocean Engineering</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Laser Imaging Detection and Ranging</td>
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<tr>
<td>LLC</td>
<td>International Convention on Load Lines</td>
</tr>
<tr>
<td>LR</td>
<td>Lloyd's Register</td>
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<tr>
<td>L&amp;R</td>
<td>Launch and Recovery</td>
</tr>
<tr>
<td>MARPOL</td>
<td>International Convention for the Prevention of Pollution from Ships</td>
</tr>
<tr>
<td>MLIT</td>
<td>Ministry of Land, Infrastructure, Transport and Tourism</td>
</tr>
<tr>
<td>MUNIN</td>
<td>Maritime Unmanned Navigation through Intelligence in Networks</td>
</tr>
<tr>
<td>NIST</td>
<td>National Institute of Standards and Technology</td>
</tr>
<tr>
<td>NTNU</td>
<td>Norwegian University of Science and Technology</td>
</tr>
<tr>
<td>OCT</td>
<td>On-board Control Team</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>pms</td>
<td>planned maintenance scheme</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<td>---------</td>
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<tr>
<td>PSC</td>
<td>Port State Control</td>
</tr>
<tr>
<td>RMSS</td>
<td>Remote Maneuvering Support System</td>
</tr>
<tr>
<td>ROs</td>
<td>Recognized Organizations</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>RSOs</td>
<td>Recognized Security Organizations</td>
</tr>
<tr>
<td>SA</td>
<td>Situation Awareness</td>
</tr>
<tr>
<td>SAR</td>
<td>Search and Rescue</td>
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<tr>
<td>SFV PROT</td>
<td>Torremolinos Protocol of 1993 relating to the Torremolinos International Convention for the Safety of Fishing Vessels</td>
</tr>
<tr>
<td>SOLAS</td>
<td>International Convention for the Safety of Life at Sea</td>
</tr>
<tr>
<td>STCW</td>
<td>International Convention on Standards of Training, Certification and Watchkeeping for Seafarers</td>
</tr>
<tr>
<td>S-VDR</td>
<td>Simplified Voyage Data Recorder</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aircraft System</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
<tr>
<td>UGV</td>
<td>Unmanned Ground Vehicle</td>
</tr>
<tr>
<td>USV</td>
<td>Unmanned Surface Vessel</td>
</tr>
<tr>
<td>VDR</td>
<td>Voyage Data Recorder</td>
</tr>
<tr>
<td>VTS</td>
<td>Vessel Traffic Services</td>
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1. Introduction

- Ships -

Obviously, ships are an indispensable mode of transport for the world economy. According to the International Maritime Organization (IMO) (2016c), over 80% of world cargo is carried by international shipping. Ships have a long history and can be seen in paintings from around 4000-3100 BC (University College London, n.d.). Why have ships been important for such a long time period? The reason is that ships are the most efficient mode of transport and can carry a huge amount of cargo at once compared to other transport modes. Tennessee-Tombigbee Waterway (n.d.) estimated that ships can carry one ton of cargo over a distance that is 2.5 times longer than trains, using the same amount of fuel. In addition, they can reach islands by sea and, so ships are indispensable in these areas.

- Regulations -

Safety is of utmost concern in the maritime field, especially for shipping. As an example, after the Titanic sank in 1912, the International Convention for the Safety of Life at Sea (SOLAS) was adopted in 1914 with heightening concern toward safety worldwide. Since then, SOLAS is the one of most essential maritime Conventions in the world. SOLAS has been amended countless times by the IMO to deal with new
technologies and often corresponds to maritime accidents. In addition, IMO has been working to improve maritime safety by setting regulations related to not only the ship itself but also related issues such as traffic and the human element. In this regard, among others, the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and the Convention on the International Regulations for Preventing Collisions at Sea (COLREG) play important roles. STCW, in principle, regulates training, certification and watchkeeping standards for seafarers (IMO, n.d.-b). COLREG regulates ship operation for the purpose of avoiding collision (IMO, n.d.-a). IMO regulates ships and shipping from the both soft and hard aspects. From the side of the shipping industry, if its ships have accidents, they will lose credibility. In addition to other reasons, that is mainly why maritime regulations importantly need to have minimum requirements for ship safety.

- Innovation of Navigational equipment -

As mentioned above, regulations are an important factor, but for safe, efficient and sustainable operation of ships, navigational equipment is most crucial. There are several reasons, such as reducing workload for human operators and supporting correct navigation. In the ancient period, celestial navigation was an essential and usual navigational method. Crew needed to calculate the ship’s position by using celestial bodies. However, times have changed and currently, there is Global Navigation Satellite System (GNSS), such as Global Positioning System (GPS), so that crew can identify the ship’s position much more easily and in real-time. In addition, by using Electronic Chart Display and Information System (ECDIS), Automatic Identification
System (AIS), Radar and GPS, navigators do not need to manually track the position. For the most part, they can know the positions of other ships and can detect their distance as well. Those technical systems are not perfect but they contribute to reducing the workload of navigators. In addition, the crew is able to know the position whenever they want so that they can correct the course easily, which makes it a little easier to navigate congested or narrow waters. This factor, beside others, might contribute to reducing accidents.

- Unmanned ship -

Recently, there is one interesting development aiming at so-called unmanned ships. This type of ship is owned or operated by States and used exclusively on government non-commercial services at the present time. For instance, the US Navy and the UK’s Royal Navy are using unmanned ships for mine countermeasures e.g. in the Persian Gulf (White, 2015). Another example is that the Japanese Coast Guard is operating a surveying ship to research a submarine volcano. Although they need a so-called mother ship to controls it by remote techniques. Introducing unmanned ships to commercial shipping might be an epoch-making event for the shipping industry. For example, Rolls-Royce is one of the leading companies that has shown an interest in introducing unmanned ships and has already researched unmanned ships (Rolls-Royce, 2015). According to Rolls Royce and other supporters of unmanned ships, the big advantage of such ships is that they might reduce maritime accidents caused by fatigue and alcohol abuse. Actually, accidents are a huge issue for the shipping industry. It is said that almost all causes of accidents are related to the human factor, such as fatigue and
alcohol abuse, stemming from the current trend wherein the amount of work of seafarers is increasing and crew size per ship is decreasing. These situations cause fatigue (ITF, 2016). Nevertheless, humans have been taking an important role in the operation of ships since ships started to operate. In addition, shortage of seafarers is becoming a global issue (“Seafarer shortage,” 2015). If the number of seafarers on board can be reduced, this problem would be solved as well. Furthermore, other transport modes, such as trains and airplanes, already have unmanned systems. The automobile industry has also been trying to develop autonomous vehicle.

However, there is a huge problem that remains. It rises from Conventions that do not correspond to the purpose of operating unmanned ships. For instance, obviously, there is no regulation about remote controlled equipment. Just focusing on equipment, there is also no proven procedure for survey of this equipment. In the same way, there are further aspects and a lot of work which needs to be done before unmanned ships may be introduced to commercial shipping, and avoidance of maritime accidents is sufficiently considered and ensured.

Taking this background into consideration, this dissertation will identify and highlight the need for changes to existing Conventions. Chapter 2 will provide the background and theoretical underpinnings and focus on the general idea of unmanned ships. In chapter 2, the definition of unmanned ships will be given. The differences between an autonomous mode and remote control will be discussed from literature review. In addition, a comprehensive survey and review of projects that research and develop
unmanned ships will be summarized and explained. In particular, the purpose and the goals of those projects will be studied and clarified. Moreover, the difficulties will be identified and challenges needed to solve will be described. There are many challenges that need to be addressed before putting unmanned ship into service. Challenges will be identified from the literature and current projects. Chapter 3 will highlight the survey scheme for unmanned ships. In this chapter, the current survey scheme and its applicability to unmanned ships will be explained. Introducing unmanned ships into the shipping industry may have a significant effect on survey schemes. In particular, remote control centers on land are a new concept for the shipping industry and need to be inspected since those centers may control ships. Additionally, challenges will be identified and explained, most importantly, flag State surveys. Currently, surveys focus on ships. However, unmanned ships consist of the ship and the remote control center. The remote control center is part of the unmanned ship. The potential approach to carry out surveys of remote control centers will be discussed. In this regard, there are two more important challenges, such as interval of survey and PSC. The interval of surveys of remote control centers is crucial since remote control centers may deal with several ships. In addition, if there is no crew, there is a question as to how PSC surveys will be carried out. Checking operational matters would be an especially critical matter. In chapter 4, the result of a review of SOLAS Chapter V will be presented. Chapter V concerns safety of navigation and this chapter requires ships to have equipment for safety of navigation. On this basis, a review is carried out from the point of view of applicability of Chapter V to unmanned ships. Some regulations can apply without amendments, but some cannot. Potential bottlenecks will be explained. In addition, the
points for consideration and recommendations will be given. The definitions of master, officer and crew, requirement of minimum manning and pilot services are important issues to be addressed. Identified challenges concerning these issues and possible solutions will be given. Finally, conclusion will be made.
2. Background & Definitions

2-1 Definition of Unmanned ships

An essential aspect of this research is the definition of unmanned ships. The word ‘unmanned’ appears in several regulations; however, at the moment, there is no definition of unmanned ships in IMO Conventions and regulations.

According to Oxford University Press (n.d.), the definition of unmanned is “Not having or needing a crew or staff”. Also, there are similar terms in different transport modes, such as unmanned aircraft, Unmanned Aerial Vehicle (UAV) and Unmanned Ground Vehicle (UGV). An unmanned aircraft is; “an aircraft that does not carry a human operator and is capable of flight with or without human remote control” (US Department of Defence, n.d.). UAVs are “… capable of operating without an internal pilot; are tethered by a radio control link; and can be preprogrammed for both flight and payload operations prior to launch” (Unmanned Aerial Vehicle Systems Association, n.d.). A UGV is “any piece of mechanized equipment that moves across the surface of the ground and serves as a means for carrying or transporting something, but explicitly does not carry a human being” (Nguyen-Huu & Titus, 2009). From these definitions, it can be simply said that ‘Unmanned ship’ describes a ship that operates without any human operator onboard.
An unmanned ship is comparable to any drone, such as an unmanned floating, flying or driving object known from military or aerospace uses. Typical unmanned vehicles are the cruise missiles of the US Air Force and submarine boats used to research the bottom of the deep sea or wrecks. For example, Tomahawks, the famous cruise missiles, are operated by four systems: Inertial Guidance System (IGS), Terrain Contour Matching (Tercom), GPS and Digital Scene Matching Area Correlation (DSMAC), to hit the target without remote control (Brain, n.d.). In addition, submarine boats are of two types, autonomous underwater vehicles (AUV) and remotely operated vehicles (ROV). Both are unmanned, but there is a typical difference between them. The AUV is operated autonomously without operator, on the other hand, the ROV is connected to a ship by wire and operated remotely from the ship (National Ocean Service, n.d.). From this point of view, unmanned vehicles, as such, can be remote controlled or operate in an autonomous mode.

Remotely controlled vehicles are usually connected to a control station or center by a wire, such as ROVs, or by wireless radio connection to send command signals to steering controls, such as UAVs. The unmanned vehicle in remote control mode is controlled by a human operator from a remote position. Remote controlled vehicles may, per definition, have humans on board, but they are considered as being passive, like passengers.

Meanwhile, vehicles operating in an ‘Autonomous mode’ move without any interaction with a human operator and do not have or use a connection to a control.
station or center, such as the AUV. Those vehicles are equipped with systems allowing ‘self-steering’ by sensor-based detection of objects like obstacles and to self-initiate an action e.g. to keep the shortest track to an ordered destination or to avoid potential damage e.g. by collisions with other objects. Technical systems installed onboard ‘decide’ on the basis of programmed algorithms and input data gathered by sensors (Armstrong, 2016; Google’s Autonomous Vehicle, n.d.).

To conclude from above discussion, the definition of unmanned ship is a ship that may operate in remote controlled and/or autonomous mode without any human operator onboard.

2-2 Survey of selected past and ongoing research activities

The development of unmanned ships is a new trend in the maritime sector. There are many countries, organizations and companies interested in unmanned ships that are carrying out research and technological development projects. There are several projects past and ongoing, which focus mainly on technology. In this chapter, seven published projects will be summarized and explained.

.1 Maritime Unmanned Navigation through Intelligence in Networks (MUNIN)

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) was launched and funded by the European Commission (EC) under its Seventh Framework Programme (FP7) (MUNIN, n.d.-b).
The project was started in 2012 and ended in 2015. The purpose of this project was to investigate the technical, economic and legal feasibility of unmanned ships (MUNIN, 2016). There are several important characteristics of this project as follows (Okamoto, 2015):

- The ships will be operated by the autonomous shipping system on board; however, the ships will also be supervised and controlled by the operators on land.
- Unmanned ships must be able to minimize the risk of collision and comply with COLREG.
- The sensors for safety and operation might be used to search for objects.

In order to research problems of unmanned shipping, in MUNIN, the following concept has been developed and applied to the technical developments and studies throughout the project. The ship considered as unmanned was used a dry bulk carrier for case study because this type of ship has low additional cargo requirements compared to container ships (MUNIN, n.d.-a). Also, MUNIN developed a possible scenario for voyage execution, as Figure 1 shows.

In this scenario, an on-board control team (OCT) will command the approach to a port and the departure from a port on board a ship. Unmanned operation will be implemented from "full ahead on passage" (FAOP) to "end of sea passage" (EOSP). An emergency control team (ECT) may be needed for emergency situations (Rødseth & Tjora, 2014). This is very similar to a scenario already described by Shaw (1995).

Moreover, MUNIN developed:

- An Advanced Sensor Module, which takes care of the lookout duties on board the vessel by continuously fusing sensor data from existing navigational systems, like e.g. Radar and AIS, combined with modern daylight and infrared cameras;

- An Autonomous Navigation System, which follows a predefined voyage plan, but with a certain degree of freedom to adjust the route in accordance with legislation and good seamanship autonomously, e.g., due to an arising collision situation or significant weather change;

- An Autonomous Engine and Monitoring Control system, which enriches ship engine automation systems with certain failureprediction functionalities while keeping the optimal efficiency and which takes care of the additionally installed pumpjet that acts as a certain rudder and propulsion redundancy;

- A Shore Control Centre, which continuously monitors and controls the autonomously operated vessel after its being released from its crew by its skilled nautical officers and engineers. It comprises amongst others the
certain positions:

- A Shore Control Centre Operator, who monitors the ship operation of several autonomous ships at the same time from a desktop cubicle station and controls the vessels by giving high level command like, e.g., updating the voyage plan or the operation envelope of the autonomous system;

- A Shore Control Centre Engineer, who assist the operator in case of technical questions and who is in charge of the maintenance plan for the vessels based on a condition based maintenance system ensuring sufficient reliability of the technical system for the next autonomous journey;

- A Shore Control Centre Situation Room Team that can take over direct remote control of one vessel in certain situations via a shore side replica of the unmanned vessels bridge including a Remote Manoeuvring Support System that ensures an appropriate situation awareness in direct control despite the physical distance of crew and vessel (MUNIN, n.d.-a, para.4).

However, according to Rule 5 of COLREG, proper look-out by eye and ear is required on every ship to assess the situation and the risk of collision (Convention on the International Regulations for Preventing Collisions at Sea, 1972, 1972). An Advanced Sensor Module does not completely take this principle into account yet. If there is no change of Rule 5 of COLREG, an Advanced Sensor Module needs to be extended to
also cover “acoustic” look-out.

Furthermore, MUNIN carried out a cost-benefit analysis, safety and security analysis, and legal and liability analysis. According to the three analyses, autonomous ships can save money, can be safe and secure, and will impact current regulations (MUNIN, 2016). For instance, according to its research, the MUNIN concept ship can save up to 7 million USD over a 25-year period compared to a conventional bulk carrier. In addition, it was found that there is a possibility to reduce maritime accident risks by up to 10%, compared to manned ships, due to the elimination of fatigue (MUNIN, n.d.-a). However, it seems that there are still doubts about the safety of unmanned ships. For example, it may be true that unmanned ships can avoid existing human errors, mostly fatigue, but it may also true that there are possibilities that unmanned ships will have accidents because of new human errors, such as improper monitoring and software bugs. These factors may be considered as new human errors because unmanned ships will be observed by humans and their systems will be developed by humans (Mni, 2011). Also, the reliability of the system will be an important element in operating unmanned ships without accidents because crew can take action in conventional ships, but operators may not be able to intervene if systems go out of control and/or if the connection between ship and shore is lost (AAWA, 2016).

.2 Advanced Autonomous Waterborne Applications Initiative (AAWA)

Advanced Autonomous Waterborne Applications Initiative (AAWA) was launched by Rolls-Royce in 2015 (Rolls-Royce, 2015). Rolls-Royce is a leading company in power
and propulsion systems in aerospace, marine, energy and off-highway sectors (Rolls-Royce, n.d.-b). It was established in 1906, originally as a car company, in the UK (Rolls-Royce, n.d.-c). In the maritime sector, Rolls-Royce provides “encompassing vessel design, the integration of complex systems and the supply and support of power and propulsion equipment” for offshore, merchant and naval sectors (Rolls-Royce, n.d.-a).

The purpose of this project is to bring:

- together universities, ship designers, equipment manufacturers and classification societies to explore the economic, social, legal, regulatory and technological factors which need to be addressed to make autonomous ships a reality. It will produce the specification and preliminary designs for the next generation of advanced ship solutions (Rolls-Royce, 2016, para.2).

This project is funded by Tekes (Finnish Funding Agency for Technology and Innovation) and will be completed at the end of 2017. In addition, Finland’s top academic researchers from Tampere University of Technology; VTT Technical Research Centre of Finland Ltd; Åbo Akademi University; Aalto University; the University of Turku; and leading members of the maritime cluster including Rolls-Royce, NAPA, Deltamarin, DNV-GL and Inmarsat are participating in this project (AAWA, 2016).

They realized that sufficient technologies exist; however, the problem is how to
integrate these technologies. In this project, there are three factors that are focused on:

- The safety and security implications of designing and operating remotely operated ships
- The legal and regulatory implications
- The existence and readiness of a supplier network able to deliver commercially applicable products in the short to medium term (AAWA, 2016, p.6).

Thus far, there are five findings from this project as follows:

1. There will be no single remote or autonomous ship solution but rather a hybrid of the two which will depend on the type and function of the vessel.

2. The technologies needed to make remote and autonomous ships a reality exist. The challenge is to find the optimum way to combine them reliably and cost effectively. The development on decision support systems for autonomous vessels will be a gradual and iterative process and subject to extensive testing and simulation.

3. The operation of remote and autonomous ships will be as least as safe as existing vessels. There is potential to reduce human based errors but at the same time new types of risk will arise and will need to be identified and addressed.

4. Legislation can be changed if there is a political will. For remote and autonomous shipping to become a reality effort is needed at all regulatory levels. The legal challenges of constructing and operating a demonstration vessel at a national level need to be explored whilst simultaneously considering appropriate rule changes at the IMO. Questions of liability for
autonomous ships are subject to national variations, but generally it seems that there is less need for regulatory changes in this field. What needs to be explored, however, is to what extent other liability rules, such as product liability, would affect traditional rules of maritime liability and insurance.

5. Remote and autonomous ships have the potential to redefine the maritime industry and the roles of players in it with implications for shipping companies, shipbuilders, maritime systems providers and technology companies from other (especially the automotive) sectors (AAWA, 2016, pp.13-14).

The new types of risk mentioned in the third finding will arise from software and sensor systems. In addition, the reason why there is less need for regulatory changes in the liability field, according to the forth finding, is that “significant national variations exist as states’ participation to the maritime liability conventions is not as uniform as for the safety conventions discussed above and as liability issues to a larger extent depend on national traditions and the legal system concerned” (AAWA, 2016, p.50).

The next stages of the project are as follows (AAWA, 2016):

- The improvement and verification of technological solutions
- Identification of risks (Technical and Legal)
- Seeking legislation challenges at a national level
- Creating cost and income models by seeking stakeholder opinions.
.3 ReVolt (DNV-GL)

DNV-GL is the biggest classification society according to the number of registered ships which is 12,886 vessels, and 267m GT at the end of 2015 (“Top 100 classification societies,” 2016). DNV-GL was created by merger of Det Norske Veritas (DNV) and Germanischer Lloyd (GL) in 2013. Both classification societies had a long history. DNV was founded in 1864 in Norway and GL was founded in 1867 in Germany (DNV-GL, n.d.-a, n.d.-c). They have five areas, namely the maritime industry, the oil and gas industry, the energy industry, business assurance and software (DNV-GL, n.d.-d). In the maritime industry area, there are six services, specifically, ship classification, offshore classification, maritime advisory, certification of materials and components, flag state and coastal state services, and maritime software (DNV-GL, n.d.-b).

DNV-GL initiated a new concept of unmanned ship known as ReVolt in 2013 and launched it in 2014. This project will run until 2018 (DNV-GL, n.d.-e). ReVolt is a concept for zero emission unmanned ships for short voyages with battery power. The size of the ship is approximately 1,800 dwt and 100 teu capacity boxship (Osler, 2015a). This concept was developed to address the shift of transportation of cargo from land to sea because capacity of land transportation might not be able to cope with increased demand in the future. However, the profit of coastal shipping is small. It is not enough to encourage the coastal shipping industry to follow this trend. According to their estimation, ReVolt can save more than one million USD per year and it is going to be up to 34 million USD for 30 years. That is why DNV-GL thinks unmanned ships can be the answer of this situation. Nevertheless, they also believe that some
technologies, such as sensor fusion and collision avoidance, are not mature enough to operate this kind of ship. They continue to research these technologies through collaboration with the Norwegian University of Science and Technology (NTNU) (DNV-GL, n.d.-e).

.4 Cyber-enabled ships: ShipRight procedure guidance - autonomous ships (LR)

Lloyd’s Register (LR) has been developing procedures and guidance for autonomous ships to correspond with earlier introduction of autonomous operations (Lloyd’s Register Group Services Limited, n.d.-b). LR was founded in 1760 in London and this is the first classification society in the world. Currently, it is one of the leading classification societies and a member of the International Association of Classification Societies (IACS) (Lloyd’s Register Group Services Limited, n.d.-a).

In February 2016, LR published a guidance concerning Cyber-enabled ships; “Deploying information and communications technology in shipping – Lloyd’s Register’s approach to assurance”. According to LR (2016a, p.4), “The cyber-enabled ship is a ‘system of systems’”. In this guidance, LR identifies six risks to be taken into account when introducing cyber-enabled ship as follows:
- System
- Human-system
- Software
- Network and communications
- Data assurance
- Cyber security (Lloyd’s Register Group Services Limited, 2016a, p.1).
For each risk, this guideline explains the factors which should be considered. Moreover, LR briefly explains how to apprise cyber-enabled systems. However, they consider that it is not appropriate to apply prescriptive regulations so they created a process map modelled on a risk-based approach as Figure 2 shows (Lloyd’s Register Group Services Limited, 2016a).

![LR process map](image)

Figure 2: The LR process map. Reprinted from Cyber-enabled ships Deploying information and communications technology in shipping – Lloyd’s Register’s approach to assurance, by Lloyd's Register Group Services Limited, 2016, p11.

When the concept of operation is developed, two steps, requirements definition and refining, are required to clarify the concept before implementing a risk-based approach.
so that concepts need not be changed at a later stage. Moreover, a risk-based approach might be more assured and appropriate if the concept is identified clearly.

Following this guidance, LR developed and published Cyber-enabled ships: ShipRight procedure – autonomous ships in July 2016. In this procedure, LR identified seven autonomy levels as follows:

AL 0) Manual – no autonomous function.

All action and decision making is performed manually – i.e. a human controls all actions at the ship level. Note: systems on board may have a level of autonomy, with ‘human in/on the loop’; for example, pms and engine control. Straight readouts, for example, gauge readings, wind direction and sea current, are not considered to be decision support.

AL 1) On-ship decision support

All actions at the ship level are taken by a human operator, but a decision support tool can present options or otherwise influence the actions chosen, for example DP Capability plots and route planning.

AL 2) On and off-ship decision support

All actions at the ship level taken by human operator on board the vessel, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off the ship, for example DP capability plots, OEM configuration recommendations, weather routing.

AL 3) ‘Active’ human in the loop
Decisions and actions at the ship level are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them. Data may be provided by systems on or off the ship.

AL 4) Human on the loop – operator/supervisory
Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them.

AL 5) Fully autonomous
Unsupervised or rarely supervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level.

AL 6) Fully autonomous
Unsupervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level (Lloyd’s Register Group Services Limited, 2016b, p.2).

This procedure provides the framework in accordance with seven autonomy levels from AL0 to AL6 as shown in Figure 3.
Figure 3: LR frameworks. Reprinted from Cyber-enabled ships ShipRight Procedure, by Lloyd's Register Group Services Limited, 2016, pp.21-22.
In accordance with these frameworks, actions to be taken are identified based on the autonomy levels. So, it is easy to follow the assessments, processes and considerations required based according to autonomy levels.

In addition, this procedure explains how to assess six risks, namely system, human-system, software, network and communications, data assurance and cyber security, which are identified in the first guidance. For example, for cyber-security, it is required to use the National Institute of Standards and Technology (NIST) Framework for Improving Critical Infrastructure to identify the potential threats in order to respond to these threats to protect ships. Moreover, this procedure provides a check list to assess the security of the system (Lloyd’s Register Group Services Limited, 2016b).

.5 Autonomous unmanned vehicle systems (AMOS)

AMOS (Centre for autonomous marine operations and systems) was established by the Departments of Marine Technology and Engineering Cybernetics at NTNU and international and national collaborators, such as: the Research Council of Norway, Statoil, DNV-GL, MARINTEK, SINTEF Fisheries and Aquaculture, and SINTEF ICT, and selected as a Centre of Excellence (CoE) by the Research Council of Norway in 2013 (NTNU, n.d.-a, 2013).
Their vision is as follows:

To establish a world-leading research centre for autonomous marine operations and systems.

To nourish a lively scientific heart in which fundamental knowledge is created through multidisciplinary theoretical, numerical, and experimental research within the knowledge fields of hydrodynamics, structural mechanics, guidance, navigation, and control.

Cutting-edge inter-disciplinary research will provide the necessary bridge to realise high levels of autonomy for ships and ocean structures, unmanned vehicles, and marine operations and to address the challenges associated with greener and safer maritime transport, monitoring and surveillance of the coast and oceans, offshore renewable energy, and oil and gas exploration and
production in deep waters and Arctic waters (NTNU, 2013, p.2).

In order to achieve this vision, AMOS has two research areas: as “Unmanned vehicles and robots” and “Safer, smarter and greener marine operations” (NTNU, n.d.-b, para.1). There are four projects related to “Unmanned vehicles and robots”. Project 3 (“Autonomous unmanned vehicle systems”), in particular, is related to unmanned ships (Sørensen, 2015, p.48). This project focuses on the following topics:

- Autonomous system and payload architectures
- Coordinated operation of a sensor network of unmanned vehicles and floating nodes
- Integrated underwater navigation and mapping
- Autonomous object detection and tracking in marine environments using infrared sensors
- Sensor-based guidance and path optimization
- Coordinated and cooperative control architectures for intelligent task execution and collision avoidance in uncertain maritime environments (NTNU, 2013, p.18).

.6 Development of Autonomous USV for Maritime Survey and Surveillance

This project is led by the Korea Research Institute of Ship & Ocean Engineering (KRISO), sponsored by Ministry of Oceans and Fisheries, R.O.K (Kim, 2016). KRISO was established in 1973. It deals with national issues by developing and researching technology in the areas of “environmentally friendly future shipping technology, ships
and ocean engineering technology, maritime accident response and marine traffic system technology, and underwater robot and maritime equipment technology” (IALA, n.d., para.3). This project was established in July, 2011 and will be completed in July, 2018. It mainly focuses on the development of Autonomous Unmanned Surface Vessels (USV) for maritime survey and surveillance. They suppose that this system can be useful to dangerous and/or time-consuming operations, such as illegal fishing surveillance and pollution monitoring and control (The Korea Advanced Institute of Science and Technology, 2016). The objective of this project is to develop an autonomous USV which has following performances (Kim, 2016):

- Specification: maximum size 3tons; maximum speed 45kts on up to Sea state 4
- To be remotely operated from a mother ship
- To equip automatic obstacle detection/tracking and collision avoidance system, launch and recovery (L&R) system and wireless communication system
- To enable maritime survey and surveillance system to be remotely controlled.

Figure 5: The concept of ship. Reprinted from Maritime Safety & Unmanned Technologies, by S.Kim, 2016, p.17.
.7 Highly reliable intelligent ship

This project was implemented in Japan to develop highly reliable plants and highly automatic operation systems from 1983 to 1988 to respond to the report that was submitted by the Transport Policy Council. The aim of the development of highly automatic operation systems was to develop the integrated comprehensive system of marine and land. This system can operate ships without any interaction by crew on board and receive support from a shore based system, which is linked through satellites. Highly automatic operation systems can be divided into two categories of systems, namely optimal automatic operation system, which deals with operation mainly in high seas and automatic port entrance and leaving system, which deals with operation in harbors. The optimal automatic operation system comprises of optimal route planning system, monitoring and evaluating system of sea condition and weather, system of monitoring and evaluating of hull condition and attitude control, and prevention system of collisions and groundings. The automatic port entrance and leaving system consists of an automatic harbor operation system, automatic berthing and re-berthing system, automatic anchoring and mooring system and automatic cargo handling system. In 1988, all of the systems were simulated on a computer.

From this research, it was found that almost all technologies exist. Also, several problems for putting them into practical use were found as follows (Japan Ship Technology Research Association, 1993):

- Improvement of sensor technology to detect other ships
- Use of GPS
- Amendment of regulations
- Improvement of reliability of equipment without maintenance
- Addition of learning ability to AI (Artificial Intelligence)
- Improvement of cost benefit

The survey of the seven selected projects demonstrates and shows that the concept of unmanned ships was already in existence in the 1980s, but it has not been put into practice yet. In addition, the project ‘Highly reliable intelligent ship’ already found that almost all technologies exist and sensor technologies should be further developed for practical use. Statements of Rolls-Royce and MUNIN are concluding this in a similar manner. However, currently ongoing projects are still focusing on development of sensor technologies and they are struggling to overcome the challenges. Furthermore, classification societies are interested in developing unmanned ships from not only the administration side, like LR, but also the manufacture side, like DNV-GL.

2-3 Identification of problems of introducing unmanned ships to the existing maritime transportation system

Unmanned ships are a new but strong trend in the maritime sector. However, there seem to be a lot of problems not yet solved. That is why there are several projects that carry out research and implement surveys in order to make unmanned ships possible. These challenges or problems can be divided into three categories, technical, administrative/regulatory and operational. In this sub chapter, challenges or problems will be classified into these categories and explained.
1 Technical challenges and problems

As mentioned earlier, according to AAWA (2016), there are enough technologies to make unmanned ships a reality. However, the integration of these technologies is an important concern. In particular, the fusion of sensors is a main topic (AAWA, 2016). On the other hand, Situation Awareness (SA) is an important factor for safety of navigation and, currently, crews are in charge of that. Safahani & Tuttle (n.d.) define SA as “the perception of the elements in the environment within volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (p.1). Since unmanned ships do not have humans on board, sensors will have to substitute for eyes. There are, of course, enough sensor technologies, such as Laser Imaging Detection and Ranging (LIDAR), Radar and Cameras. Nevertheless, one problem still remains because Rule 5 of COLREG requires every ship to implement look-out by eye and ear (Baldauf, 2016). Also, single sensor technology is not enough to create SA for unmanned ships. It means that the inputs from sensors must be integrated in order to create SA because this data might be used for route planning, and collision and grounding avoidance. For example, Google’s autonomous car, which is the most advanced autonomous car navigation, is struggling to deal with new environments, such as new and unmapped roads, and accidental events, such as extreme weather conditions and traffic regulations (AAWA, 2016).

Another technical concern is how to secure the system from cyber risk, such as hacking and jamming. Actually, this is not only for unmanned ships but also for conventional ships (Arnsdorf, 2014; Osler, 2015b; Patraiko, 2014). For example, IMO approved
Interim Guidelines On Maritime Cyber Risk Management to implement cyber risk management in order to address cyber security (IMO, n.d.-d). IMO has already realized that cyber security is an important issue to the shipping sector. However, according to Osler (2015b), unmanned ships will further increase cyber risk. There are two reasons. Firstly, internet access speed is getting faster and unmanned ships require high-speed internet, meaning that hackers can connect and hack the systems faster than before. If speed is slow, it takes time to hack, so hackers might be held back. Secondly, unmanned ships are controlled by computers installed on board. If hackers successfully hack the ships, they can control ships easily. This may even change the way that piracy is conducted because pirates do not need to get on board to loot ships. Needless to say, it is going to be safe for the shipping sector since nobody will be on board, so nobody will be held hostage. On the other hand, MUNIN (n.d.) stated that it should be possible to design the system to be able to have more defense and resistance against hacking than conventional ships.

In addition, monitoring and controlling on board equipment and cargo must be implemented by the system on board. This activity is quite crucial for crew to sense the abnormities of cargo or the failures of equipment in advance. Therefore, the system has to be able to identify abnormities or failures and take appropriate actions (MUNIN, 2016).

Furthermore, it becomes easy for pirates to get on board without any objection. Currently, ships may have security guards on board so that they can protect themselves
from piracy. However, if unmanned ships carry security guards, that is reversing the logical order of things. It is crucial to consider how to design pirate-proof ships (Grey, 2014). For example, it seems that the design of Rolls-Royce looks difficult to get on board as Figure 6 shows.


.2 Administrative and Regulatory challenges and problems

The main challenge is that Conventions do not correspond to unmanned ships. According to Toor (2015), there is a perception that regulatory challenges could create
a bigger bottleneck than technical ones. International shipping currently works under international regulations. States implement regulations and ships need to comply with these regulations. However, these regulations were developed for conventional ships, not for unmanned ships. In other words, there is no regulation for unmanned ships yet. It may be interpreted that unmanned ships do not need to comply with existing regulations. In reality, there is no definition that clarifies whether the definition of ship includes unmanned ships or not (AAWA, 2016). Certainly, this is a grey zone, but many think that the definition of ships includes unmanned ships. In addition, there is a minimum manning requirement in SOLAS. In this situation, unmanned ships are illegal to operate on an international voyage (Arnsdorf, 2014; Toor, 2015).

Looking into details of Conventions, according to AAWA (2016), SOLAS, COLREG, STCW and liability regulations must be reviewed and amended. Firstly, SOLAS is the main Convention for maritime safety and addresses a range of factors under its 14 chapters. However, it is difficult to apply this Convention to unmanned ships since equipment, design and operational procedures will be different from conventional ships because no human operator will be on board. In order to make unmanned ships as safe as conventional ships, SOLAS must be reviewed and amended carefully.

Secondly, COLREG is another important Convention that regulates the operation of ships to avoid collision, addressing factors such as look-out (IMO, n.d.-a). On unmanned ships, sensors will act as a substitute for humans to implement look-out. However, COLREG requires crew to be on board to implement look-out. It should be
considered whether sensors can be replacement for humans or not (AAWA, 2016). A review and revision of Rule 5 of COLREG, which requires look-out by eye and ear, should also be considered.

Thirdly, STCW is a Convention that regulates training, certification and watchkeeping standards for seafarers (IMO, n.d.-b). This Convention applies to seafarers on board, not persons on shore (AAWA, 2016). Persons who are in charge of remote control and/or supervising ships from shore are not regulated in this Convention. In other words, no regulations or authorization schemes apply to those persons. Since they have authority to control ships, there must be regulations to authorize them. A potential approach to solve this operational and administrative problem may start from Vessel Traffic Services (VTS) rules and regulations. This is an example of the type of scheme applicable to shore based operators, such as Vessel Traffic Services (VTS). IMO developed “GUIDELINES FOR VESSEL TRAFFIC SERVICES (Resolution A.857(20))” and IALA developed “Standards for Training and Certification of VTS Personnel (IALA Recommendation V-103)”. These guidelines provide model training courses for VTS operators and certification schemes to qualify VTS operators to ensure that they have sufficient knowledge, skill and experience to handle VTS (IALA, 2013; IMO, 1997).

Lastly, the liability of unmanned ships needs to be more comprehensively discussed. When accidents happen under the controlled of the systems, who will be liable for accidents? This must be clarified before unmanned ships are put into service. Some
car companies have stated that “we are the suppliers of this technology and we are liable for everything the car is doing in autonomous mode. If you are not ready to make such a statement, you shouldn’t try to develop an autonomous system” (AAWA, 2016). Needless to say, legislation for cars may be different from ships and maritime legislation, so it is difficult and needs to be studied in detail to adopt this principle.

Furthermore, in reality, no proposals on unmanned ships have been made in IMO yet (Arnsdorf, 2014). From this point, it might be said that no States are ready to accept unmanned ships and/or put a priority on unmanned ships, even though some classification societies have projects about unmanned ships. According to United Nations Convention on the Law of the Sea (UNCLOS) (1982), ships need to be registered under the flag of one State. Ships need to comply with the national regulations of that state in accordance with international regulations, but there are no international regulations. It is possible for flag states to develop their own national regulations; however, it might be difficult to navigate to another country with different regulations. So, lack of international regulations is already causing a lack of national regulations. This means that no State can sail unmanned ships, except for domestic internal navigation purposes.

.3 Challenges and problems regarding the operation of unmanned ships

There are several challenges/problems related to operation, such as maintenance, cargo management, response to emergency situations, search and rescue (SAR), and work load.
Firstly, to the replacement of the daily maintenance operations is one of the difficult tasks. Daily maintenance is an essential factor for maintaining ships in good condition (Hapag-Lloyd, 2016). There are two benefits. One is that the docking period of a ship can be minimized and another is that the risk of technical failure might be reduced. These benefits may be able to maximize profits because the operation of ships can be maximized. In addition, when it comes to selling ships, good condition is an essential point. However, unmanned ships do not have crew on board to implement daily maintenance during voyages.

Secondly, responsibility for cargo management is another crucial problem. Normally, the first officer is in charge of cargo management on conventional ships. In particular, the management of the loading and unloading of cargo is an essential job for the first officer. However, in unmanned ships, there is nobody who can implement cargo management on board. So, it is necessary to find another person who can be in charge of cargo management or a completely new solution needs to be established. A possible solution could be the port operators or designated person, but they need to be trained and procedures must be developed (AAWA, 2016).

Thirdly, response to emergency situations should be considered. It takes time to respond to emergency situations from shore (Hapag-Lloyd, 2016). Of course, it is possible to install additional equipment for these situations, but it may raise the price of ships and reduce the benefits of unmanned ships. Also, there is no clear instruction to determine how much additional equipment might be sufficient or what kind of
additional equipment might be needed.

Fourthly, SAR needs to be discussed rigorously. Under SOLAS Chapter V, ships are required to engage in SAR when they receive a distress call. Unmanned ships cannot provide rescue operations, although they could possibly to assist in search operations. If there are only unmanned ships, this is not going to be a problem. However, there might be manned and unmanned ships together. The SAR procedure of unmanned ships should be discussed and developed in accordance with their ability. Unmanned ships may provide some life-saving appearance and could be brought to the emergency scene, for instance.

Finally, limitation of work load of operators on shore should be identified. As mentioned earlier, there is no regulation for operators on shore. It might be possible to apply the labor laws of land to them. However, there is no information as to how many ships an operator could handle at once. For example, in Unmanned Aircraft System (UAS), some mistakes have already happened when the operator changeover or handoff. These mistakes may cause accidents (AAWA, 2016). Work load should be limited in order to avoid accidents and operators should have some margin to be able to respond to any situation. In addition, in order to prevent this kind of mistakes, certification of operators might be helpful or even a compelling need. For example, there are several guidelines for VTS operators. These guidelines provide training requirements and certification scheme of VTS operators to maintain appropriate level (IALA, 2013; IMO, 1997). This kind of approach can be applied and has to be further
developed to completely adapt training and qualification rules and regulations to remote control operators as well.
3. Surveys of ships

In order to consider unmanned ships, it is beneficial to use the potential scenario of introducing unmanned ships into maritime transportation. For example, MUNIN applied a basic scenario about unmanned ships to implement its research. It used a dry bulk carrier operating in international trade. This kind of ship has key characteristics, such as low cargo requirements, high attractiveness for slow steaming and long cargo transportation compared to the container trade. These characteristics are suitable to MUNIN’s purposes because its focus is autonomous operation in high seas (MUNIN, 2016). When it comes to operation, there are several factors to ensure the safety of ships, such as proper regulations, surveys of ships and port State control (Maritime Bureau MLIT, 2016). In this chapter, the survey scheme will be explained and possible challenges will be identified.

3-1 Existing scheme

Surveys of ships are an important factor to ensure that ships are seaworthy. Surveys have quite a long history. They were started in the 18th Century by LR. At that time, the aim was to provide information on the quality of ships to merchants and underwriters by surveying the conditions of hulls and equipment (Lloyd’s Register Group Services Limited, n.d.-a). Surveys were first developed for insurance purposes.
In the 19th Century, other classification societies were established to carry out this service and some countries also started to survey their ships, including Japan. Japan started surveys in 1889 to check the seaworthiness of ships in accordance with national regulations. The Titanic accident was an epoch-making event which made surveys a global occurrence. After the Titanic accident, the international community developed and adopted SOLAS in 1914 to respond to the necessity for international regulation. Under SOLAS, flag States have an obligation to implement surveys of ships flying their flag. This is the reason why surveys spread all over the world. Many items are required to be checked by surveys (Chubu District Transport Bureau MLIT, n.d.). IMO states that:

All ships must be surveyed and verified by officers of the flag State Administrations or recognized organizations (ROs)/recognized security organizations (RSOs)/nominated surveyors so that relevant certificates can be issued to establish that the ships are designed, constructed, maintained and managed in compliance with the requirements of IMO Conventions, Codes and other instruments (IMO, n.d.-e).

It is simply said that surveys are used to verify whether ships comply with regulations or not. It is the obligation of flag States to provide surveys and it is an obligation for ships to take surveys before they start to navigate. Currently, there are a number of regulations that have requirements of surveying, such as SOLAS, International Convention for the Prevention of Pollution from Ships (MARPOL) and International Convention on Load Lines (LLC). So, surveyors need to carry out surveys individually
because application of regulations may be different depending on the ship. There are various types of surveys depending on regulations. For example, under SOLAS Chapter I, there are five main surveys, initial, annual, intermediate, periodical and renewal surveys. The definitions of these surveys are as follows:

- An initial survey is a complete inspection before a ship is put into service of all the items relating to a particular certificate, to ensure that the relevant requirements are complied with and that these items are satisfactory for the service for which the ship is intended.

- A periodical survey is an inspection of the items relating to the particular certificate to ensure that they are in a satisfactory condition and fit for the service for which the ship is intended.

- A renewal survey is the same as a periodical survey but also leads to the issue of a new certificate.

- An intermediate survey is an inspection of specified items relevant to the particular certificate to ensure that they are in a satisfactory condition and fit for the service for which the ship is intended.

- An annual survey is a general inspection of the items relating to the particular certificate to ensure that they have been maintained and remain satisfactory for the service for which the ship is intended (2013 Consolidated Version of the Survey Guidelines under the Harmonized System of Survey and Certification, 2011, 2013).

Ships need to take initial surveys to get Certificates. The validation of Certificates is
usually five years. There are several Certificates that will be issued after initial and renewal surveys under SOLAS. Moreover, the certificates that a ship is required to carry also depends on the exact type of ship. For instance, like the bulk carrier used in the MUNIN scenario, a ship should have a Cargo Ship Safety Construction Certificate, a Cargo Ship Safety Equipment Certificate and a Cargo Ship Safety Radio Certificate (the Cargo Ship Safety Certificate can be an alternative to these three Certificates) (DNV-GL, 2015). These Certificates are valid for five years and renewal surveys are required to renew the Certificates. A periodical, an intermediate and an annual survey are required within the validation of Certificates, as follows (2013 Consolidated Version of the Survey Guidelines under the Harmonized System of Survey and Certification, 2011, 2013):

- Cargo Ship Safety Construction Certificate
  - Initial surveys
  - Annual surveys
  - Intermediate surveys
  - Renewal surveys

- Cargo Ship Safety Equipment Certificate
  - Initial surveys
  - Annual surveys
  - Periodical surveys
  - Renewal surveys

- Cargo Ship Safety Radio Certificate
  - Initial surveys
- Periodical surveys
- Renewal surveys.

The frequency of each surveys is as follows:

- Annual survey should be held within three months before or after each anniversary date of the certificate
- Intermediate survey should be held within three months before or after the second anniversary date or within three months before or after the third anniversary date of the appropriate certificate and should take the place of one of the annual surveys
- Periodical survey should be held within three months before or after the second anniversary date or within three months before or after the third anniversary date in the case of the cargo ship safety equipment certificate and should take the place of one of the annual surveys and within three months before or after each anniversary date in the case of the cargo ship safety radio certificate (2013 Consolidated Version of the Survey Guidelines under the Harmonized System of Survey and Certification, 2011, 2013).

Through the review, it can be said that surveys of ships are a strict scheme to make ships comply with regulations in order to secure safety of navigation.

- Side effects of surveys -

There are some side effects of surveys. The first is that the crew may learn more about
their ships and keep things tidy and in order while they are preparing for survey. During a survey, a lot of items might be checked and some items are not used often. Usually, items which are used often come in the front and items which are not used often enter in the back. However, items which are not used often are sometimes quite important for emergency situations. So, it is good to keep things tidy and in order. Also, as experienced when conducting surveys, some crew forget how to use emergency steering gear. A survey may provide a good opportunity for crew to review some important procedures. Another thing is that ships can improve their conditions. Ships may take major maintenance which cannot be achieved by daily maintenance. Even if daily maintenance is perfect, the condition of ships is not always perfect because there is a limitation to what the crew can do on board. Also, the crew might check the condition of the ship as a whole and might be able to fix defects which do not relate to survey.

- PSC -

Nevertheless, survey is not a perfect system for two reasons. Firstly, surveys ensure that ships comply with regulations at the timing of survey and do not ensure that ships comply with regulations until next survey. While ships are operating, technical failures might occur and these can be deficiencies that are not in compliance with regulations. Secondly, the capacity of some flag States is insufficient to implement surveys. This may contribute to cause improper surveys (Xu, 2001). These factors, such as lack of maintenance and improper survey, may create substandard ships which do not comply with regulations (Anderson, 2002; Xu, 2001). Substandard ships, such as Erika and
Amoco Cadiz, caused huge disasters. In order to eliminate substandard ships, port State control (PSC) was developed (Xu, 2001). PSC is an on-site inspection which allows port States to carry out inspections to verify whether foreign ships are in compliance with regulations or not (Maritime Bureau MLIT, n.d.). PSC officers have the power to detain ships if deficiencies are found. This is quite an important factor because detained ships cannot operate and may lose contracts. Needless to say, in this situation, ships are not able to make profits. In order to avoid this situation, ships must be maintained properly to comply with regulations.

3-2 Analysis of challenges
The combination of surveys and PSC is an effective way to maintain the safety of ships. Certainty, this would apply to unmanned ships. However, since unmanned ships are a new concept, there could be some impacts on these schemes. The big challenge is that, according to present state of the art, unmanned ships will consist of ships and remote control centers. Currently, there is no scheme to check this kind of facility. The main challenge is how to implement flag State surveys to unmanned ships, especially if they are connected to a remote control center. In addition, determining the interval of surveys is another challenge because remote control rooms may supervise several ships at the same time. Furthermore, since no crew is on board, how to carry out PSC is an essential item to be elaborated. In this sub-chapter, these three challenges, flag State survey, interval of surveys and PSC will be analysed.
Flag State Survey

As mentioned above, flag State surveys are the basic concept to maintain ship safety. There is no doubt that surveys are required for unmanned ships as well. However, there is a big difference between manned ships and unmanned ships. That is, unmanned ships have remote control centers. Remote control centers are a new concept not only for IMO but also for the shipping industry. In order to consider the procedure for carrying out surveys on unmanned ships, two factors should be discussed, namely the relationship between unmanned ships and remote control centers, and surveyors.

- Relationship between Ships and Remote Control Centers-

As mentioned earlier, a remote control center can be considered as part of an unmanned ship. When shipping companies want to introduce unmanned ships into the shipping market, a ship and a remote control center will be created at the same time. However, when it comes to a second ship, only the ship will be constructed because a remote control center might be capable of handling several ships at simultaneously. This is the challenge. For ships, surveys will be implemented as usual and certificates will be issued, but what about the remote control centers? Is it required for remote control centers to take a survey each time a new ship is introduced under its control? The answer is yes and no. The reason it is yes is that the remote control center should show the capability to handle newly introduced ships. It is, of course, not required to take a whole survey, but an efficacy test should be performed to verify the capability of remote control centers. On the other hand, the reason it is no is that it is possible to clarify the capacity of a remote control center and what kind of systems should be on
board to connect to the remote control center at its initial survey. Needless to say, it is required to identify which ships or systems on board are controlled by which remote control centers. In order to do so, a new Certificate for remote control centers should be developed and must be kept there. If a new Certificate for remote control centers can specify the system on board which can be connected to the remote control center, it may be easier to identify which ships or systems on board can be controlled by which remote control center. For example, the approach of the Certificate for ECDIS can be applied to new Certificate for remote control centers because the Certification process for ECDIS clearly identifies components of ECDIS, such as panel computer and software, with e.g. model name. So far, a remote control center, in the same sense, can also be considered a complete system comprising of soft and hard ware.

- Surveyors -

Surveyors implement ship surveys. In IMO Instruments Implementation Code (III Code), there are requirements as follows:

Flag State surveyors

28 The flag State should define and document the responsibilities, authority and interrelation of all personnel who manage, perform and verify work relating to and affecting safety and pollution prevention.

29 Personnel responsible for, or performing surveys, inspections and audits on ships and companies covered by the relevant international mandatory instruments should have as a minimum the following:

1 appropriate qualifications from a marine or nautical institution and relevant
seagoing experience as a certificated ship's officer holding or having held
a valid management level certificate of competency and having maintained
their technical knowledge of ships and their operation since gaining their
certificate of competency; or
.2 a degree or equivalent from a tertiary institution within a relevant field of
engineering or science recognized by the flag State; or
.3 accreditation as a surveyor through a formalized training programme that
leads to the same standard of surveyor's experience and competency as that
required in paragraphs 29.1, 29.2 and 32.
30 Personnel qualified under paragraph 29.1 should have served for a period of
not less than three years at sea as an officer in the deck or engine department.
31 Personnel qualified under paragraph 29.2 should have worked in a relevant
capacity for at least three years.
32 In addition, such personnel should have appropriate practical and theoretical
knowledge of ships, their operation and the provisions of the relevant
national and international instruments necessary to perform their duties as
flag State surveyors obtained through documented training programmes.
33 Other personnel assisting in the performance of such work should have
education, training and supervision commensurate with the tasks they are
authorized to perform.
34 Previous relevant experience in the field of expertise is recommended to be
considered an advantage; in case of no previous experience, the
Administration should provide appropriate field training.
35 The flag State should implement a documented system for qualification of personnel and continuous updating of their knowledge as appropriate to the tasks they are authorized to undertake.

36 Depending on the function(s) to be performed, the qualifications should encompass:

.1 knowledge of applicable, international and national, rules and regulations for ships, their companies, their crew, their cargo and their operation;

.2 knowledge of the procedures to be applied in survey, certification, control, investigative and oversight functions;

.3 understanding of the goals and objectives of the international and national instruments dealing with maritime safety and protection of the marine environment, and of related programmes;

.4 understanding of the processes both on board and ashore, internal as well as external;

.5 possession of professional competency necessary to perform the given tasks effectively and efficiently;

.6 full safety awareness in all circumstances, also for one's own safety; and

.7 training or experience in the various tasks to be performed and preferably also in the functions to be assessed.

37 The flag State should issue an identification document for the surveyor to carry when performing his/her tasks (IMO Instruments Implementation Code (III Code), 2013).
Taking into account these requirements, surveyors must be well qualified to implement appropriate surveys. Surveyors have sufficient knowledge and are specialists in ships, but they are not specialists in computer systems and telecommunication systems. Moreover, there is no person who has experience with unmanned ships. So, surveys for ships may not be changed; on the contrary, check points would be reduced because there will no longer be accommodations. However, as mentioned in chapter 2-3, operating systems will use a lot of sensors to create SA, and must be complex and advanced systems. Remote control centers would be connected to ships by high-speed and high-capacity telecommunication systems based on high technologies. In this regard, the biggest challenge for surveyors is to carry out surveys, especially initial surveys, of remote control centers. The reason why initial surveys are the most difficult is that surveyors need to verify and approve the systems as well as the functions of remote control centers. Needless to say, regulations will be developed which incorporate such requirements.

In order to solve this challenge, development of specific surveyors of remote control systems with advanced knowledge of computer systems can be a possible solution and a requirement. It would be beneficial to check these high technologies in detail but when it comes to thinking of remote control centers as a part of ships, new surveyors must have basic knowledge about ships and communication with ship surveyors is crucial to share the information.

Another solution is to provide sufficient training to all existing ship surveyors to be
able to handle both ships and remote control systems. The benefit of this solution is that one surveyor can take care of the whole survey process. The weak point is that the responsibility of one surveyor may increase and too much information will be required. Both ideas have pros and cons. It is better to develop requirements for surveyors of remote control centers first and leave some space for flag States to decide which approach is suitable for their country. Furthermore, for unified implementation of surveys, development of survey procedures and training procedures might be helpful. Detailed and thorough studies are needed to define the knowledge, skills and related requirements.

.2 Interval of Surveys

As mentioned in chapter 3-1, ships take safety related surveys annually. The introduction of unmanned ships may not change this basic principle because the requirements for safety are unchanged. Even though there is no crew on board, the same level of safety should be ensured as on conventional ships. If the same requirements related to safety apply to unmanned ships, this idea is practicable. However, the big concern is the interval of surveys for remote control centers. The survey interval depends on the reliability of the systems used in remote control centers. Evaluating the reliability is a significant factor to consider. There is no information or experience about prolonged use of systems. Test operation might be very important to collect data for evaluation. There is also the factor that remote control centers may handle several ships. Taking this into account, the worst possible scenario is that remote control centers may be operated twenty four-seven. A possible solution, among
others, may be that the survey interval might be decided by work hours like airplanes. For example, there are four types of survey, ‘A check’, ‘B check’, ‘C check’ and ‘SI check’. Every survey is carried out based on work hours and ‘A check’ is for general visual inspection every 300 hours (Japan TransOcean Air, n.d.). However, these surveys are carried out by airlines which are certified to implement surveys by States in accordance with approved service manuals and States implement on-site inspection of airlines to verify the status of implementation (Civil Aviation Bureau MLIT, n.d.). Moreover, consistency cannot be established with interval of surveys of ships. Introducing a different scheme may increase the burden on flag States and the timing of surveys cannot be estimated. In order to maintain the original procedure of implementing surveys annually, back-up systems might be a potential approach. Certainly, this will increase cost, but when remote control centers terminate their functions, ships are uncontrollable. This will increase the risk of accidents. In conclusion, sufficient data collection is an urgent matter to consider when determining the appropriate interval of surveys of remote control centers. In order to help this, it might be a good option to ask or even require shipping companies to provide data of fleet operation centers (FOC).

3 Port State Control

Since there is no crew on board, implementation of PSC may become more difficult. The principal of PSC is to verify whether ships flying foreign flags comply with regulations or not. The scope of PSC is not only the structure and equipment of ships but also operational matters, such as Certificates of seafarers and record book.
However, there is no crew to accept PSC officers on board and all records may be kept in remote control centers. In addition, remote control centers would not move once they are established. Taking these factors into account, PSC for ships and PSC for remote control centers will be discussed.

- PSC for ships -

The procedure for PSC for ships will probably not change significantly. The design of ships might be substantially changed because accommodation will no longer be required, but the basic structure of ships and navigation equipment may remain the same. However, the most fundamental change is that there will be nobody to accept PSC officers on board. If PSC officers cannot get on board, PSC will no longer work in the traditional manner. This situation may potentially increase substandard ships. In order not to do so, a designated person from the shipping company should be there when the ship is in port. Nevertheless, PSC is not routine work and there is no announcement that a PSC inspection will be implemented. Taking this aspect into account, is it possible to require a shipping company to allocate a representative for PSC at every port? This will be a major topic for discussion between States and industries. This is not a realistic idea because it would increase cost and reduce the benefits of unmanned ships. In this case, the responsibility of the flag States becomes more significant than for conventional ships.

- PSC for remote control centers -

Unfortunately, PSC for remote control centers is impossible. PSC is done by port
States where ships currently exist, but remote control centers are limited to one place and there is no need to move, although in the future there might be an option to have mobile control centers. Since, for now, remote control centers will be immobile, port States do not have the chance to implement PSC inspections of remote control centers. However, remote control centers have significant functions for the operation of unmanned ships. If PSC inspection is impossible for remote control centers, the reliability and compliance of regulations of remote control centers fully relies on flag States. In this case, the responsibility of flag States become greater than for conventional ships.

- Solution -

The reason for the development of PSC cannot be forgotten. If there are only flag State surveys, substandard ships may increase and substandard remote control centers may be created. These situations will increase the risk rate of accidents. In order to solve the challenge of PSC, audit by third parties or IMO may be a possible solution instead of PSC. The aim of this new audit scheme would be to eliminate substandard ships and remote control centers, which may become an issue after the introduction of unmanned ships, to maintain safety level to the same level as conventional ships. The IMO Member State Audit Scheme (IMSAS) can possibly be recipients of this scheme. However, not every member State of IMO will have unmanned ships as their flag ships in the near future, and it would take time to review all countries that have unmanned ships under IMSAS. In this regard, it seems to be a better idea to develop an expert group to verify and check the condition of ships and remote control centers. The expert
group would consist of specialists in computer systems and telecommunication technologies and PSC officers, and would be independent. An independent expert group has more flexibility to move and implement audits, and they have enough knowledge to evaluate remote control centers from a technical and impartial standpoint.
4. SOLAS Chapter V

According to Toor (2015), legislation is the main barrier to the introduction of unmanned ships. Since ships can navigate all over the world through the oceans, international unified regulations are essential to keep the playing field level. However, IMO has not started to consider unmanned ships because they have not received any proposal from member States or industries (Arnsdorf, 2014). It will be an enormous task for IMO to review and revise all related regulations owing to fast development of technologies (Corbett, 2015). Taking this into account, in this chapter, the applicability of SOLAS Chapter V, which requires ships to have navigational equipment for safety of navigation, to unmanned ships will be discussed and possible bottlenecks will be identified.

4-1 Review

In order to review the applicability of SOLAS Chapter V to unmanned ships, it is important to confirm current regulations first by using a case study. In this study, a dry bulk carrier which is operating in international trade will be used like in the MUNIN concept study (MUNIN, 2016). After the confirmation, the applicability to unmanned ships will be discussed.
SOLAS has 14 Chapters, and Chapter V is “SAFETY OF NAVIGATION”. In Chapter V, there are 37 regulations and one appendix, as follows:

- Regulation 1 Application
- Regulation 2 Definitions
- Regulation 3 Exemptions and Equivalents
- Regulation 4 Navigational Warnings
- Regulation 5 Meteorological services and warnings
- Regulation 6 Ice Patrol Service
- Regulation 7 Search and rescue services
- Regulation 8 Life-saving signals
- Regulation 9 Hydrographic Services
- Regulation 10 Ships' Routeing
- Regulation 11 Ship Reporting Systems
- Regulation 12 Vessel Traffic Services
- Regulation 13 Establishment and operation of aids to navigation
- Regulation 14 Ships' manning
- Regulation 15 Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures
- Regulation 16 Maintenance of Equipment
- Regulation 17 Electromagnetic compatibility
- Regulation 18 Approval, surveys and performance standards of navigational systems and equipment and voyage data recorder
- Regulation 19 Carriage requirements for shipborne navigational systems and equipment
- Regulation 19-1 Long Range Identification and Tracking of Ships
- Regulation 20 Voyage data recorders
- Regulation 21 International Code of Signals
- Regulation 22 Navigation bridge visibility
- Regulation 23 Pilot transfer arrangements
- Regulation 24 Use of heading and/or track control systems
- Regulation 25 Operation of main source of electrical power and steering gear
- Regulation 26 Steering gear: Testing and drills
- Regulation 27 Nautical charts and nautical publications
- Regulation 28 Records of navigational activities and daily reporting
- Regulation 29 Life-saving signals to be used by ships, aircraft or persons in distress
- Regulation 30 Operational limitations
- Regulation 31 Danger Messages
- Regulation 32 Information required in danger messages
- Regulation 33 Distress Situations: Obligations and procedures
- Regulation 34 Safe navigation and avoidance of dangerous situations
- Regulation 34-1 Master's Discretion
- Regulation 35 Misuse of distress signals
- Appendix Rules for the management, operation and financing of the North
For the purpose of this study, SOLAS Chapter V regulations were categorized into three aspects, requirements for States (Reg.3-15, 17,18), requirements for ships (Reg.14, 16, 17, 19-30) and requirements for masters and officers (Reg. 23, 24, 26, 28, 31-35).

- Present state -
From the point of view of ships, requirements for ships and for masters and officers are important. The application of some regulations depend on ship type, size, construction date and navigation area. For example, regulation 30 is only applicable to passenger ships. In the same way that regulation 22 only applies to ships (>55m) constructed on or after 1 July 1998. When it comes to a dry bulk carrier which is operating in international trade, almost all requirements (Reg.14, 16, 17, 19-29, 31-35) are applicable. Presently, a bulk carrier needs to be equipped with all navigational systems and equipment, the long-range identification and tracking information, VDR and pilot transfer arrangements. That ship also must carry International Code of Signals and Volume III of the IAMSAR Manual and keep minimum safe manning documents. It should be designed in accordance with Regulation 22, Navigation bridge visibility. The master and officers on board are required to implement these requirements, as necessary.
- Unmanned ships –

If a dry bulk carrier is an unmanned ship, the question is which regulations might be affected. There are three main areas which will be affected, the obligation of masters, officers and crew, minimum manning requirement and pilot services.

As the name ‘unmanned’ suggests, there is no crew on board. As such, the implementation of the current obligation of masters and officers becomes a big concern. Since the vessel is unmanned, who is in charge of these obligations? Taking this situation into account, these regulations need to be reviewed and amended, and the definition of master, officer and crew might be re-identified. So far, it seems to be the shore-control operator who is responsible, but he is rather equivalent to watch officer, not necessarily to the captain. In addition, minimum manning requirement is another big issue. When a flag State is satisfied with the number and qualifications of crew, it will issue a minimum safe manning document. It is true that the decisions are left to flag States. So, it might be possible to be approved without crew on board, but shall be defined in relation to manning of remote control centers. However, it may safely be said that this requirement was developed based on manned ships because there was no unmanned ship yet in the shipping trade, nor has it been discussed. This issue is closely related to the issue of definitions of master, officer and crew because if the definition of officer includes remote controller, the minimum manning requirement can be complied with, without a person on board (AAWA, 2016).

Moreover, pilot services might become an issue. In this chapter, ships are required to
equip Pilot transfer arrangements under Regulation 23. The application itself is not an issue because a ship can be equipped regardless of whether a crew is on board or not. However, the application of these arrangements is an important concern. This regulation would probably need to be extended to not only pilot but also crew transfer arrangements, as MUNIN’s concept suggests that there might be a crew from/to pilot embarkation station.
4-2 Analysis of challenges

As mentioned above, when it comes to unmanned ships, there are three main issues related to SOLAS Chapter V, namely definitions of master, officer and crew, requirement of minimum manning and pilotage service. Definitions of master, officer and crew relate to the following regulations (The International Convention for the Safety of Life at Sea, 1974, 1974):

- Regulation 5 Meteorological services and warnings
  This regulation requires States to collect meteorological data from ships and provide information about meteorological data, such as warnings of gales, storms and tropical cyclones when appropriate, and weather information twice a day.

- Regulation 6 Ice Patrol Service
  This regulation identifies the Ice Patrol Service which provides escort services to ships navigating in the region of icebergs during the ice season and requires States to study and observe ice conditions in the North Atlantic.

- Regulation 11 Ship Reporting Systems
  This regulation identifies the requirements of ship reporting systems, such as how to establish ship reporting systems, what functions IMO has for ship reporting systems and what obligations the master of a ship has.

- Regulation 14 Ships' manning
  Under this regulation, States need to make sure that ships flying their flags are properly
manned from the point of view of safety of life at sea. In addition, ships shall have a minimum safe manning document, which would be issued by States as evidence, and are required to establish a working language on board.

- Regulation 16 Maintenance of Equipment

Appropriate maintenance of equipment is required under this regulation. If repair service is not available at a port, ships may be allowed to sail to the next port that has repair service, under the master’s responsibility.

- Regulation 22 Navigation bridge visibility

This regulation defines the requirement for the visibility of ships (>55m) constructed on or after 1 July 1998.

- Regulation 23 Pilot transfer arrangements

This regulation identifies the requirement for pilot transfer arrangements and the responsibility of the officer for the rigging of the pilot transfer arrangements and the embarkation of a pilot.

- Regulation 24 Use of heading and/or track control systems

This regulation requires ships to maintain condition to be able to switchover from auto to manual control in given situations, such as busy area and restricted visibility. The helmsman may be called to take over the steering in these situations by the officer of watch. Switchover must be supervised by the officer.
- Regulation 26 Steering gear: Testing and drills
This regulation identifies the requirement for steering gear test before departure, the requirements for emergency steering drills and the requirement for instructions of steering gear, which must be displayed on the bridge and in the steering gear room. In addition, officers are required to know the operational procedure for the steering gear. Furthermore, records of tests and drills have to be kept.

- Regulation 29 Life-saving signals to be used by ships, aircraft or persons in distress
A table of the life-saving signals which are described in Volume III of the IAMSAR Manual and illustrated in the International Code of Signals must be available to the officer of watch to communicate with SAR units.

- Regulation 31 Danger Messages
The masters of ships are required to communicate information about ice, derelicts and other direct dangers to navigation, tropical cyclones (storms), storms other than tropical cyclones and sub-freezing air temperatures to neighboring ships and competent authorities when they face these situations.

- Regulation 32 Information required in danger messages
The information to be included in danger messages about the situations identified in Regulation 31 is defined. It is a voluntary requirement for the master of a ship who sent a message about tropical cyclones to observe the situation hourly at least, no
longer than three hours if possible.

- Regulation 33 Distress Situations: Obligations and procedures
This regulation identifies the obligations of masters when they receive a distress call from any source. Generally, they need to provide SAR services. Ships which respond to a distress call might be requisitioned by the master of a ship in distress or SAR authorities. In addition, they should treat persons who are rescued humanely.

- Regulation 34 Safe navigation and avoidance of dangerous situations
This regulation requires masters to make a voyage plan by using appropriate nautical publications, taking some aspects, such as ships' routeing systems and weather conditions into consideration.

- Regulation 34-1 Master's Discretion
The Master's discretion for safety of life at sea and protection of the marine environment must not be interfered with by the companies which operate ships.

Requirement of minimum manning relates to Regulation 14 Ships' manning. Pilotage service relates to Regulation 23, Pilot transfer arrangements. In this sub-chapter, these issues will be discussed and some possible solutions will be given.

.1 Definition of Master, Officer and Crew
In SOLAS Chapter V, masters, officers and crew have obligations to implement some
requirements. However, there is no person on board an unmanned ship. In this situation, nobody can implement these obligations. It is important to clarify the definitions of master, officer and crew before discussion. Actually, there is no definition of these in SOLAS. However, other Conventions have these definitions. According to STCW, definitions of master and officer are as follows:

- Master means the person having command of a ship.
- Officer means a member of the crew, other than the master, designated as such by national law or regulations or, in the absence of such designation, by collective agreement or custom (STCW ANNEX ChapterI RegulationI/1, 1978).

According to Torremolinos Protocol of 1993 relating to the Torremolinos International Convention for the Safety of Fishing Vessels (SFV PROT), the definition of crew is: “Crew means the skipper and all persons employed or engaged in any capacity on board a vessel on the business of that vessel” (SFV PROT ANNEX ChapterI Regulation2, 1993).

Taking only these definitions into consideration, it is said that the definition of master does not mention whether the master should be on board or not. This is quite a surprise result that a master can be on shore if a master can have command of a ship on shore, in accordance with definition. So, if a remote controller is assigned as the master of an unmanned ship, there is a master of that unmanned ship. There is also an example that a pilot may sometimes give advice from shore within mandatory pilotage area because
a pilot cannot get on board e.g. due to extreme weather conditions. However, the definition of pilot remains. The definition of master may not require amendment for unmanned ships. Needless to say, the definition of master must be clarified.

However, officers and crew are identified as persons who work on board. In this regard, there are two ways to fix this situation. One is to change the definition to include remote controllers, enabling them to be officers or crew. The benefit of this solution is that it may reduce the work to amend the necessary regulations to correspond to unmanned ships. There are many regulations that identify the obligations of officers and crew under IMO Conventions. If the remote controller is included in their definition, these regulations may not need to be revised. However, the disadvantage is that if these obligations cannot be implemented from shore, requirements should be divided into two parts, for officers and crew on board and for officers and crew on shore. This may make regulations a little bit confusing and would require careful phrasing and wording.

Another solution is to establish a new definition of remote controller. The benefit of this is that the definition and regulations would be clear. The disadvantage is new regulations need to be established for remote controllers, which will increase the amount of work. It is important to clarify how to treat remote controllers under IMO. Furthermore, regardless of solutions, the requirements for master, officer and crew must be reviewed. There is a possibility that revision of the obligations may create unfair treatment between officers and crew on board and for officers and crew on shore.
if officers and crew on shore have more limitations. Further aspects may appear, which will need to be considered and covered accordingly.

.2 Requirement of minimum manning

Minimum manning is an important factor for safety of navigation. Before ships start navigation, they need to propose the plan of manning and receive the minimum safe manning document that will be issued by flag States. When flag States verify the plan, there are some criteria as follows:

2.1 A proposal for the minimum safe manning of a ship submitted by a company to the Administration should be evaluated by the Administration to ensure that:

.1 the proposed ship's complement contains the number and grades/capacities of personnel to fulfil the tasks, duties and responsibilities required for the safe operation of the ship, for its security, for protection of the marine environment and for dealing with emergency situations; and

.2 the master, officers and other members of the ship's complement are not required to work more hours than is safe in relation to the performance of their duties and the safety of the ship and that the requirements for work and rest hours, in accordance with applicable national regulations, can be complied with.

2.2 In applying such principles, Administrations should take proper account of existing IMO, ILO, ITU and WHO instruments in force which deal with:

.1 watchkeeping;
.2 hours of work or rest;
.3 safety management;
.4 certification of seafarers;
.5 training of seafarers;
.6 occupational safety, health and hygiene;
.7 crew accommodation and food;
.8 security; and
.9 radiocommunications (IMO, 2011, pp.9-10).

However, the decision to approve a proposal for the minimum safe manning of a ship is left to flag States. In ships are unmanned, there is no person on board and remote controllers on shore are possible alternatives to masters, officers and crew. However, as mentioned above, the current definition of officer does not include remote controller. It means that remote controllers cannot be alternatives to officers under current regulations. In this situation, it is doubtful whether ships can receive minimum safe manning documents or not. What kind of action is required to solve this situation? This is closely related to the definitions of master, officer and crew. The requirement of minimum manning has to be reviewed and revised in accordance with the solution that is adopted from the two suggested solutions for definitions of master, officer and crew. If the definitions of these include remote controller, this requirement may not have to be revised because the principle of manning may expand and the minimum safe manning document will be issued to unmanned ships. On the other hand, if a new definition of remote controller is established, the requirement must be revised,
depending on cases of manned ships and unmanned ships. Flag States need to make sure that the requirements are relatively equal to both ships.

In addition, if unmanned ships are operated in fully autonomous mode, not remotely controlled, who is going to be an alternative for remote controllers who engage in minimum manning? This is also big concern to be solved. One possible idea is to assign someone to be responsible for a ship. However, in this situation, is it right to apply the principle of minimum manning to ships? Remember that this requirement is for safety of navigation by requiring persons on board. If ships can operate fully in autonomous mode, it means that those ships are as safe as manned ships. On the other hand, this may bring another concern which is how to evaluate whether or not unmanned ships are as safe as manned ships.

.3 Pilot services

According to Regulation 23, ships need to carry pilot transfer arrangements and officers are responsible for the rigging of the pilot transfer arrangements and the embarkation of the pilot. However, on unmanned ships, who will accept the pilot and who can be in charge of the rigging of the pilot transfer arrangements and the embarkation of the pilot? The answer is no one. Needless to say, unmanned ships can carry a person for that purpose, but this is not realistic because of cost-benefit. Also, even though pilots can be on board, there might be no bridge. So, it may be impossible to be on board for pilotage services. Maybe, exemption can also be applied to unmanned ships. For example, ferries which frequently navigate within mandatory
pilotage area may not need to have pilots on board because they have demonstrated sufficient knowledge and skills to maneuver their ships in these fairways and port areas. So, the case of unmanned ships may be possibly one of such exemption cases. The careful discussion, of course, will be required. Here under, three possible solutions will be developed and discussed.

- Controller certified as a pilot -
This idea is that remote controllers are trained to be pilots in order to provide pilotage service themselves. Since the remote control center is immobile, it is almost impossible to get pilots to foreign ports. The benefits are that they can manage themselves and they know how to use the systems. On the other hand, there are two main issues. Firstly, pilots need to have local knowledge and experience as seafarers. Currently, pilots are typically specified to one port. In order to implement this, many controllers are required and they would need to be pilots at specific ports which require pilots. Secondly, there is doubt as to whether foreign States would allow this activity or not. If pilotage service is provided by States, it is going to be a challenge for them to work as pilots of these countries. However, in the MUNIN study, remote control using a Remote Maneuvering Support System (RMSS) was tested. This would lead to another option: providing helmsman with skills and knowledge of a pilot, and ability to steer the ship in remote mode using RMSS.

- Training will be given to pilots about systems -
This idea is to maintain the current pilotage scheme. In order to implement this idea,
training of pilots on remote control systems should be provided. The benefits are that the controller does not need to be familiar with ports, unlike pilots, and pilots can keep their jobs if they can adapt to this situation.

On the other hand, there are several issues. Firstly, how many pilots can be trained? Who is going to be responsible for this? Appropriate training would be required, but who can give the training to the pilots? If it is the obligation of States, some States do not have enough capacity to do. Secondly, as remote control centers are immobile, pilots need to have their own remote control center. In addition, there is no information as to whether the systems are standardized or not. If not, they need to prepare for all possible systems. It may be costly. Also, they need to establish high speed telecommunication systems, which may raise cyber risks.

- Pilot skills may be integrated into autonomous ship systems -

This idea is to integrate pilot skills into ship systems. It seems that the benefit is that it is going to be easy for ship owners to manage ships because no arrangement is required for pilotage any more. However, the way to transfer the know-how of pilots is a huge concern. Systems should have the same functions as pilots and information has to be up to date. This idea can be applied when fully autonomous operation becomes available.
5. Conclusion & Outlook

5-1 Conclusion

.1 The main purpose of this dissertation

Definitely, the new trend of the shipping industry is the development of unmanned ships. There are several motivations, such as response to the increase of demand in the shipping trade, improving ship safety by reducing human factors which are main causes of accidents and efficient operation of hydrographic surveys. This concept sounds futuristic, but it is strongly believed that it is coming in the near future. For example, according to Corbett (2015), the first unmanned coastal ship will be introduced by 2025. In order to make it possible, several projects have been or are being carried out by interested countries, companies and research institutions. These projects mainly focus on the operational challenges including technologies. However, the biggest challenge, which is legislation, has not or has only very roughly been addressed on a global level. Taking these aspects into consideration, this dissertation has summarized the main projects, identifying technical, legislative and operational challenges. It has also discussed the survey scheme and reviewed selected regulations of SOLAS Chapter V, which deals with safety of navigation and derived recommendations.
2 Method

Firstly, the research was implemented by a broad survey of literature, research reports and journal publications, and materials available via internet. The following important key words were used: unmanned ships, autonomous ships, remote control ships, SOLAS, CORLEG, auto pilot, safety navigation, IMO, autonomous car, unmanned vehicle, drone. Secondly, important information from projects, such as objective and methodology, was summarized and challenges were identified from the collected information. Thirdly, a review of survey schemes and SOLAS Chapter V was undertaken from the point of view of conventional ships and unmanned ships to identify the existing problems and challenges for the introduction of unmanned ships in commercial shipping, and potential solutions were presented.

3 Background & Definitions

There is no definition of ‘unmanned ship’ in international regulations. Through reviewing the literature, it was found that there are some definitions of unmanned vehicles in other transport modes, such as an unmanned aircraft, UAV and UGV. From these definitions, two important aspects were found to define ‘unmanned ship’. First, unmanned ships do not carry operators. Second, unmanned ships can be operated by remote control or in autonomous mode. Taking these aspects into consideration, the definition of unmanned ship was identified as ‘a ship that may operate in remote controlled and/or autonomous mode without any human operator onboard’.
- Considered projects -

In addition, in order to summarize and study the current situation of the development of unmanned ships, seven selected projects were reviewed and summarized, namely MUNIN, AAWA, ReVolt (DNV-GL), Cyber-enabled ships: ShipRight procedure guidance – autonomous ships (LR), Autonomous unmanned vehicle systems (AMOS), Development of Autonomous USV for Maritime Survey and Surveillance, and Highly reliable intelligent ship.

Firstly, the concept of MUNIN was to establish and develop an autonomous shipping system by implementing a case study which used a dry bulk carrier. The scenario of MUNIN was that a dry bulk carrier will be operated in open seas as unmanned ships, and approaching to and departing from ports will be operated by humans on board. The project also carried out a cost-benefit analysis, safe and security analysis, and legal and liable analysis to estimate the impacts on revenue, safety and security of ships and regulations. According to the analyses, unmanned ships are technically feasible and can increase profit, be safe and secure, and require regulations to be amended.

Secondly, the objective of AAWA is to make autonomous ships possible by researching the economic, social, legal, regulatory and technological factors. According to the project’s research, it was found that sufficient technologies are available to make it possible; however, the way to integrate these technologies is the biggest challenge. It was also realized that regulations will be the biggest obstacle to the introduction of unmanned ships.
Thirdly, the project ‘ReVolt’ is led by DNV-GL, which is the biggest classification society, and the motivation of this project is to shift the transportation of cargo from land to sea, by unmanned ships, due to capacity of land transportation within Europe. So, the concept of ReVolt is zero emissions unmanned ships for short voyage with battery power. Zero emissions are an important aspect, not covered by other projects.

Fourthly, LR has developed two documents which are ‘Cyber-enabled ships; Deploying information and communications technology in shipping – Lloyd’s Register’s approach to assurance’ and ‘Cyber-enabled ships: ShipRight procedure – autonomous ships’. In these documents, six risks to be considered before the introduction of unmanned ships and seven autonomy levels from AL0 (manual) to AL6 (fully autonomous) were identified, defined and explained. Also, how to apprise cyber-enabled system was explained.

Fifthly, AMOS is the center for autonomous marine operations and systems. It has established nine projects and Project 3 (Autonomous unmanned vehicle systems) is related to unmanned ships to develop autonomous systems and an object detection system by sensors.

In addition, KRISO is leading a national project called ‘Development of Autonomous USV for Maritime Survey and Surveillance’ to develop USV for dangerous and/or time-consuming operations of maritime survey and surveillance.
Lastly, a highly reliable intelligent ship project was implemented by Japan in the 1980s. At that moment, it was confirmed that technologies existed to create automatic operation through the project. However, several points to be improved were also identified, even at that early stage of the project.

Each project has different emphasized objectives and concepts, but the main point is to contribute to the development of unmanned ships. All projects mainly focus on technologies. Among these projects, the main challenges are how to integrate the technologies and the usage of sensors for obstacle detection.

- Challenges/Problems of unmanned ship -
Unmanned ships are still under development. In this regard, there are many challenges and problems that should be addressed prior to the introduction of unmanned ships into the shipping business. Taking this situation into account, challenges and problems were identified and categorized into three sectors, technical, administrative/regulatory and operational.

The main challenge of technologies is how to integrate the technologies that are already available because multiple sensor technologies are required to create SA. Autonomous cars have same challenges, for example, Google’s car is struggling to deal with new environments. In addition, cyber security is another big challenge because unmanned ships may create an easier situation for pirates to loot ships by hacking.
The conclusion from more or less all of the projects is that legislation is the biggest challenge for unmanned ships. The reason is that none of the IMO Conventions correspond to unmanned ships and IMO has not started to review and amend SOLAS, COLREG, STCW and liability or any other regulations that are important for the commercial operation of unmanned ships. Since unified and harmonized implementation of regulations is a crucial factor to maintain fairness for all shipping companies, regulations are an essential matter. For each regulation, the main points that will be affected by unmanned ships were identified.

Several operational challenges/problems were identified, such as maintenance, cargo management, response to emergency situations, SAR, and work load. There are two factors that create these challenges/problems, no crew on board to implement and no information about work load of remotely controlled ships from shore. In addition, possible solutions were presented to some cases.

4 Surveys of ships
Implementing surveys is a primary concern to flag States. In order to identify the challenges, a review of the current survey scheme was implemented by using a case study. Through reviewing the scheme, three main factors were identified, flag State surveys, interval of surveys and PSC.

Flag State surveys are fundamental activities to ensure that ships comply with regulations. Certificates issued after surveys are evidence to show the compliance of
ships. Without appropriate implementation of surveys, ships might be substandard. In order to prevent this from happening, the impacts on unmanned ships were discussed and the points that should be addressed were identified, such as relationship between unmanned ships and remote control centers, and surveyors. For these points to be solved, possible approaches for pragmatic solutions were developed and discussed.

Interval of surveys is another factor to be considered. Since remote control centers may handle several ships, they will be operated twenty-four-seven. So, reliability of systems must be tested and data should be collected to ensure a sufficient level of reliability. Survey intervals based on work hours and back-up systems were proposed as possible solutions. For emergency cases, back-up arrangements including operational procedures need to be developed and provided.

PSC is another scheme to ensure that ships comply with regulations. Since this is an on-site inspection, it is difficult to implement on unmanned ships as well as remote control centers. However, PSC plays an important role in the maritime industry. So, an audit scheme was proposed as a possible solution to be an alternative to PSC with the same functions as PSC.

.5 SOLAS Chapter V

SOLAS Chapter V is an essential chapter for safety of navigation. At first, each regulation was listed and simply categorized into three aspects, namely requirements for States, requirements for ships and requirements for masters and officers. Before
discussion of the applicability to unmanned ships, the applicability to conventional ships was reviewed by using a case study. Taking this review into consideration, the applicability to unmanned ships was discussed and three main factors were identified, such as definition of master, officer and crew, minimum manning requirement and pilotage.

Definitions of master, officer and crew should be clarified before discussing the requirements for masters and officers. Through the research, the definitions of these were found in other Conventions which may be generally used in the maritime industry. It is also found that these definitions were developed for conventional ships. In this regard, two developed suggestions were discussed, taking the strong and weak points of both suggestions into consideration.

The purpose of the minimum manning requirement is to enable ships to navigate safely from the point of view of manning. The problem and solution of this requirement depends on the definitions of master, officer and crew and both cases, depending on suggestions regarding the definitions, were discussed.

The style of pilotage may require change though the principles should remain the same. Three suggestions were drafted, namely controller certified as a pilot, advanced training given to pilots about systems and pilot skill to be integrated into systems. For these suggestions, scenarios, benefits and bottlenecks were discussed.
5-2 Recommendations

.1 Technology

- Short term -

Based on the research, generally speaking, it is said that basic technologies already exist to make unmanned ships a reality. However, integration of sensor technologies is still under development. This is an essential factor for unmanned ships, so it is crucial to develop this because ships cannot navigate without proper and sufficient SA, which will be provided by sensor technologies. In the short term, it is important to develop integration of sensor technologies to create sufficient SA and identify other factors which need to be developed and improved.

- Medium term -

It seems that unmanned remote control ships can be introduced faster than unmanned autonomous ships. It is a good idea to have remote control ships first. On open seas, it is rare to see other ships. So, it is possible to test autonomous systems on open seas by using remote control ships and data can be collected to improve response capability to extreme conditions and verify the reliability in practical use. Land tests cannot reveal all of the problems and challenges, such as durability in practical use. Real situational tests might help to develop technologies more than land tests and can identify other challenges to be addressed.

- Long term -

Try to seek fully autonomous ships, including operation at congested areas, berthing,
re-berthing, anchoring and mooring. It might be very difficult to introduce fully autonomous ships because manned ships will still exist. If fully autonomous ships want to operate in areas where at the same time manned ships operate, they must have same thought process as masters and crews and must be able to imagine what a master of another ship intends to do. The transfer of knowledge, skill and experience of seafarers to autonomous systems is essential to put fully autonomous ships into practical use. This is a big challenge, but appropriate research and tests can help.

2 Legislation/Administration

- Short term -

IMO should start the process of reviewing all relevant regulations to enable unmanned ships to navigate and identify and address challenges related to regulations accordingly. Otherwise, when technologies are ready, legislation may not be ready. From the review of SOLAS Chapter V, it may be concluded that it takes time to review all regulations and there are many issues to be addressed. It is essential to identify all challenges first and decide how to address them later. Also, if it is possible, a review of each regulation should be implemented at the same time to discuss the issues as a whole. In addition, States should be involved in discussions at IMO. Active commitment will help States to maintain their view of unmanned ships and to be ready to accept unmanned ships flying their flags. Also, it is very important for IMO that States assert their opinions so that IMO can develop better and appropriate regulations.
- Long term -
IMO needs to amend regulations whenever appropriate. From time to time, regulations may require amendment in accordance with new situations, lessons learned and operational experience, and IMO needs to keep regulations up to date. In addition, States should try to keep their national legislation up to date, and maintain and improve, if possible, their capacity to implement new regulations.

.3 Operational
- Short term -
The first step is to identify the challenges and problems related to operation by case studies. Some challenges can be solved and/or must be solved before introducing unmanned ships. In particular, remote control centers must be considered. This is a new concept and experience. The operation of control centers and the work requirements of controllers should be discussed. Experience from VTS and FOC operation should to be taken into account as well as experience from other transport modes or industries.

- Medium term -
After the introduction of unmanned ships, new challenges may arise to be addressed. This trend may last for quite a long time because it may take time until unmanned ships face all situations. For example, when AIS became mandatory, several challenges were revealed, like wrong information was sent. In addition, effectiveness of operation can be discussed. To seek effectiveness, feedback from real operations is important.
- Long term -
For fully autonomous unmanned ships, feedback from remote control operations might be or even has been collected and analysed, especially focused on how to operate fully autonomous unmanned ships with manned ships being a big concern. The possibility is up to technology but operational ideas can help as well, but there is a need for further study. For example, in busy areas, new TSS might be introduced to separate manned ships and unmanned ships. As such, it is critical to consider and investigate how fully autonomous unmanned ships can be possible from the point of view of operation, as with respect to the management of traffic flows and potential need to introduce separation or safety zones between manned and unmanned ships.

5-3 Summary
This dissertation provided definitions and underpinnings of unmanned ships, studied existing survey schemes and identified and explained the challenges related to surveys. A review of the applicability of SOLAS Chapter V regulations has been performed and problems related to unmanned shipping are determined and discussed. Finally, some potential solutions and approaches to overcome those problems are introduced. However, it is expected that further studies and technical development is needed to realize unmanned ships. It is obvious even if unmanned ships will not come a reality that a lot of the technical solutions can and will be applied to today’s manned ships and may contribute to maritime safety and efficiency.
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