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Evaluating the impacts of digitalization on ship operation: examining how to enhance maritime safety

Yuki Ichimura

WORLD MARITIME UNIVERSITY
Malmö, Sweden

EVALUATING THE IMPACTS OF DIGITALIZATION ON SHIP OPERATION:

Examining how to enhance maritime safety

By

YUKI ICHIMURA
Japan

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Declaration

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

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

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(Date):
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Supervised by:
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Abstract

Title of Dissertation: **Impacts of digitalization on ship operation**

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Contemporary society is already experiencing the so-called "fourth industrial revolution" (Industry 4.0). Industry 4.0 is expressed as "cyber-physical", and led by several cutting-edge technologies, including Artificial Intelligence (AI), Big Data, Cloud Computing and Internet of Things (IoT). These technologies have great potential to change the way of life in all aspects of society, including shipping. For example, Yara, a Norwegian fertilizer manufacturer, and Kongsberg Maritime, a Norwegian engineering company, have launched a construction project to build an autonomous ship, *Yara Birkeland*, by using AI, Big Data and IoT techniques. The ship is expected to be in service in late 2021. In addition, Elon Musk, an industrialist, and his company Space Exploration Technologies (Space X) have constructed autonomous and unmanned ships to collect and reuse the exhausted first stage of a rocket. Therefore, the shipping industry has also entered the era of Industry 4.0, quite often called 'digitalization' in the wider literature. Up to now, each underlying technology of digitalization in the maritime field, such as autonomous navigation, has been researched to a certain level. However, the overall impacts of digitalization have not been well analysed. Therefore, this dissertation will evaluate the impacts of digitalization on ship operation, especially from the perspective of maritime safety. In addition, many states and companies have tried to exploit digitalization, so this dissertation will analyse strategies of major shipping countries, shipping companies and classification societies in relation to digitalization. Furthermore, this dissertation will discuss challenges to progress further with digitalization, and evaluate the actions of IMO to surpass the limitations. All these questions will be researched by literature review. In summary, two types of vessels may emerge in the future: autonomous ship and smart ship. In terms of strategies, States can play a role of legislation, coordination among stakeholders, R&D, Maritime Education and Training (MET) and improved IMO Instruments Implementation by introducing AI, Big Data and IoT. Shipping companies will use digitalization to increase cost efficiency and meet the needs of customers. Classification societies are required to accurately assess risks to use digital technologies. Limitations which can prevent digitalization are cost, cyber security issues, data related issues, such as capacity of telecommunication, human element, reliability, social acceptance, and liability and regulatory related issues. IMO will not be able to tackle all issues, so governments, classification societies and the shipping industry are also required to cope with these issues to make fully use of digitalization.

KEYWORDS: Digitalization, Internet of Things, Cloud Computing, Artificial Intelligence, Maritime Autonomous Surface Ship

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List of Abbreviations

AI	Artificial Intelligence
AIS	Automatic Identification Systems
ASC	Autonomous Ship Controller
ASDS	Autonomous Spaceport Drone Ship
BIMCO	Baltic and International Maritime Council
CLIA	Cruise Lines International Association
COLREGs	The International Regulation for Preventing Collosions at Sea, 1972
DMA	Danish Maritime Authority
ECDIS	Electronic Chart Display and Information System
ECR	Engine Control Room
EU	European Union
FAL	The Facilitation Committee of IMO
FMEA	Failure Mode and Effect Analysis
FOC	Fleet Operation Centre
FRAM	Functional Resource Analysis Method
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAZOP	Hazard and operability
ICS	International Chamber of Shipping
ICT	Information and Communication Technology
IMO	International Maritime Organization
INS	Inertial Navigation System
INTERCARGO	International Association of Dry Cargo Shipowners
INTERMANAGER	International Ship Managers' Association
INTERTANKO	International Association of Independent Tanker Owners
IoT	Internet of Things

ISM Code	The International Safety Management Code
ISPS Code	The International Ship and Port Facility Security Code
IUMI	International Union of Marine Insurance
LEG	The Legal Committee of IMO
LIDAR	Light Detection and Ranging
MASS	Maritime Autonomous Surface Ship
MET	Maritime Education and Training
ML	Machine Learning
MSC	The Maritime Safety Committee of IMO
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NCSR	The sub-committee on Navigation, Communication and Search and Rescue of IMO
OCIMF	Oil Companies International Marine Forum
PHA	Preliminary Hazard Analysis
RADAR	Radio Detection and Ranging
R&D	Research and Development
RSE	Regulatory Scoping Exercise for MASS
SAR	Search and Rescue
SATCOM	Satellite Communication
SCC	Shore Control Centre
SOA	Service Oriented Architecture
SOLAS	The International Convention for the Safety of Life at Sea, 1974
STCW	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
STPA	System-Theoretic Process Analysis
UNCTAD	United Nations Conference on Trade and Development
USCG	United States Coast Guard
VHF	Very High Frequency

Chapter 1 Introduction

1.1 Background

Up to now, the world has been transformed by several stages of the wider industrial revolution phenomenon. The first industrial revolution occurred in the 18th and 19th centuries, which changed the world from a rural society to a highly industrialized one. This revolution was led by steam power and its relevant techniques. The second industrial revolution was driven by mass production and electricity. The third revolution was computerization, and the introduction of Information Technology (IT) has made society more 'intelligent' since the middle of the 20th century (Dalaklis & Fonseca, 2019). The maritime industry has also been greatly influenced by these revolutions. Firstly, the steam engine drove wind power away as the main energy source of vessels. Secondly, increasing demand for raw materials due to improvement in production has raised the volume of trade, which has vitalized shipping. Thirdly, shipbuilding was improved by innovations in the metallurgical field. Finally, the introduction of electronics and IT has changed the way of business in the shipping industry (Dalaklis et al., 2020).

It is said that society has now entered the fourth stage of the industrial revolution (Industry 4.0), and the maritime industry is expected to be greatly influenced by disruptive innovations (Dalaklis, 2018; ; Stanić et al., 2018; Cicek et al., 2019; Dalaklis & Fonseca, 2019; Sullivan et al., 2019; Aiello et al., 2020; de la Pe˜na Zarzuelo et al., 2020; Jo et al., 2020). These disruptive technologies include the Internet of Things (IoT), Big Data Analysis and Artificial Intelligence (AI). Due to the rapid development of these technologies, the conventional paradigms of vessel control might be fundamentally changed soon (Dalaklis, 2018; Dalaklis & Fonseca, 2019).

One particular interest for the maritime industry is the example of the *Yara Birkeland*, constructed by the Norwegian agricultural company Yara and the marine engineering company Kongsberg Maritime. The *Yara Birkeland* is the world's first autonomous and fully electric container vessel using above cutting-edge technologies (Kongsberg

Maritime, 2017). Furthermore, Elon Musk, an entrepreneur, and his company Space Exploration Technologies (Space X) have sought to use autonomous and unmanned barges to collect cost-efficient reusable rockets. The approach of Elon Musk is to collect and reuse the first stages of rockets after launching, and it is expected that the cost of launching a reused rocket is $15 million although it costs $50 million to launch a new reusable rocket ("How much", 2021). Under the project, unmanned barges called "Autonomous Spaceport Drone Ship (ASDS)" are used to capture the exhausted first stage. On 8th April 2016, the first stage succeeded in landing on an ASDS (Nair, 2016). There are two ASDSs operating, and they can sustain their positions autonomously, or by remote control from another support ship. The drone ships are towed by tug boats to the targeted area where the first stage is expected to land. Tug boats and other supporting ships leave the barges during landing to keep a safe distance and observe the landing. After landing, the drone ship with a booster is towed to the original port ("Just Read", n.d.; "Of Course", n.d.). The latest ship *A Shortfall Of Gravity (ASOG)* is under construction ("A Shortfall", n.d.). The ship is fully autonomous and does not require support by tug boats anymore (Arevalo, 2021).

It becomes obvious that the shipping industry is experiencing intense and on-going technological transformation, and all activities in the maritime field will be completely transformed in the near future (Ma, 2019) thanks to so-called 'digitalization'. Therefore, this dissertation will focus on the impacts of 'digitalization'[1]

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[1] In any case, before elaborating on the potential impacts, definitions of basic words used in this dissertation will be summarized in Appendix A.

1.2 Overview of the impacts of digitalization and actions for digitalization

The impacts of so-called 'Digitalization' on ships have the potential to completely change shipping operation. The tasks of seafarers may be transformed into more digital ones, such as system management and monitoring of operations, and operational work may be decreased (WMU, 2019a). The continuous development of communication technology has enabled a collaborative environment among crew, officers ashore and "machines", a term often used to describe "unmanned ships" (Dalaklis, 2020). Through these technologies, officers ashore can appropriately understand what is happening in the sea in real time, and safety is increased. Regarding changing roles of seafarers, Kitada et al. (2019) suggested that traditional maritime leadership by a ship master might be changed to non-maritime leadership, and more collaborative leadership through coordination between humans and automation may be needed. Digitalization in the surrounding field of ships can also influence ship operation, resulting in time and money savings. For example, electronic certificates have the potential to reduce administrative burdens on stakeholders including crew (IMO, 2016).

To cope with digitalization, many entities, including companies, international organizations, States and shipping organizations, such as classification societies, have already responded. As examples of actions taken by shipping companies, CMA CGM, a major liner shipping company, stated in its digital strategy that the company works with the world's biggest tech companies, such as IBM, as well as various start-ups to make the most of digitalization (CMA CGM, 2018a). NYK line stated in its mid-term management plan that the company will transform the entire supply chain in a more sustainable manner by using the latest digital technologies, such as digital twin, optimization of routes and autonomous shipping (NYK line, 2018).

Many States, as well as private companies, have developed strategies for digitalization to make the most use of the advantages of digitalization. For example, the Ministry of

Land, Infrastructure, Transport and Tourism of the Japanese Government (MLIT) has released a policy named 'i-Shipping' to raise the competitiveness of Japanese shipbuilding, and R&D of an autonomous ship is one of the pillars of the policy (MLIT, 2019). Prior to investment by companies or big projects conducted by States, it is important to develop regulations to cope with digitalization proactively for diffusion of digitalized ships. For example, the introduction of autonomous ships can create some legal and regulatory problems because the current regulatory framework is based on safe manning (Kitada et al., 2019; Ma, 2020). The strategic direction of IMO includes integration of new and advancing technologies into its regulatory framework (IMO, 2017). Under this strategic direction, three committees (MSC, FAL and LEG) have conducted a Regulatory Scoping Exercise (RSE) for the use of MASS, and member states identified which instruments under the auspices of each committee should be amended (IMO, 2020; IMO, 2021a). Additionally, IMO issued interim guidelines for MASS trials on June 2019 (IMO, 2019).

1.3 Aims and Objectives

As highlighted in section 1.2, digitalization has huge impacts on the shipping industry, and will revolutionize the industry in the near future. Therefore, many entities including companies, States and international organizations, have tried to take in and respond to digitalization. In this context, it is important to evaluate how ship operation will be conducted in the future, including change of crew's role, architecture of digitalized ships and degree of safety, and how various stakeholders have tried to achieve their digitalization goals. In addition to positive impacts, there are many limitations which prevent digitalization, such as capacities of telecommunication, data availability, and cyber security (Ma, 2020). Therefore, it is also important to reveal potential problems. Moreover, the shipping industry cannot make the most of digitalization without an appropriate international regulatory framework. On the above background, this paper tackled the following four research questions.

1.4 Research Questions

The issues which were addressed in the dissertation are:

i. How does digitalization affect ship operation?
ii. Which areas of digitalization are concerned in the strategies developed by companies as well as States?
iii. What are the limitations in maritime digitalization?
iv. How can IMO, States and the maritime industry contribute to digitalization and reduce the above limitations?

Note

Among many impacts that digitalization is expected to bring, the increase in maritime safety is probably the most important one. Many research papers have pointed out that digitalization can substitute or provide support to human operators, so given the fact that human error is responsible for more than 70% of accidents, digitalization is expected to enhance maritime safety (Lloyd's Register, 2016; Moræus et al., 2016; Ramos et al., 2019; Dalaklis, 2020; Kim et al., 2020; Ma, 2020). Therefore, this dissertation focuses on safety of navigation among the benefits of digitalization.

1.5 Research Methods

This study utilised a literature review as the main tool to investigate the above questions. The details by question are as follows:

i. How does digitalization affect ship operation?

A literature review was conducted to answer this question because it was considered that the topic of digitalization of ships has been sufficiently researched. Specifically, the author searched the keywords "maritime autonomous" "Maritime 4.0" "Shipping 4.0" and "shipping digitalization" by using the One Search database of the WMU Library site. As a result, 29 available papers were identified. Overly technical papers which aim to develop specific technology were excluded. In addition, the author used five papers, one book and two presentation materials written or provided by WMU professors.

ii. Which areas of digitalization are concerned in the strategies developed by companies as well as States?

To answer this, a literature review was used because major shipping companies and States tend to publicise actions or strategies for digitalization online. Regarding national strategies, this dissertation examined the national maritime strategies of the top 10 ship owing nations based on vessel value: China, Denmark, Germany, Greece, Japan, Norway, Singapore, the Republic of Korea, the United Kingdom, and the United States (SAFETY4SEA, 2020). According to the statistics of ownership of the world fleet, ranked by carrying capacity in dead-weight tons provided by UNCTAD (UNCTAD, 2020), these countries share 66% of the world fleet. To assess ship owning countries, there might be a measure to categorize it based on gross tonnage (top 10 flag States). However, some major flag States introduce Flag of Convenience, such as Panama, Liberia and the Solomon Islands. These countries are developing countries and they may lack the technical capacity to develop new and advancing technologies and integrate them into their fleet. Therefore, this dissertation focuses on vessel value instead of gross tonnage. In the case that strategies were not available online (China), the author tried to investigate directly with the concerned Government via e-mail. However, there was no response from the Chinese Government, so the author analysed the course of action of the State by using newspaper articles gathered online.

Regarding company strategies, this dissertation examined the strategies of the top 10 liner shipping companies and IACS members. In the case that strategies were not available online, the author tried to investigate directly with the concerned organisations via e-mail, but none of them replied. Therefore, all strategies gathered are taken from the relevant websites.

iii. What are the limitations in maritime digitalization?

This dissertation highlighted challenges of digitalization and puts forward possible solutions in papers and materials identified in relation to research question i.

iv. How can IMO, States and the maritime industry contribute to digitalization and reduce the above limitations?

To answer this question, the progress of IMO RSE regarding autonomous ships was reviewed. In addition, IMO’s action for digitalization, such as development of cyber security guidelines and the concept of e-navigation were identified. Furthermore, a comparison was conducted between the current status of the development of regulations regarding digitalization and identified challenges and solutions to develop recommendations to revise existing IMO regulations.

1.6 Expected results

This study had assumed that the following information could be a result:

1. Details of digitalized ships from the academic point of view, e.g. collaborative work among crew, officers ashore and machine becomes dominant, the architecture of digitalized ships differs from current ships, and the degree of safety will increase due to digitalization
2. Inventory of company and State actions toward digitalization of ships
3. Comparison of actions or strategies among States and companies e.g. States will more focus on maritime education and training for digitalization.
4. Comparison between the concept of digitalized ships from the academic point of view and directions in which companies or States want to proceed. e.g. company strategies are more innovative than State strategies or academic predictions
5. Potential limitations, such as unemployment, data availability and cybersecurity
6. Recommendations to surpass the limitations and facilitate digitalization, such as enhanced cyber security, development of industrial standards for data acquisition and training of digital equipment for crew

This information is considered to make a contribution to the body of knowledge since, at the time of writing, no existing research has been found that addresses points 2, 3, 4 and 5 above.

Chapter 2

Chapter 2.1 Literature Review

2.1.1 Impacts of Digitalization

In the maritime field, AI is expected to be a critical technology to realizing autonomous ships (Dalaklis, 2018; Tsaganos et al., 2020). In addition, AI can realize optimization of shipping routes and suggest the best speed and course during one navigation (Dalaklis et al., 2021). Furthermore, data collection through IoT technique, broadband communication technology and Big Data analysis will also enable remote monitoring or control from shore (Lambrou et al., 2019). Ma (2020) explained that although there is still much uncollected information including the work of crew, recent technological developments, such as voice and image recognition and sensors, have changed the situation, which enables increasing data collection and development of IoT. In addition to data collection, the author pointed out that communication and storage of data, especially cloud computing, are also important for IoT.

In this chapter, the result of the literature review regarding the impacts of AI, IoT and Big Data on the digitalization of ships in terms of safety navigation are presented. In addition, advanced communication technology is also crucial for IoT and Big Data because data should be transferred from the source by communication. Therefore, the impact of advanced communication technology is also explained in this chapter.

2.1.1.1 Impacts of AI

Technical Overview of AI

AI can be described as the simulation of human intelligence processes by machines. AI makes it possible for machines to demonstrate autonomous behaviour, with little or no human intervention (Lloyd’s Register, 2016). Tsaganos et al. (2020) defined AI as computer systems which are able to learn from data, appropriately recognize patterns-correlation within the specific data set, and finally decide courses of actions with limited human intervention. According to the authors, AI is based on the technique called Machine Learning (ML), and ML is an effective tool for both classification and/or regression of non-linear systems. There are two typical types of learning methods: supervised learning and unsupervised learning (El-Kahlout & Abu-Naser, 2020; Tsaganos et al., 2020). Supervised learning is a learning model for computers to make predictions on unforeseen input. Supervised learning algorithms use known sets of data as input and known output to learn the relationships between input and output (El-Kahlout & Abu-Naser, 2020). Supervised learning is further categorized into classification algorithm and regression algorithm (Tsaganos et al., 2020). In the case of unsupervised learning, on the other hand, there is no known output, so algorithms usually try to find patterns among different inputs (Kwekha-Rashid et al., 2021). ML enables processing of huge amounts of structured or unstructured data, contributing to realizing cutting-edge technologies such as IoT and image recognition (WMU, 2019b).

There are two ways to use AI. The first way is to support decision making by seafarers by providing live, compiled information to the crew on demand. In the second way, AI will use compiled information given by the ML technique to make a decision and behave in a timely and correct manner, which enables autonomous operations. The important thing is that AI itself cannot provide intelligence independently, and other techniques such as sensors, data processing and communication, are also indispensable for AI to function well. Specifically, sensors provide data collection, which enables AI to 'sense' the external environment and 'understand' the situation, which supports AI to develop situational awareness (Lloyd's register, 2016).

Impacts of AI

Lambrou et al. (2019) suggested that AI has impacts on shipping in two ways: autonomous vessels and smart ships. In the case of autonomous ships, AI will improve situational awareness, and it will support many ship tasks, such as detection of anormal situations for navigation, maneuvering and collision avoidance. Condition based monitoring and maintenance are also some of the major application areas. On the other hand, smart ships aim for commercial or operational optimization. In this field, AI will assist many tasks at tactical levels, leading to asset optimization, fleet planning, and compliance monitoring related to environmental regulations. At the strategic level, the authors mentioned that AI may contribute to market monitoring. Within the above impacts, autonomous navigation and monitoring are considered to be safety matters, so the following item will elaborate more on the impacts of autonomous ships (impacts of monitoring will be discussed in item 2.1.1.2).

Impacts of autonomous ships

Bastiaansen et al. (2019) explained that the Autonomous Ship Controller (ASC) will mainly play a role in autonomous navigation. The system follows a programmed trajectory and speed. The system also monitors and surveys the external environment by using various sensors, and it can correct minor errors. Chae et al. (2020) illustrated that autonomous ships will introduce various kinds of sensors, including GPS, optical and infra-red (IR) camera, INS, and LIDAR.

Munim (2019) explained the concept of “vessel platooning” or “vessel train”, where several autonomous ships follow a leading manned ship. This concept is supported by real-time ship to ship wireless communication technology. Vessel platooning is considered to be useful for liner shipping, especially for inland water transport, where the route is fixed. According to the author, vessel platooning will contribute to reduction of operational cost.

In relation to remote control from shore, Shore Control Centre (SCC) may take work which is done onboard conventional ships in the case of autonomous ships. Moræus et al. (2016) predicted that SCC will play a role in VTS reporting, VHF communication, condition monitoring and maintenance planning for safe navigation. Pietrzykowski and Hajduk (2019) also mentioned that the role of SCC will undoubtedly rise. As an example, the authors suggested that SCC could provide autonomous ships with optimal routes taking into account weather to enhance safety.

As an application of remote control, Munim (2019) suggested the idea to use unmanned autonomous ships in the Northern Sea route to minimize the risk to human life in the severe polar climate. Dalaklis (2019) explained that SAR services in the Arctic may not be able to meet the increasing needs of the polar route. In order not to expose seafarers to harsh conditions in the Arctic under the scarce SAR services, the author concluded that remote control could contribute to safe navigation in the Arctic. In this case, escorting ice-breakers may be able to play a role in control stations.

Regarding data analysis to operate autonomous ships, Lloyd's Register (2016) suggested that ship systems be redesigned so that ships can operate without seafarers onboard. Therefore, maintenance strategy and new maintenance interaction systems will be developed, and SCC will equip the user interface of such maintenance systems. However, due to the limited capacity of radio and satellite communication, some functions related to monitoring and data analysis will be onboard.

2.1.1.2 Impacts of IoT

Technical Overview of IoT

IoT refers to a worldwide dynamic network which links uniquely identified physical and virtual objects for communication, configuration and actuation (Sullivan et al., 2020). In other words, it means the extension of internet connection to natural or artificial objects identifiable by an IP address (Ma, 2020) or a set of physical objects which can access the Internet or other networks, allowing them to communicate with human or machines for monitoring or improvement (Lloyd's Register, 2016). Aiello et al. (2020) predict that by 2025, many ship systems and equipment will be connected to the Internet, and stakeholders can access them from wherever they are.

From the technical perspective, Lloyd's Register (2016) and Moræus et al. (2016) emphasized the importance of advanced sensor modules to realizing IoT. Sensors, actuators, or processors are integrated into technical systems of ships, such as engines, propellers, cargo systems, or data fusion systems in the case of ships adopting IoT (Lambrou et al., 2019). Moræus et al. (2016) suggested that sensors and sensor data processing will substitute the perception of human navigators, and autonomous ships will be equipped with "advanced sensor modules" composed of infrared and visual spectrum cameras, radar and AIS to detect objects and decide whether they are dangerous or not. WMU (2019b) analysed the case of *Yara Birkeland*, and mentioned that a variety of sensors, such as radar, lidar, AIS, cameras and IR cameras, are essential tools to remotely control autonomous vessels. The authors also explained that advanced sensors are indispensable to realising auto-docking, which is one of the necessary functions of autonomous ships.

Impacts of IoT

Lloyd's Register (2016) predicted that sensors will continue to develop, and they will be able to provide enough resolution for autonomous navigation in the near future. WMU (2019b) predicted that data obtained through AIS, cameras and IR cameras would be sent to SCC and the vessels could be controlled by SCC after analysis of the data. Similarly, Lloyd's Register (2016) and Ma (2019) suggested that data from ships will be sent to a cloud or local servers by IoT, and solutions to the current situation around the vessel will be created after analysis of the data.

Ma (2020) explained that IoT can increase system reliability because it enables continuous monitoring against ship systems and equipment, and machine-learning algorithms can analyse the data and detect failures. Moræus et al. (2016) also noted that more advanced condition monitoring and remote monitoring of engine room and critical equipment will reduce malfunctions and breakdowns during deep sea navigation. It also contributes to better maintenance planning. Such monitoring systems will integrate multi-level sets of decision support data to reduce bandwidth and allow performance tracking. Sullivan et al. (2020) explained that real-time data acquisition through IoT will enable the development of a virtual model, and operators, engineers and managers can use the model to test and optimise whole systems before they make physical changes (digital twin). Wróbel and Weintrit (2020) proposed that autonomous ships could gather the latest hydrographic data in near shore waters and straits and at port, contributing to navigational safety.

2.1.1.3 Advanced communication technologies and their impact

Data transfer technique is also indispensable to realising digitalization of ships because it enables support from shore. Up to now, communication between ships and between ships and shore has been developed in two ways. The first one is short/medium range communications used for ship to near ship/shore communications, and Very High Frequency (VHF) and Medium Frequency (MF) communications are mainly used (Lloyd's Register, 2016). It also includes mobile communication (Plass et al., 2014; WMU, 2019a). There is no unified definition of the range identified, but the USCG has identified the capacity of short-range VHF communication as 5-10 miles (9-19 km). For longer range than VHF communication, long-range communication, such as satellite communications (SATCOM) and High Frequency (HF) communications are used (USCG, n.d.). These technologies have realised distress safety systems, electronic navigation and voice communications, but these communications are narrowband in nature. SATCOM can provide higher data rates than HF (a few kbps) and MF/VHF (tens of kbps), but the maritime industry is of the view that it is too expensive to use SATCOM (Lloyd's Register, 2016).

However, technical innovation has changed this situation. Coastal shipping can now use the Fourth Generation (4G) of mobile communications networks, which can cover about 30 km from shore. In addition, it is expected that SATCOM technology will become more advanced and its operational cost will become cheaper through innovation in the Ku and Ka bands, high power satellites, multiband access and inter-satellite communications (Lloyd's Register, 2016). The Low Earth Orbit (LEO) technique, which uses a set of satellites in LEO functioning together as a system and provides worldwide or near-worldwide coverage, is also expected to significantly decrease communication costs (Aiello et al., 2019). The VHF Data Exchange System (VDES) will also raise its throughput and reliability of data services for important ship systems. Development of Wireless Mesh Networking (WMN) is considered to be a cheaper alternative to SATCOM. It automatically establishes multiple paths, and ships can relay communications to one another on busy shipping lanes (Lloyd's Register, 2016). Lambrou et al. (2019) explained that the Fifth Generation (5G) of mobile communications also contributes to realizing the "Internet of ships". 5G is a high-speed communication technology, so it is expected to realise autonomous driving ashore (Ma, 2020). Lloyd's Register (2016) explained that 5G can cover 100km off the coast if it is appropriately introduced, so it can be a useful communication channel for autonomous ships navigating coastal areas. As a result of development of communication technologies, autonomous ships can use many different layers of networks and connectivity, including the network which deals with information from equipment onboard obtained by the IoT technique for monitoring and crew and passenger networks for operational and convenience services.

2.1.1.4 Impacts of Big Data

Technical Overview of Big Data

Dalaklis et al. (2021) define Big Data as a huge amount of data, and explain how dealing with such data has been an issue. Ma (2020) gave the meaning of Big Data as finding or discovering any useful pattern, model or answer to a question from a large amount of data. The author explained that data is a resource, and people will use appropriate methodologies for data processing to obtain final outcomes, i.e. solutions, decisions and actions. To analyse huge amounts of data, AI is often used because AI is an intelligent computer and AI is able to learn and adapt data processing that conventional computing could not. Therefore, AI can automate and improve complex data analysis (Surya, 2015).

Impacts of Big Data

Ma (2020) explained that Big Data (assisted by AI) can contribute to navigational safety because Big Data can realise detection of abnormalities and anticipation of danger by monitoring data on weather and sea conditions, location of a ship, speed, and electronic sea chart data, assess them in real-time and compare them against a certain standard. In addition, monitoring meteorological-ocean data can contribute to creating historical data for ships navigating on the same route, and other vessels navigating on the route can use the data to decide whether the meteorological conditions are good or bad and switch to another route if possible. WMU (2019b) suggested that the ASC will use and analyse a large amount of data obtained by IR cameras to decide actions based on surrounding conditions of ships. Finally, de la Pe˜na Zarzuelo et al. (2020) illustrated that Big Data can influence shipping in two ways: optimization of operation (safe and energy efficient operation, and schedule management) and better fleet planning (service planning, fleet allocation and chartering).

2.1.1.3 Future navigation from an academic point of view

This section will explain the overall effects driven by AI, IoT (including advanced communication) and Big Data. It will discuss the future vision of navigation and, since many papers refer to modality of human operators in the future, it will also describe the future of work in the maritime field.

Future navigation

Lloyd's Register (2016) predicted that vessels will evolve into smart ships that integrate AI, advanced sensors and communication technologies with minimal crews onboard. Specifically, the author suggested two changes in relation to future vessels: (1) from the digital ship to the intelligent ship [Short to Medium Term], and (2) from the intelligent ship to the autonomous ship [Medium to Long Term]. The intelligent ship uses Big Data acquisition, communication and analysis, and provides intelligent, real-time and proactive decisions in the field of design, operation and maintenance of ships. Sensors and robotics technology will further substitute for human operators, resulting in semi-autonomous ships or fully autonomous ships including remote controlled ships. The author concluded that these smart ships will contribute to safe navigation by removing human operators from dangerous work and minimizing human error.

Similarly, WMU (2019b) predicted that there are two ways which ships will evolve: autonomous ships and smart ships. The autonomous ship is designed to navigate autonomously, with or without seafarers onboard (as defined in Appendix A). However, the author explained that the business model of autonomous ships will be totally different from conventional ships or smart ships. Smart ships are the result of improvements to conventional ships through the adoption of computerized systems, increased monitoring of navigational systems and engines, and possible fuel shift. The paper calls this improvement 'digitalization', and explains that 'digitalization' itself is not a necessary step for autonomous ships in terms of the business model by evaluating the case of *Yara Birkeland* in Norway. The project aims to substitute cargo transport operated by trucks with autonomous container ships between specific places for environmental reasons. In addition, higher labor cost in Norway is another reason to develop autonomous vessels. Therefore, the project does not replace traditional ships operating on the same route, so the capacity of the vessel is limited (3,000 to 4,000 TEU) as compared with traditional container ships (20,000 TEU). Furthermore, the ship is owned by the shipper itself instead of a traditional shipowner. Thus, autonomous ships are totally different from smart ships, and cannot easily replace traditional shipping routes except for short-range domestic passenger ferries.

Lloyd's Register (2016) predicted that autonomous navigation will be initiated from coastal shipping where costs to employ seafarers occupy a higher percentage of total costs as compared with ocean-going vessels. In addition, it is relatively easier to establish national laws to regulate autonomous ships than to create international laws. WMU (2019b) also predicted that autonomous ships will start to navigate on short-range domestic passenger routes. The paper explained that in the future, digitalization would accompany fuel change, especially for short-range ferries, from heavy oil to battery. Because auto crossing, which is an essential technology of autonomous ships and can control the level of acceleration, deceleration, track, speed, and use of fuel according to the situation of sea, is more fitted with electrical propulsion ferry, battery-powered ferries with digitalized equipment, such as auto-docking, are expected to be gradually constructed. Electrical propulsion powered by battery can free crew from painful daily maintenance of engines, so it also contributes to reduction of burdens on seafarers and seafaring costs. If innovation increases battery power, longer range ferries and cruise ships will benefit from autonomous navigation (WMU, 2019b).

In the case of the smart ship, WMU (2019b) predicted that some AI-based technologies used for autonomous ships will be also gradually introduced into conventional ships, and conventional ships will evolve into smart ships. The author suggested three key technologies regarding smart ships. The first one is Dynamic Positioning (DP), which enables a ship to adjust its position in accordance with its external environment, such as wind, current and wave size. Auto crossing is another key technology. Finally, the author suggested auto-docking. The author explained that the first step for smart ships will be the introduction of advanced sensor-based monitoring and navigation. Further automation of engine room will follow through enhanced decision-support systems. This automation will accompany higher redundancy in engine operating and monitoring systems.

Pietrzykowski and Hajduk (2019) envisaged that automation will start with small ships in coastal shipping and ocean-going ships with the limited number of crew. In the case of coastal shipping, such as small passenger ferries, all stages of operational tasks will be conducted by autonomy. In the case of an ocean-going ship, navigation will be conducted by autonomy and other tasks will be carried out by crew or operators in SCC.

Future of work

WMU (2019b) pointed out that current paper-based work of seafarers will be digitalized, and it will change the officers' work from the bridge or engine room to a computer screen. Dalaklis et al. (2020) introduced the notion of "net-centric" (users can get appropriate information whenever and wherever they need it) to shipping because currently onboard decision-making has been greatly influenced by dynamic collaboration among different stakeholders, and the net-centric philosophy can improve situational awareness and decision-making at sea. Given the fact that the shipping industry has entered the era of digitalization and equipment onboard ships has been increasingly connected, the maritime industry will gradually adopt net-centric concept. Management, human operators and machines will work together, including SCC, for the safety and efficiency of shipping. Similarly, Aiello et al. (2020) explained that digitalised ships must be relevant to the notion of cyber-physical systems, and such systems should be constituted by distributed, decentralised, networked heterogeneous and (semi)autonomous components which actively cooperate with each other to enhance the value chain of collaborative companies. Lloyd's Register (2016) also predicted that a new relationship between human and machines will arise, categorizing three possibilities: (1) work assisted by AI, such as optimized voyage planning (2) 'co-bot', which means human-machine collaboration e.g. a human-robot team to conduct routine maintenance (3) machine manager e.g. a partially manned fully autonomous ship. To cope with such changes in the nature of work, the author emphasized the importance for crew to re-skill and up-skill.

Lloyd's Register (2016) projected that roles, organisational structure and responsibilities will change from operating at sea to monitoring, managing and supervising systems from shore. Kitada et al. (2019) suggested that leadership and organized work onboard will dramatically change due to digitalization. Although organizational roles of crew are based on organizational ranks and the master has had authoritative power and responsibilities up to now, technological innovation will increase connectivity between a ship and shore and the master will not be the only decision-maker. The authors predicted that increasing digitalization will push the role of crew toward monitoring of navigational systems or engines. In this case, leadership can be explained as capacity to consult with a manager or expert ashore by proactively proposing the best alternative solution for the shipping company. Furthermore, human-automation or human-human coordination will become more important. Thus, digitalization has the possibility to make the boundary between a ship and shore opaque.

Future shipping

To synthesise the above literature review, the future of shipping will be described in Figures 1 and 2:

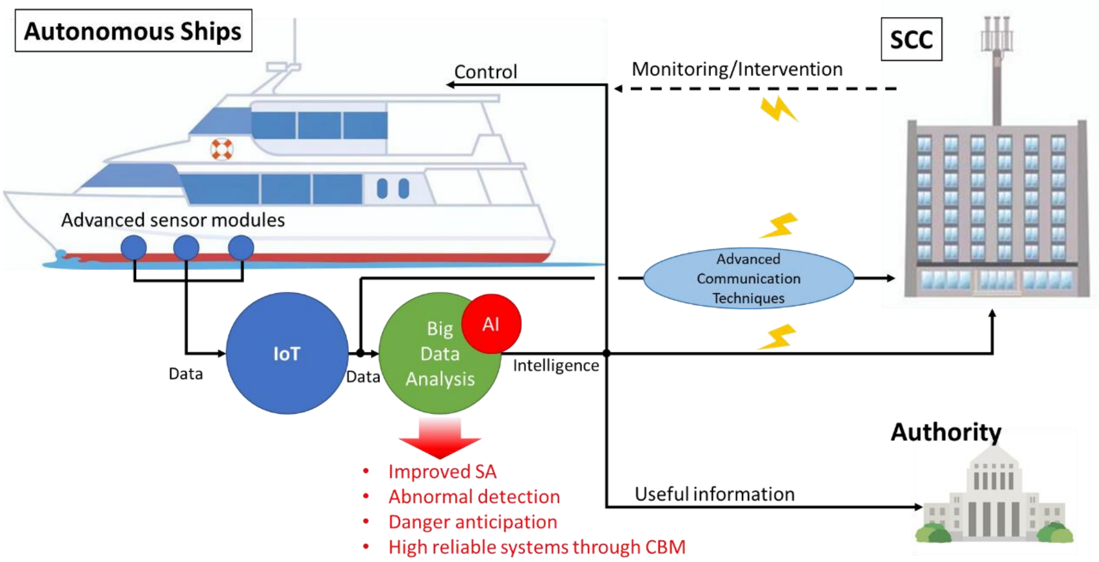

Figure 1 Future shipping (autonomous ship)

Source: Created by the Author

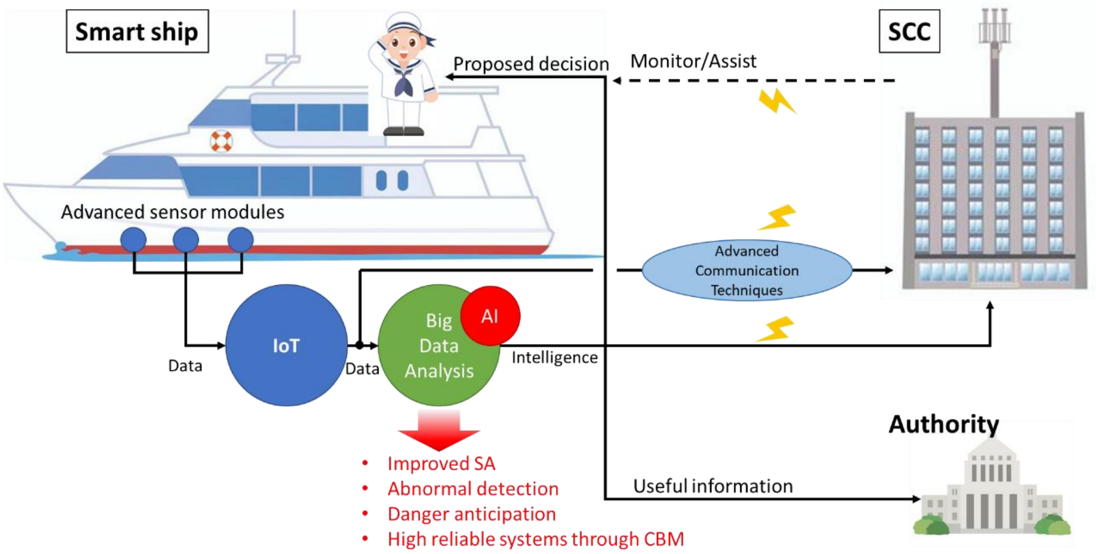

Figure 2 Future shipping (smart ship)
Source: Created by the Author

An autonomous ship is totally different from a conventional ship in terms of business model and will start from short-range domestic shipping. On the other hand, a smart ship is an extension of a conventional ship, and the ship is supported by AI, IoT and Big Data. For both cases, much navigational data will be gathered through IoT techniques. Data will then be analysed by AI (Big Data Analysis), and AI will provide intelligence for navigation and make decisions to control the ship. Some navigational data through sensors, such as cameras, will be sent to the SCC along with the intentions of AI. When transferring data, advanced communication techniques, such as LEO, will be used, and data will be monitored by operators in the SCC. When operators do not agree with the decision by AI or AI does not have appropriate solutions to cope with the surrounding situation, operators will take over control of the ship. In case of a smart ship where seafarers are onboard, AI will propose probable courses of action instead of control, and seafarers will make the final decision for navigation.

There are four merits of digitalization for navigational safety. The first one is improved situational awareness. Since many sources of information are integrated and analysed by AI, an autonomous navigation system can provide accurate situational awareness. In addition, there is no problem of fatigue in case of machines, which reduces human error. Secondly, through Big Data analysis, autonomous ships can detect abnormal situations and predict the possibility of dangerous situations. Finally, through continuous monitoring of data, especially for engines, autonomous ships can detect any sign of failure. This enables operators to conduct more accurate maintenance from regular basis to condition basis, which enhances reliability and decreases malfunction. Some navigational data, such as data obtained by sonar, if such equipment is available onboard, will be sent to the authority, and the authority can use it to enhance safety at sea, by updating hydrographical information, for example. Humans may continue to be involved in navigation from shore (in the case of an autonomous ship except for some unmanned autonomous ships, such as ASDS) or onboard (in the case of smart ship), and a new type of collaboration between humans or human and machine will arise.

2.1.2 National Strategies for Digitalization of ships

Pietrzykowski and Hajduk (2019) clarified the role of stakeholders in relation to autonomous ships. According to the authors, States are required to formalize regulations to mitigate operational risks under the principle of "as low as reasonably practicable (ALARP)". The authors also explained that maritime administrations will play a role in coordination to balance the aims of other stakeholders by using the competence of approvals and supervision, taking into account the economic, environmental and social background. In addition, States may conduct R&D projects for digitalization as part of science, technology and innovation policy. With respect to institutes in charge of R&D of autonomous ships, the authors suggested that such entities should develop cognitive functions by creating new technologies. In line with the three roles of Governments for digitalization (legislation, coordination and R&D), which Pietrzykowski and Hajduk (2019) described, this dissertation analysed the national strategies of the top 10 ship-owing countries(overview of each strategy is summarized in Appendix B).

In terms of legislation, four countries (Denmark, Germany, Japan and the UK) explained the necessity of establishing appropriate international law, especially for autonomous ships, while three countries (Singapore, the UK and the US) referred to national legislation for digitalization. Although there is a difference concerning whether national law or international law should be established first to realise digitalization, this result shows that many countries are eager to establish appropriate regulations for digitalization and continue to fulfil the role of Government. Within the countries under the scope of this dissertation, Norway and Korea did not mention to legislation. However, the project manager for innovation and new technology in the Norwegian maritime administration made a presentation about the legislation in

Norway for autonomous ships (Medhaug, 2019), so the country may be willing to create appropriate regulation for *Yara Birkeland*. In the case of Korea, the strategy is valid for only one year, and given the fact that legislation takes time, the country may give up integrating the description of legislation. In addition, the country seems to actively participate in the RSE conducted by IMO because the country was one of supporting members of review of instruments. Therefore, it can be concluded that all countries have tried to establish appropriate regulations governing digitalization although there might be differences in priorities.

Regarding coordination among stakeholders, almost all countries referred to cooperation with national maritime industries, such as enhancement of the entrepreneurial environment (Denmark), joint projects (Germany, Norway and the UK) and establishment of data sharing mechanisms (the UK and the US). However, there is no description concerning what the authors expected from government, i.e. balancing the aims of stakeholders by using the competence of approvals and supervision, taking into account the economic, environmental and social background. Therefore, there is a concern that governments focus too much on facilitation of digital business in the maritime fields (economic impacts), and disregard environmental and social impacts. However, the negative environmental impact of digitalization, which is the assumption that digitalization will exacerbate environmental issues, is hard to imagine because many studies has concluded that digitalization will contribute to pollution prevention through modal shift, possible fuel change or optimized operation (Moræus et al., 2016; Munim, 2019; WMU, 2019b; Aiello et al., 2020; Ma, 2020; Sanchez-Gonzalez et al., 2021). Social impacts of digitalization may still be problematic, especially unemployment due to automation. However, given the fact that people in developed countries tend not to choose to become seafarers and seafarer shortages often exist (WMU, 2019b), the impact of unemployment due to automation might be limited, and, as such, Governments may not prioritise this issue. WMU (2019b) explained that autonomous ships could create new routes and would not replace existing routes, other than domestic short-range passenger ferries. Therefore, it can be concluded that many countries have tried to fulfil their duties to coordinate stakeholders, especially from the economic perspective, to progress digitalization.

Regarding R&D, almost all countries (except for Greece) have indicated that they will enhance R&D for digitalization, especially autonomous ships, IoT and Big Data. Besides the three elements which Pietrzykowski and Hajduk (2019) suggest, five countries (Germany, Norway, Singapore, the UK and the US) intend to enhance MET for the era of digitalization. Taking into account the fact that the STCW Convention requires Flag States to educate and train seafarers, improving MET to integrate digital skills is considered to be an important role of governments. Among them, the UK's strategy refers to the necessity to establish an appropriate international framework for MET to cope with digitalization. In addition to MET, the USCG's strategy referred to improvement of ship inspection and certification by introducing AI, Big Data and cloud computing. It also explained that the USCG will also enhance the capacity of its officers to cope with digital technologies, such as AI and cybersecurity. Survey and certification are important roles of flag States for maritime safety, so improvement of national inspection by introducing new technologies is also a crucial role of governments. Although some states may totally rely on Recognized Organizations in the field of ship inspection, governments conducting surveys (such as Japan) might be required to enhance capacity to cope with digitalization.

In summary, this chapter identified five directions of major maritime administrations for digitalization through the review of national strategies:

1. National and international legislation to cope with digitalization, especially autonomous navigation
2. Coordination among stakeholders
3. R&D for AI, Big Data and IoT
4. Improved MET to integrate AI, Big Data and IoT
5. Improvement of IMO Instruments Implementation by introducing AI, Big Data and IoT if necessary

Table 1 summarizes which governments refer to which items above;

Table 1

Roles of Governments for digitalization and their reference in strategies by country

Roles of Governments／Countries		China	Denmark	Germany	Greece	Japan	Norway	Singapore	Korea	UK	US
1. Regulating the use of digital technologies	International law	N/A	○	○	-	○	-	-	-	○	-
	National law	N/A	-	-	-	-	-	○	-	○	○
2. Coordinating among stakeholders		N/A	○	○	-	○	○	-	-	○	○
3. Proceeding R&D		○	○	○	-	○	○	○	○	○	○
4. Improving MET		N/A	○	○	-	-	○	○	-	○	○
5. Improving IMO Instruments Implementation		N/A	-	-	○	-	-	-	-	○	○

○: Referred in the strategy

- : not mentioned in the strategy

All these elements are necessary to raise maritime safety. Firstly, it is necessary to establish or revise safety standards to realize digitalization. Secondly, cooperation with stakeholders includes joint experiment with autonomous ships and data sharing. An experiment with autonomous ships means to evaluate the safety level of autonomous ships, and data sharing involves data related to safe navigation, such as hydrographical data and meteorological data. Thirdly, digital technologies can contribute to maritime safety as described in section 2.1.1.3, so R&D of digital technologies enhances safe navigation. Fourthly, personnel should be well familiar with digital technologies in the future navigation, so it is necessary, for safe navigation, to train personnel to deal with digitalization. Finally, survey, inspection and certification are the essential tools to implement IMO instruments and ensure maritime safety, so digitalization in this field is relevant to maritime safety.

Within the countries, only China did not seem to publicize its strategy. This might be because the country is generally lacking the capacity to innovate (Abrami et al., 2014; West, 2021), and the country is forced to rely on acquiring new and advancing technologies from other developed countries, by various measures including illegal ones (Blumenthal & Zhang, 2021; U.S. Embassy in Georgia, n.d.). In the maritime field, Chinese hackers attacked Universities in the US to steal maritime technologies for military service in 2019 (Volz, 2019).

2.1.3 Companies' Strategies

Pietrzykowski and Hajduk (2019) suggested that the maritime industry aims to maximize its profits by introducing new technologies. Specifically, shipowners will minimize operational costs including crew costs. The authors also explained that classification societies will try to minimize the risk of operational errors in a preventive manners. In line with the above two roles of companies for digitalization, this dissertation analysed companies' strategies (overview of each strategy is summarized in Appendices C and D).

2.1.3.1 Analysis of major shipping companies' strategies

In terms of cost, which is the objective of shipping companies for digitalization as written by Pietrzykowski and Hajduk (2019), three companies referred to increase in cost efficiency (OOCL) by optimizing assets (ONE) and supply chain (Hapag-Lloyd). CMA CGM did not explain cost efficiency, but this might be because the strategy focuses on the company's efforts to contribute to sustainable development, and the discussion of cost efficiency seems not to match the intention of the strategy. According to Wallgren (2018), the chief information officer of the company implies that the company is interested in digitalization because it can optimize its supply chain, and save money, so the focal point is the same as the other three companies. Other than cost efficiency, two companies (CMA CGM and ONE) explained that they will use digital technologies to meet the needs of customers, including container tracking, and real-time freight estimate. The other two companies also referred to these technologies. Only one company (CMA CGM) explained that the company would invest in autonomous navigation. The following Table 2 summarizes which companies refer to which items above;

Table 2

Roles of companies for digitalization and their reference in strategies by country

Roles of companies／Companies	CMA CGM	Hapag-Lloyd	ONE	OOCL
1. Increasing cost efficiency	-	○	○	○
2. Fulfilling the needs of customers	○	○	○	○

○: Referred in the strategy
- : not mentioned in the strategy

From the above observation, shipping companies may not be interested in radical innovation, such as autonomous ships, although it has potential to increase maritime safety. Rather, they seem to be keen on using digital technologies to increase cost efficiency through optimization of assets and supply chain, and satisfy customers' needs through digitalized services. Although this dissertation cannot analyze the strategy of Maersk, the world's largest shipping company, the CEO of the company Soren Skou argued that it would be impossible to operate 400-meter long container ships without seafarers onboard at least in his lifetime, and autonomous ships would not be a driver of efficiency (Wienberg, 2018). This remark is compatible with the assumption that ships will evolve in two ways: autonomous ships and smart ships. Since different business models might be required for autonomous ships, major shipping companies may not prefer such vessels and they do not prioritize development of autonomous ships in their strategies. Rather, autonomous ships will be driven by new comers, such as Yara, instead of traditional shipping companies. On the other hand, smart ships will fit with traditional shipping companies because they will optimize operation onboard and provide useful information, such as location and condition of cargo, for shore, which contributes to cost efficiency and meeting customers' needs. Among the benefits of smart ships, optimization of assets, such as condition-based maintenance will enhance maritime safety, and this might be a role for shipping companies in digitalization in terms of navigational safety.

In summary, this chapter identified two directions for major shipping companies for digitalization through the review of companies' strategies:

1. To increase cost efficiency, such as optimization of assets
2. To meet the needs of customers, such as container tracking

However, they seem not to use radical innovation, such as autonomous navigation, to attain these objectives due to the difference of business model. Regarding maritime safety, these goals are familiar with the concept of smart ship because optimization of assets will include condition-based maintenance. Therefore, this chapter concluded that existing shipping companies will contribute to maritime safety through realization of smart ships.

2.1.3.2 Analysis of classification societies' strategies

In terms of risk mitigation function which Pietrzykowski & Hajduk (2019) described, all available strategies referred to condition-based maintenance and the digital twin concept. As written in item 2.1.1.2, monitoring will increase reliability of equipment onboard, contributing to maritime safety. Digital twinning provides accurate simulation of ships, which enhances safe navigation. Therefore, it seems that classification societies have tried to mitigate risks by using digital technologies. However, Chae et al. (2020) pointed out that it is difficult to assess the risks of MASS by using only traditional risk assessment measures, such as FMEA, HAZOP and PHA, and the authors recommended using the latest methods, such as FRAM and STPA. Although none of strategies referred to the introduction of the latest risk assessment methods, classification societies will be forced to use or develop appropriate measures to evaluate the risks of autonomous ships. In any case, to assess the risk will contribute to optimization of use of assets, which matches shipping companies' intentions to optimize their asset management, as analyzed in item 2.1.3.1. Therefore, both entities can cooperate with each other to advance digitalization.

In addition to the above analysis, certain classification societies seem to be reluctant to publicize or reveal their strategies regarding digitalization to outsiders. This tendency is also observed among the major shipping companies. It is indicative of the fact that classification is globally commercialized and classification societies compete with each other. Hence, they are forced to focus on business profit beyond their public roles, of which flag States are formally in charge (Silos et al., 2013). This might be a reason that some classification societies do not want to publicize their strategies regarding digitalization, just like private companies, in terms of business confidentiality.

Chapter 3

3.1 Limitations of digitalization

There are many papers which referred to limitations of digitalization. Chae et al. (2020) suggested that cyber security, performance and the cost to introduce intelligent systems and reliability of them are critical issues to be addressed to realize MASS. In addition, Lloyd's Register (2016) suggested that (1) legal liabilities, (2) socio-technical challenges such as inappropriate design, (3) new skills for digitalization and (4) social acceptance such as mixed traffic are key challenges. Furthermore, WMU (2019a) explained that there are six issues related to automation: (1) economic benefits, (2) regulation and governance, (3) technical feasibility, especially secure, reliable and robust worldwide data connection with enough bandwidth, (4) social acceptance, (5) knowledge and skills, and (6) labor market dynamics (operators who have ocean-going experiences will disappear). Moreover, UNCTAD (2020) explained many limitations of digitalization, including international regulations, data harmonization and cybersecurity. Besides, many papers pointed out specific technical challenges, such as telecommunication capacity. Through the literature review, the following major issues are identified to realize digitalization of ships:

- **Cost**
- **Cyber security**
- **Data related issues**
- **Human element**

- **Reliability**
- **Social acceptance**
- **Liability and regulatory related issues**

This chapter will provide an overview of the above major challenges and suggest possible solutions.

3.1.1 Cost

Overview of the issue

An autonomous ship requires high redundancy, which increases construction cost. In addition, it requires large sums of money to equip advanced systems on board and develop SCC (Moræus et al., 2016). The new building cost of an autonomous ship is estimated to be three times as high as a conventional ship of the same size (Munim, 2019). However, Moræus et al. (2016) conducted a feasibility study on an autonomous bulker (MUNIN project) and concluded that the autonomous bulker would be economically feasible in some circumstances, and it improves the benefit by US$ 7 million over 25 years as compared to an ordinary conventional bulker. Taking into account the optimized operation realized by an autonomous ship, operational cost can be reduced by US$ 1 million per year (Munim, 2019).

There is another scenario which increases the operational costs of an autonomous ship. Guerra (2017) explained that under compulsory pilotage, a pilot may refuse to interact with unmanned autonomous ships, which requires unmanned autonomous ships to be controlled by human operators onboard during departure and arrival. In this case, crewing cost and construction cost to equip the bridge will occur, which undermines the cost-saving effect. However, the above mentioned MUNIN project was conducted under the assumption that crew are onboard during departure and arrival, so this issue may be limited under some conditions. Guerra (2017) also suggested other scenarios in which the pilot would take over remote control or an operator in SCC would obtain a pilot license for the operation area in question.

To discuss the problem of cost, it might be better to analyse whether an autonomous ship is feasible in terms of its business model. WMU (2019b) analysed *Yara Birkeland*, and pointed out that the current business model of autonomous ships is limited to short and local routes in a country that has manufacturing companies that can develop innovative solutions for transport systems, such as modal shift. Therefore, the author concluded that the business model should be expanded under the consultation of an expert.

Similarly, Munim (2019) illustrated that developing an effective business model is one of the major constraints to realizing an autonomous ship because it requires expensive advanced technology. Therefore, the author explained that justification of higher initial investment (three times higher than a conventional ship) is necessary to secure added customer benefits. The author recommended that makers of autonomous ships possess them and offer them to a shipping company on a pay per use basis. The author also recommended that governments provide financial and non-financial incentives to makers of autonomous ships and stakeholders to construct autonomous ships and develop a value chain. Actually, some states seem to be willing to subsidize development of autonomous ships. In the case of *Yara Birkeland*, about one third of the total construction cost is funded by the Norwegian Government (WMU, 2019b).

Possible solution

In summary, the literature review indicates that in the current conditions, the application of autonomous ships is limited with fixed route and shipper in terms of economic reasons. Therefore, an appropriate business model which can pay high initial costs to introduce autonomous equipment should be developed for the spread of autonomous ships. Otherwise, financial support by Government, such as subsidies, might be necessary. On the other hand, there is no paper found which refers to the cost problem of smart ships. Digitalized equipment used for smart ships is considered to be gradually adopted if the shipowner thinks that it brings economic benefit through operational optimization.

3.1.2 Cyber Security

Overview of the issue

An autonomous ship may decrease accidents at sea, but it can cause non-navigational accidents including cyberattacks (Munim, 2019). Although an autonomous ship is not navigating up to now, cyber security is still a big issue in the maritime industry (de la Pe˜na Zarzuelo et al., 2020; UNCTAD, 2020). In addition to ships, Pietrzykowski and Hajduk (2019) emphasised the importance of cyber security to realize SCC. Therefore, if digitalization proceeds further in the maritime industry, the impact may become more serious. For example, a cyber-attack against crucial control systems of vessels can cause serious consequences such as grounding, collision and environmental damage (Chae et al., 2020).

Possible solution

To mitigate the risk of cyberattacks, de la Pe˜na Zarzuelo et al. (2020) suggested that it is important to conduct some measures, such as regular updates of operating systems, secure satellite connections, stronger passwords, information sharing, resilience exercises and awareness campaigns for employees.

Petković et al. (2019) suggested that blockchain could be a solution for cyberattacks against autonomous vessels. The authors explained that unlike traditional distributed databases, all nodes on the network communicate with each other and collaborate to maintain all data, which eliminates invalid data introduced by a hacker because honest nodes will not accept it and fix it in case of blockchain. Due to this mechanism, blockchain has successfully blocked cyber-attacks for more than 10 years. Currently, several shipping companies have announced that they will introduce blockchain into trade procedures, such as bills of lading, but the authors propose that blockchain is also useful for control of autonomous ships from SCC. Specifically, blockchain enables control data and critical ship data to be shared, stored and managed by certified users, which eliminates threats of hackers tampering with data or stealing critical data.

In summary, it is necessary for the maritime industry to appropriately take measures to cope with cyber security for digitalization. Current measures taken by the international regulatory framework will be discussed in subsection 3.2.2. In addition, to make the industry more cyber-resilient, it is recommended to use blockchain for communication between an autonomous ship and shore since operation of an autonomous ship requires high level security. Furthermore, it is not well researched how cyber-attacks can influence the operation of autonomous and unmanned ships, including remotely controlled ships. Therefore, further research is expected in this field.

3.1.3 Data related issues

3.1.3.1 Capacities of Telecommunication

Overview of the issue

To control autonomous operation and support real time decision-making, high data rates, real-time transmission, high data integrity, high resilience and robustness are required for data transmission between shore and ships (Chae et al., 2020). For example, data transmission of 3D maps and high-resolution video to assist autonomous navigation requires a few Mbps transmission rate (Lloyd's Register, 2016; Aiello et al., 2020; Chae et al., 2020). To realise such real-time, high speed and high-capacity data transmission, it costs huge sums of money for ships to use this data rate via satellite communication (Aiello et al., 2020).

Possible solution

Aiello et al. (2020) illustrated that WiMAX technology has been regarded as a feasible option for medium to long-range broadband maritime communications. It covers 50-100km and has data rates of more than 20 Mbps. This technology might be useful for domestic shipping or short sea shipping where vessels navigate within 100km from shores, but it is insufficient for ocean-going ships in terms of coverage. For ocean-going autonomous ships, development of Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) may save the cost of satellite communication in the future (Aiello et al., 2019).

In summary, although high speed, high-capacity telecommunication is a necessary element to digitalize ships, it highly depends on innovation in the field of telecommunication technology. New satellite technologies, such as MEO and LEO may resolve the issue, but it seems to take time to develop a constellation of satellites. Therefore, autonomous navigation may be limited to coastal shipping before space infrastructure is well developed. To further support diffusion of autonomous ships, Governments are required to invest in R&D of new space technologies. Actually, the UK Government pledges to assist such R&D to facilitate digitalization in its maritime strategy (as shown in Appendix B).

3.1.3.2 Data availability

Overview of the issue

Lloyd's Register (2016) suggested three challenges regarding data availability. Firstly, data might be incorrectly gathered and processed, which results in inaccurate or poor situational awareness, wrong decisions and incorrect actions taken by autonomous ships. Secondly, most navigational sensing systems, such as radar, are designed for human operators. Therefore, these systems are too immature to provide intelligence. For example, a radar operator should identify and ignore clutter on the radar display by manually looking along the bearing and confirming the track. Thus, the AI systems should be trained to provide sophisticated intelligence. Thirdly, current sensors may not be able to provide enough resolution to satisfy the watchkeeping requirement of COLREGs and STCW.

Possible solution

To develop more integrated, robust and net-centric navigational systems onboard, Dalaklis et al. (2020) proposed a top-down engineering method based on system theory. In this approach, mission objectives and capacity required to achieve them are firstly identified, avoiding focusing on past solutions or specific equipment. Then, a series of interconnected functions are described. By using the functions identified, all services, hierarchy and interconnections are also specified. The authors applied this notion to ships and explained that the objective of the integrated system is to organize, synchronize and coordinate activities of shipping companies, including both ship and shore sides, by utilising a net-centric, seamless information exchange architecture to create a collaborative environment, which can optimise operations, to improve the quality and speed of decision-making and to secure navigational safety. To realise such systems, the authors identified four critical services: (1) a navigation and guidance service, (2) a ship propulsion, energy and maintenance service, (3) a cargo handling and monitoring service, and (4) a logistics and supply service. The authors explained that this approach enables seamless integration of information. As an example of the navigation and guidance service, navigational data are provided by many sources, including GNSS, gyro compasses, laser compasses, and magnetic compasses. Since each equipment has its own advantages and disadvantages, data from different sources can complement each other to secure robustness and fault tolerance.

3.1.3.2 Data vulnerability

Overview of the issue

Up to now, there have been many incidents of hacking or jamming, so digitalization may spur this situation. For example, positioning data from GNSS can be jammed or hacked, leading to grounding or collision (UNCTAD, 2020). In addition to GNSS, Dalaklis and Baldauf (2018) pointed out that AIS has vulnerability because the system is based on open-source and open frequencies, which increases the risks of malicious transmissions and manipulation by hackers.

Possible Solution

To tackle this problem, it can be recommended to introduce the net-centric architecture described in item 3.1.3.2. Chae and Kim (2020) also proposed that safety sensors used for ship critical systems should have at least homogeneous and/or heterogeneous redundancy and diagnosis and/or prognosis to secure robustness and fault tolerance.

3.1.4 Human Element in digitalization

Although unmanned autonomous ships have the possibility to reduce human errors, human factors are still important elements in the design and operation of such vessels because operation of autonomous ships involves SCC operators (Ramos et al., 2019; Chae et al., 2020). Ramos et al. (2019) analysed the potential impacts of the human element in SCC and concluded that SCC operators can be a final safety barrier for avoidance of accidents even if a high level of autonomy is realized. Yoshida et al. (2020) showed that poor situational awareness of operators in SCC can be a risk given the fact that the main causes of collisions are wrong decision-making and poor lookout during navigation. In addition to the problem of SCC, many papers and national strategies reviewed in chapter 2 pointed out the importance of MET for digitalization. This subsection will analyse the challenges of digitalization from the perspective of the human element.

3.1.4.1 System Design for autonomous ships and smart ships

Overview of the issue

Regarding operation of unmanned autonomous ships, Pietrzykowski & Hajduk (2019) stated that the types of events that should be notified to operators and how they are informed (information or warnings) should be clarified. Lloyd's Register (2016) explained that human-machine integration should be carefully taken into consideration from the perspective of user-centred design for safe navigation because to interface and interact with new technologies is a new way of working for seafarers.

In the case of smart ships, Man et al. (2018) expressed concern that digitalization will decrease the number of engineers onboard and, unless appropriate measures are taken, the burden on the remaining engineer will increase, causing human error. The authors pointed out that equipment in the engine control room (ECR), such as alarming system and monitor, is not optimized in terms of ergonomics, which prevents engineers from noticing changes in the surrounding environment. As examples, the authors showed that there is no integrated overview system which can continuously access all platforms in the ECR and give necessary information to engineers readably. The cause of this problem is that the IT service used for integration of equipment depends on manufacturers and vendors. In addition, there are almost no international regulations or guidelines related to design and operations of ECR (Man et al., 2018).

Possible solution

Lloyd's Register (2016) concluded that collaboration among providers of technology, seafarers and experts of behavioral scientists is necessary to mitigate the risk of the human element. Similarly, to tackle the problem of ECR, Man et al. (2018) recommended developing appropriate strategies to govern the information in order to truly assist information processing and decision-making, instead of adding another digital service. Specifically, given the fact that digitalization involves many stakeholders, such as users, service providers, manufacturers and classification societies, the authors explained that the introduction of service-oriented architecture (SOA) is a possible solution because it can facilitate collaboration between stakeholders. In the case of SOA, all business activities are divided by functions called 'service'. Then, each service is developed, and an integrator will gather components corresponding to each service. If services are standardized in the industry, such services will be available on the cloud, and can be easily updated. As a real example, the EU has developed the Maritime Connectivity Platform (MCP) by using SOA in the e-navigation framework. The authors explained that SOA is beneficial both for bridge and ECR. However, the authors explained that it is more useful for ECR because there is almost no regulation for design of ECR (high flexibility), and operators rely heavily on digital information unlike navigators in the bridge who can use visibility outside windows. Therefore, the authors claimed the necessity to regulate human-machine relations to tackle the increasing complexities due to digitalization by using system thinking such as SOA.

In addition to the architectural point of view, Chae et al. (2020) explained that it is important to take into account human elements by using the IMO human element, human reliability assessment and operational risk assessment when designing and operating autonomous ships.

In summary, designers of digitalised systems should consider the human element by using relevant guidance. In case of unavailability of such guidance, especially for ECR, it is effective to introduce SOA in the design process. It is also important to set industrial standards of ECR operations so that providers can develop 'services'.

3.1.4.2 Safety of Navigation by SCC

Overview of the issue

It is considered that operators in SCC should develop the same level of situational awareness as a human navigator. However, operators in SCC may have limited ship sense as compared to a human navigator on board. Yoshida et al. (2020) used expert interviews and a navigational simulator and proved that it is difficult for operators in SCC to use body balance and grasp pitching, yawing and rolling from visual information. The authors explained that navigation experts tend to regard these ship senses as essential information sources and use navigational equipment such as ECDIS as supplementary information. Therefore, lacking ship senses can create poor situational awareness in SCC operators.

Possible solutions

It might be possible to duplicate the environment of the ship in the SCC with vibration, pitching, yawing and rolling by using virtual reality. However, such additional information may increase capacity of telecommunication (Yoshida et al., 2020). As there is no crucial solution found in the literature, the further research is expected on how remote-controlled ships can secure safety with limited information for the SCC.

3.1.4.3 Education and Training

Overview of the issue

Lloyd's Register (2016) suggested that digitalization of ships can create "ironies of automation", which means the more advanced technologies are introduced, the more highly-skilled personnel is needed to manipulate them. Therefore, training for shore-based operators who monitor and supervise ships is essential for digitalization (Pietrzykowski & Hajduk, 2019).

Possible solutions

Cicek et al. (2019) evaluated future skills for seafarers to cope with Industry 4.0 and concluded that increasing digitalization and automation in the maritime industry will require different and more innovative competence and expertise. The authors point out that abilities of emotional intelligence, negotiation, adapting to cultural differences and transferring knowledge are important in addition to IT and technology skills, cognitive ability and learning and researching competencies. Technical skills include operations monitoring and analysing, troubleshooting, information and data processing and programming. In addition, motivation competencies to learn will facilitate quick adaptation of crew to technological change.

Jo et al. (2020) also analysed required skills for seafarers in the era of digitalization, and concluded that seafarers' competences should be radically transformed. The authors suggested some specific skills for seafarers in the future (e-farer), including both hard skills (remote operation, Big Data analysis and cyber security) and soft skills (emergency response, stress management and self-management) as well as traditional skills. MET should be restructured taking into account such specific skills.

Furthermore, WMU (2019b) explained that autonomous ships require tasks related to remote monitoring of bridge, engine and sensor systems, and data analysis, so future seafarers should obtain abilities to mix maritime experience with digital skills and software engineering. The author specified six competencies for digitalization: Data Fluency/Data Analytics, Digital Operation of Physical Entities, Coding/Computer Programming, Digital Skills, Software Engineering and Maritime Computer Science. The author also suggested that there has been a trend wherein maritime education institutions do not integrate cutting-edge technologies into their curricula, so it is recommended that they improve their curricula so that seafarers do not have to learn such technologies through on the job training.

In addition to digital skills, Pietrzykowski and Hajduk (2019) emphasised the importance of sea-going experience because it is extremely difficult to grasp behaviours of ships and make appropriate decisions, especially during storms, without gaining experience on training vessels. Kitada et al. (2019) predicted that commercial education may be essential skills for seafarers in the case of partially automated ships so that seafarers onboard can take over business tasks ashore.

In addition to seafarers, education and training for operators in SCC is also important (Munim, 2019; Lloyd's Register, 2016)). According to Lloyd's Register (2016), these skills include: higher levels of digital and technical competency; ability to cope with both physical and cyber affairs; continuous collaboration with robotic and autonomous systems; remote and virtual working with shore-based crew including robots, experts and other personnel; capacity to cope with cyber hygiene and cyber threats; management of fleets from SCC. Up to now, the discussion to set required competences for operators in SCC has not been initiated (Yoshida et al., 2020). To set such requirements, further research is expected in this area.

3.1.5 Reliability

Overview of the issue

Malfunctions in software and hardware can cause more serious consequences for autonomous ships than conventional vessels because autonomous ships are composed of many digitalized components and one failure in a component propagates in other components. Therefore, it is important to raise the reliability of both components of autonomous ships (Chae et al., 2020).

Possible solutions

Possible solutions are introduction of remote diagnosis and development of systems which allow ships to return to ports when unmanned autonomous ships cannot be operated in an appropriate manner anymore due to critical errors. In addition, regarding collision avoidance, measures to assess safety of ship intelligence have not been developed, so further study should be conducted in this area (Chae et al, 2020). Furthermore, measures to cope with loss of communication between autonomous ships and operators in SCC should also be developed (Pietrzykowski & Hajduk, 2019).

3.1.6 Social Acceptance

Overview of the issue

Porathe (2019) suggested that AI may be able to detect the risks of collision several hours before a human navigator does, so autonomous ships may behave in different manners that a human navigator on another vessel close to the autonomous ships cannot understand. WMU (2019b) and Dalaklis (2018) suggested that autonomous ships or unmanned remotely controlled ships and traditional manned ships will navigate in the same water (mixed traffic), which may undermine safety. Human navigators may still continue to try to comply with COLREGs by following their own subjectivity. Therefore, if the behaviours of autonomous ships or unmanned remotely controlled ships are different from ships controlled by human navigators onboard, it may induce accidents.

Possible Solutions

Porathe (2019) recommended that behaviours of unmanned autonomous ships should be predictable. That is, unmanned autonomous ships should always follow COLREGs as much as possible. However, this scenario is not always possible because errors of AI can occur. Therefore, the author also recommends enabling such vessels to emit a unique signal so that AIS or ECDIS in other ships navigated by humans can detect and warn of the presence of unmanned autonomous ships. Moreover, the author expressed that the intention of behaviours of unmanned autonomous ships should be clearly shared with other ships. Therefore, the author also recommended that the voyage plan of such vessels should be shared with other conventional ships to make it easier for other ships to interpret the intention of manoeuvres of unmanned autonomous ships.

3.1.6 Liability and regulatory related issues

Guerra (2017) argued that technology itself is not a problem to realize autonomous ships, but existing legal and operational frameworks, such as law and liability, can be an issue. Maritime insurance contracts are subject to seaworthiness. The author explained that if there is a deficiency in the software of autonomous ships or if the software is susceptible to cyberattacks, the ship is considered to be unseaworthy. Therefore, the insured may not be able to take the benefit unless governments and international law guarantee that the autonomous technology is safe through research, sea trials and legislation. The author also analysed US maritime law and explained the need to determine whether an operator in SCC and his/her assistants are regarded as seafarers. The author also suggested that if the operator is not classified as a seafarer, then a new legal category in lieu of 'master' and 'crew' should be developed in the case of an autonomous ship.

Thus, establishment of appropriate law and liability is crucial for autonomous ships. The literature review identified two legal issues: COLREGs and STCW. The following subsection will firstly explain the challenges of the two conventions, and later suggest the problem of liability.

3.1.6.1 COLREGs

Overview of the issue

WMU (2019a) explained that COLREGs includes many subjective requirements, and the convention needs to be transformed into a more programmable one. Porathe (2019) gave details about the issue. According to the author, the most challenging thing is that the Convention is written in a qualitative manner so that it can be applied to as many situations as possible, which can be a major obstacle to programming collision avoidance functions. For example, Rule 2 of COLREGs permits navigators to deviate from the requirements of the convention, if necessary, to avoid accidents. However, this regulation does not specify when it is time to neglect for collision avoidance. That is, Rule 2 does not describe by when they should follow the Convention in a situation that the risk of collision is increasing. Similarly, Rule 15 (Crossing situation), Rule 17 (regulation for crossing situation) and Rule 19 (navigation in restricted visibility) also contain qualitative descriptions, such as “as soon as it becomes apparent”, “safe speed” and “restricted visibility”. Specifically, restricted visibility means visibility of human eyes, and can correspond to day-light camera image in the case of an autonomous ship. However, an autonomous ship probably relies on AIS, radar and LIDAR instead of day-light camera. Although these sensors may be better than human eyes, autonomous ships will be forced to equip day-light camera.

Guerra (2017) also explained that Rule 5 requires ships to retain an appropriate lookout by using hearing, sight and all other available measures applicable. However, these requirements are based on human perspective, and whether AI can recognize objects (sight) and detect human speech (sound) remains a problem because these abilities of AI are under development. In addition, the author pointed out that when a collision occurs due to system errors in AI abilities, courts may decide that the SCC supervising the autonomous ship is liable because such errors can be considered to mask the senses of AI during the collision, which can be negligence according to Rule 5. In addition to Rule 5, the author stated that Rule 9 also contains an ambiguous requirement. Rule 9 requires a ship navigating in a narrow channel to keep to its starboard side as long as practically possible. However, COLREGs does not specify the “narrow channel”.

Other than specific rules, there is also a problem that some vessels have a culture not to follow COLREGs (Guerra, 2017; Porathe, 2019). For example, ferries linking between Helsingborg (Sweden) and Helsingør (Denmark) have a culture not to keep out of the way in almost all situations (Porathe, 2019).

Possible solutions

Despite the above limitations, Lloyd’s Register (2016) explained that AI is considered to be able to recognize and categorize objects at sea, which allows for the correct application of the COLREGs (Porathe, 2019). Ma (2020) also explained that AI can learn COLREGs and operate a ship in line with the convention thanks to ML. Although

AI can understand COLREGs, there is still a problem of conventional ships which do not follow COLREGs. In this case, Porathe (2019) pointed out that it is possible to refine AI by using AIS data worldwide. Since AIS data include the trajectories of ships that do not follow COLREGs, AI can learn from such data and derive an appropriate route to avoid such vessels.

In summary, AI seems to be able to operate a ship in line with COLREGs despite the ambiguity of COLREGs, but the industry is recommended to demonstrate it by simulation or trial. In addition, Rules 15, 17 and 19 of COLREGs should be revised so that sensors other than day-light cameras are integrated.

3.1.6.2 STCW

Overview of the issue

Article 3 of STCW states that the Convention applies to ships with seafarers on board. However, in the case of MASS degrees 2 and 3 of IMO's definition, there is a discussion as to whether operators in SCC should be regarded as 'seafarers' or not (Chae et al., 2020; Yoshida et al., 2020). Pietrzykowski and Hajduk (2019) explained that the degrees 1 and 2 of MASS, which assume the presence of qualified or reduced personnel, are compatible with the STCW Convention, but in cases of significant reductions of crew or full automation (the degree 3 and 4), the current regulation cannot cover such situations.

Possible solution

It is natural to set new appropriate requirements for operators in SCC. Therefore, the maritime industry should start discussions to set such a regulatory framework for the training and qualification of such operators (Pietrzykowski & Hajduk, 2019), taking into account the prediction of future skills identified in item 3.1.4.3.

3.1.6.2 Liability

Overview of the issue

The report of the MUNIN project revealed that it is unclear whether the liability of masters in conventional vessels is applied to operators of unmanned autonomous ships in SCC, and further research should be undertaken (Moræus et al., 2018). Guerra (2017) stated that whether liability should be separated among operators in SCC, masters, or ship owners continues not to be addressed. The author pointed out that because an accident involving an autonomous ship will surely occur in the future, it is necessary to develop regulations proactively to decide the range of liability. The author further analysed how the negligence (against the duty to avoid collision) would be evaluated in the case of an autonomous ship controlled by SCC. The author concluded that in the case of collision, the court would probably seek to approach liability from the situation of operators in SCC, which are considered to be the master and crew, to decide whether the collision could have been prevented by the practice of duty.

Possible solutions

Guerra (2017) pointed out that the shipping industry can refer to the discussion of autonomous vehicles. As an example, Hevelke and Nida-Rümelin (2015) discussed who should take responsibility when autonomous vehicles cause accidents. The authors concluded that there are two options: the duty to intervene or a responsibility of the driver as a form of a "strict liability". In the first option, the responsibility relies on a chance for an average driver to effectively predict and prevent the accident. The authors claimed that this approach is useful for the initial stage of diffusion of autonomous vehicles. In the second option, the driver will take responsibility under the assumption that the driver is responsible only for taking the risk of using the car. That is, among millions of citizens using autonomous cars in a nation, the driver shares the responsibility with other people who do the same in the country. Although the driver does nothing wrong in case of an accident, it is considered that he or she participates in a practice which carries risks and costs for others. However, the authors suggested that this responsibility should not surpass a responsibility for the general risk taken by using the autonomous vehicle, so a tax or a mandatory insurance seems to be the most likely and practical measure. Furthermore, the authors explained that given the fact that autonomous driving can increase safety and save lives, the responsibility of manufacturers should be limited unless they sell intentionally defective vehicles.

In summary, although there are many differences between shipping and automobiles, and the future business model of an autonomous ship is unclear, the above reference might be useful for the shipping industry to consider the issue. It might be possible to substitute the driver and the manufacturer for operators in SCC and system integrators, respectively. In any case, it is recommended that the shipping industry initiate a discussion of the issue referring to the discussion in the automotive field.

3.2 Actions by IMO to tackle the limitations

3.2.1 Regulatory Scoping Exercise for MASS

The 98th session of MSC in 2017 agreed to include a new output concerning a "Regulatory scoping exercise for the use of MASS" into the committee's 2018-2019 biennial agenda with a target completion year of 2020 (IMO, 2021a). The objective of the exercise is to assess the existing IMO instruments to provide basic information to consider how operation of autonomous ships will affect them (Hurley, 2021). The framework of the exercise was approved at the 100th session in 2018, which described a two-step approach. The first stage is regarded as the initial review of IMO instruments, and instruments were categorized into the following four items:

A. Instruments which apply to MASS and prohibit MASS operations; or
B. Instruments which apply to MASS and do not prohibit MASS operations (no further action); or
C. Instruments which apply to MASS and do not prohibit MASS operations (possibly need to be clarified or amended); or
D. Instruments which do not apply to MASS

The Intersessional Working Group on MASS (ISWG/MASS) in 2019 completed the first step. The second step was to evaluate and decide the most appropriate measures to address MASS operations, taking into account technology, human element and operational factors. These measures were categorized into the following four items:

I. no action needed or to develop interpretations; and/or
II. to revise existing instruments; and/or
III. to develop new instruments; or
IV. none of the above as a result of consideration

The second step was delayed due to the COVID-19 pandemic, and was finalized at the 103rd session in May 2021 (IMO, 2021a).

The result of the exercise describes two possible avenues for the future. The first is to develop new IMO instruments, such as a “MASS Code” to holistically address the many challenges identified under the exercise. The second is to revise all instruments separately. To take the second option, possible prioritization to address instruments was also written in the result. However, the result implies that the first option is preferable because the second option may cause inconsistencies and create potential barriers for the application of existing requirements to conventional vessels. The result also recommends the development of interim guidelines to operate MASS at an early stage (IMO, 2021b).

This dissertation will not elaborate the details of the result of individual instruments because there are so many challenges identified, but three common gaps and themes were found through the exercise (IMO, 2021b):

(1) Meaning of the term ‘master’, ‘crew’ or ‘responsible person’

In many instruments, the meaning of the term ‘master’, ‘crew’ or ‘responsible person’ needs to be clarified, especially for MASS degrees three and four, where operators in SCC might control the ship. In addition, Each IMO instrument is developed under the assumption that master and crew are onboard although some requirements do not explain it. To change this precondition may have great influence on the instruments. Therefore, due consideration should be given to revising or clarifying such terms. The relevant conventions are SOLAS chapters II-2, III, V, VI, VII and IX, COLREG, TONNAGE 1969, 1966 LL Convention and 1988 Protocol, Intact Stability Code, III Code, and the STCW Convention and Code.

(2) Remote control station/center

The functional and operational requirements for SCC need to be developed. The relevant conventions are, SOLAS chapters II-1, II-2, III, IV, V and IX, STCW Convention and Code, FSS, ISM, 1966 LL Convention and 1988 Protocol, and Casualty Investigation Code.

(3) Remote operator designated as seafarer

It should be considered to regard operators in SCC as seafarers in addition to their qualifications, responsibility and the role as operators. The relevant regulations are: STCW, STCW-F, SOLAS chapter IX, and ISM Code.

In addition to the above problems, the result explains that the glossary related to MASS, such as definition and autonomous level, needs to be clarified or re-considered, taking into account lessons learned through the exercise. Based on the above prioritized challenges, new outputs for changes in the regulatory framework will be proposed (Hurley, 2021; IMO, 2021a).

Following the initiation of the RSE conducted by MSC, FAL and LEG also started the same work to review instruments governed by each committee, but the discussion is not proceeding well. The discussion of FAL was planned to be initiated at the 44th session in June 2021. However, the discussion on RSE was postponed to the next session due to time limitation (IMO, 2021c). In the case of LEG, volunteering members completed reviews of instruments, but due to time limitation, LEG could not finalise the result of the exercise at the 107th session in December 2020 and the Committee postponed the discussion to the next session on July 2021 (IMO, 2020).

3.2.2 Development of Cyber Security Guideline

MSC and FAL adopted a voluntary guideline on maritime cyber risk management in 2017 (IMO, 2017a). The guideline recommends shipowners to integrate cyber risk management into existing risk management processes so that it can complement safety and security practices under the IMO regulatory framework. (IMO, 2017a, UNCTAD, 2020). According to the guideline, cyber risk management is composed of the following five stages:

1. **Identify**: Define each member of personnel's role and responsibility for cyber risk management and identify the systems, assets, data and capabilities which pose risks to ship operations when disrupted.
2. **Protect**: Conduct risk control procedures and means, and contingency planning to protect systems and assets against a cyber incident and secure continuity of shipping operations.
3. **Detect**: Create and implement activities that are necessary for detection of cyber incidents.
4. **Respond**: Create and implement plans and activities that enhance resilience and restore systems necessary for services or operations impaired by cyber incidents.
5. **Recover**: Identify means to recover and restore cyber-related systems necessary for operations impaired by cyber incidents. (IMO, 2017b)

Based on the IMO's guideline, some major shipping organisation, including BIMCO and ICS, have developed detailed cyber security guidance for shipping companies (BIMCO et al., n.d.). MSC98 decided a resolution that approved safety management systems under the ISM Code should take into account cyber risk management in 2017 (IMO, 2017a).

Cybersecurity is also covered by the International Ship and Port Facility Security (ISPS) Code. Specifically, Under Part A, section 8.4 of the Code, shipowners are required to conduct ship security assessment, including identification and evaluation of important operations onboard, identification of threats to the important operations onboard and its likelihood, and identification of weakness. In addition, under Part B, section 8.3 of the Code, the ship security assessment should address radio and telecommunication systems, such as computer systems and networks, and other areas which can be a risk to personnel, property or operations onboard or within a port facility (UNCTAD, 2020).

3.2.3 Facilitation of E-navigation

Since the 81st session of the MSC, IMO member states have been tackling 'E-navigation', which aims to harmonize data transfer between vessels and facilities ashore including VTS for maritime safety, security and marine environmental protection (Burmeister et al., 2014; Kitada et al., 2019). The fields of e-navigation include navigational systems onboard, vessel traffic data management ashore, and communication infrastructure between ships, ship to shore and shore to shore. To develop the concept, IMO firstly identified user needs and conducted gap analysis. Then, five prioritized e-Navigation solutions were proposed in 2013, and most of them are related to improved communications between stakeholders (Burmeister et al, 2014). Much effort has been made, such as enhanced satellite support, increasing data processing capacities with computers and development of FOC. Such systems enable operators ashore to monitor and support vessels through enhanced communication among shore and vessels. E-navigation is relevant to support for human operators on board, and it does not aim to replace them unlike unmanned autonomous ships (Kitada et al., 2019).

Burmeister et al. (2014) analysed the MUNIN project and concluded that autonomous vessels can contribute to the aim of e-navigation because autonomous ships can increase navigational safety although the concept of the MUNIN project is different from conventional ships. For example, the autonomous vessel assumed in the MUNIN project can integrate a variety of navigational data through various advanced sensor modules, which eliminates false data and increases reliability and plausibility.

Regarding e-navigation, the sixth session of NCSR approved guidelines on standardized mode of operation, s-mode, which describes standardization of user-friendly design of navigational equipment, including requirements for navigational displays, operational measures and functions realized by one-click (IMO, 2019a). The eighth session of the sub-committee considered recognition of the Japanese navigation satellite system and agreed to regard the system as a world-wide radio navigation system. It is the first satellite system used for support for coastal navigation, so it is expected to increase navigational safety of coastal shipping and port calling (IMO, 2021d).

3.3 Gap Analysis between the limitations and IMO's action

This section will discuss the gaps between problems identified in section 3.1 and IMO's current actions.

3.3.1 Cost

Regarding the issue of cost, it is not IMO's role to develop an appropriate business model for autonomous ships. Article 1 of the Convention on the International Maritime Organization, 1948 implies that IMO is just a forum so that member States can discuss international conventions for maritime safety, security and marine environmental protection. Therefore, it is almost impossible for IMO to subsidize companies. Rather, it is recommended for States to support and subsidise such companies that wish to construct autonomous ships as Munim (2019) explained. However, none of the national strategies reviewed in section 2.1.2 referred to subsidies for shipowners although most strategies referred to subsidies for R&D of digitalization. Therefore, it is recommended for states to seek to develop appropriate business models with the maritime industries, including subsidies.

3.3.2 Cyber security

As noted in subsection 3.1.2, it is unclear how cyber-incidents can influence the operation of autonomous ships and remotely controlled ships, and further research is expected in this field. The current guidelines for cyber security developed by IMO are mainly for conventional ships because autonomous and unmanned ships did not exist when the guideline was developed. Cybersecurity was identified as one of the issues of SOLAS Chapter IX and ISM Code in relation to MASS under the exercise (IMO, 2021a), so it is recommended to revise the guideline in the future, taking into account the results of future research.

3.3.3 Data related issues

3.3.3.1 Capacities of Telecommunication

As well as development of business models for autonomous ships, it is difficult for IMO to directly accelerate R&D of advanced telecommunication technologies. Such a role should be played by nations. The role of IMO in this issue is to discuss and approve new communication technologies, just like the eighth session of the NCSR, which recognized the Japanese navigation satellite as a world-wide radio navigation system upon requests of member States.

3.3.3.2 Data availability

This problem is not identified under the RSE of IMO. Although IMO seeks to develop goal-based standards for MASS, this issue is a little bit technical. Therefore, it is not clear whether IMO can create very technical requirements referring to multiplexing and use of many types of data sources. Rather, as written in item 2.1.3.2, it might be classification societies that evaluate possible risks of autonomous ships, such as data availability. Therefore, it is recommended for classification societies to be appropriately able to assess the risks of autonomous ships, including data availability.

3.3.3.3 Data vulnerability

This problem is not identified under the exercise. As well as item 3.3.3.2, the risk of data vulnerability is expected to be well assessed by classification societies, instead of IMO.

3.3.4 Human Element in digitalization

Human Element in digitalization, especially the problem related to SCC, is well identified as a problem under the RSE. Therefore, it is expected that this problem will be discussed at IMO in the near future.

3.3.5 Reliability

This problem is not identified under the exercise. As well as item 3.3.3.2, the risk of reliability is expected to be well assessed by classification societies, instead of IMO.

3.3.6 Social Acceptance

As written in subsection 3.1.6, Porathe (2019) suggested that autonomous ships should emit unique signals so that conventional ships can identify the location of autonomous ships. The author also pointed out that voyage plans of autonomous ships should be shared with conventional ships so that conventional ships can recognize the intended actions of autonomous ships. Such measures might be indispensable under mixed traffic to mitigate the risk of accidents between autonomous ships and conventional ships. In any case, navigational rules of autonomous ships should be compatible with traditional maritime safety goals which crew may face for collision avoidance (Hurley, 2021). Although the problem of mixed traffic is not identified under the exercise, it is recommended for member States to discuss this issue at IMO and include such measures into the regulatory framework of IMO.

3.3.7 Liability and Regulatory related issues

The issue of liability might be a commercial one, so there might be no space in which IMO can contribute. However, as noted in subsection 3.1.6, the maritime industry should prove that autonomous ships are technically safe through legislation, R&D and experiments (Guerra, 2017), and IMO can contribute in this field. Regarding legislation, further discussion to revise IMO instruments to cope with MASS should be undertaken by member States in the near future based on the results of the RSE, taking into account the fact that some States already have autonomous ships in short service (Hurley, 2021). In addition, although IMO cannot play a role in R&D, many member States are willing to advance R&D of autonomous ships as per item 2.1.2 and such States might be able to share their experiences regarding R&D at IMO meetings to show that digital technologies are safe enough to diffuse. Regarding the experiment, IMO adopted interim guidelines for MASS trials in 2019. The guidelines elaborate specific requirements during MASS trials, such as risk management, compliance with existing instruments, manning, human element, reporting to relevant authorities and cyber risk management (IMO, 2019b). Some experiments are conducted based on this guideline. For example, NYK line conducted trials of autonomous navigation under the guidelines in 2019 (NYK lines, 2019). In addition to this Japanese experience, some States, such as Denmark, Norway and the UK, will conduct such experiments based on their national strategies analysed in subsection 2.1.2. To further show the safety level of autonomous ships, member States are expected to repeat trials under the guidelines.

Chapter 4 Summary and Conclusion

4.1 Evolution of shipping by digitalization

Digitalization of ships is a change of way of business by introducing the cutting-edge technologies of Industry 4.0, especially AI, Big Data and IoT. Due to digitalization, ships may evolve into autonomous ships or smart ships in the future. Autonomous ships are considered to require new business models because of the huge costs required for initial investment (at least three times high as conventional ships). Therefore, autonomous ships may not be a result of improvement of conventional ships, and they may not replace existing shipping routes. Smart ships, on the other hand, might be an extension of the conventional ships. Smart ships are basically manned, and decision-making onboard is supported by AI, IoT and Big Data.

In the case of an autonomous ship, much navigational data may be gathered through IoT techniques. Then, data will be evaluated by AI (Big Data Analysis), and AI will provide intelligence for navigation and make decisions to control the ship. Some navigational data through sensors may be sent to SCC, and advanced communication techniques, such as LEO, will be used when transferring data. Data will be monitored by operators in SCC, and human operators in SCC may intervene if necessary. Ultimately, ships which no longer require human intervention, such as ASDS, may be realized. In the case of a smart ship, AI may suggest probable courses of action instead of control, and seafarers will make the final decisions for navigation.

There are four ways in which these ships may contribute to maritime safety. The first one is to improve situational awareness. Since many sources of information are integrated and analysed by AI, autonomous ships may provide accurate situational awareness. In addition, human errors are expected to decrease because AI does not feel fatigue. Furthermore, autonomous ships may detect abnormal situations and predict the possibility of dangerous situations through Big Data analysis. Finally, these ships may detect any sign of failure by continuous data monitoring, especially for engines, which enables more accurate maintenance and realizes condition-based maintenance. Condition-based maintenance will enhance reliability and decrease malfunctions. Humans may continue to be involved in navigation, from shore or onboard, and a new type of collaboration between humans or human and machine will arise.

4.2 Analysis of National and Companies’ strategies for digitalization

4.2.1National Strategies

This dissertation identified the following five directions of major maritime administrations for digitalization through the review of national strategies:

1. National and international legislation to cope with digitalization, especially for autonomous navigation
2. Coordination among stakeholders
3. R&D for AI, Big Data and IoT
4. Improved MET to integrate AI, Big Data and IoT
5. Improvement of IMO Instruments Implementation by introducing AI, Big Data and IoT if necessary

4.2.2 Companies’ Strategies

This dissertation identified the following two trends of major shipping companies for digitalization through the review of companies’ strategies:

1. To increase cost efficiency, such as optimization of assets
2. To meet the needs of customers, such as container tracking

In relation to maritime safety, these courses of action are familiar with the concept of smart ships because optimization of assets may bring condition-based maintenance. Therefore, this dissertation concludes that existing shipping companies may contribute to maritime safety through smart ships.

Through the review of major classification societies’ strategies, this dissertation identified the role of risk mitigation of classification societies for digitalization. Actually, all available strategies referred to condition-based maintenance and the digital twin concept, which may increase maritime safety through improved reliability of equipment onboard.

4.3 Limitations and possible Solutions

The literature review identified six major issues (cost, cyber security, data related issues, human element, reliability, social acceptance, and liability and regulatory related issues).

For the issue of cost, appropriate business models which can surpass higher initial costs should be developed. Otherwise, financial support by governments, such as subsidies, may be necessary.

For the problem of cyber security, the literature review identified that blockchain might be useful to prevent cyberattacks. However, it is not well researched how cyberattacks can influence the operation of autonomous ships and unmanned ships, so further research is needed in this field.

For the issues of data, the literature review identified the problems of capacity of telecommunication, data availability and data vulnerability. Regarding telecommunication, new satellite technologies, such as MEO and LEO may resolve the issue. Coastal shipping can also use high-speed and high-capacity telecommunication technologies, such as 5G. To further diffuse autonomous ships, Governments are required to invest in R&D of new space technologies. Regarding data availability and vulnerability, the introduction of top-down engineering method can be a solution. That is, because each equipment onboard has its own advantages and disadvantages, data from different sources should be integrated and complement each other to secure robustness and fault tolerance.

For the issues of the human element, the literature review identified the problems of system design for autonomous ships and smart ships, safety navigation in the case of remote control, and MET. To tackle the problem of system design, it might be necessary to develop autonomous ships and smart ships in line with the notion of SOA. Regarding SCC, the literature review could not find any solution for this problem, so further research is expected. Regarding MET, many studies predicted future skills for seafarers and operators in SCC, such as cybersecurity, big data analysis and commercial skills. To set such requirements for future MET, further research is expected in this area.

Regarding reliability, the possible solutions identified are introduction of remote diagnosis and development of systems which allow ships to return to ports when the ships cannot be operated in an appropriate manner anymore due to critical errors. However, future studies should be undertaken on collision avoidance, measures to assess safety of ship intelligence, and loss of communication between autonomous ships and operators in SCC.

Regarding mixed traffic, the possible solutions identified are to design behaviours of autonomous ships in line with COLREGs and enable them to emit unique signals so that conventional ships can detect autonomous ships. In addition, the intention of behaviours of autonomous ships should be clearly shared with other ships by sharing the voyage plans of autonomous vessels with other conventional ships.

Regarding the liability issue, the shipping industry is required to clarify this issue and develop appropriate regulations regarding liability, taking into account discussions of autonomous vehicles. It is also necessary to develop national and international laws to regulate autonomous or unmanned ships. Regarding the issue of regulations, relevant international instruments, especially COLREGs and STCW should be updated, taking into account the results of RSE.

4.4 IMO's actions for digitalization

Up to now, IMO has tried to cope with digitalization by way of RSE, development of cyber security guidelines and the concept of e-navigation. RSE well identified basic issues regarding digitalization, especially concerning the human element. Many issues, including cost, reliability and liability, are not referred to in the exercise, but these issues seem to be addressed by other entities, such as governments and classification societies. The further action required for IMO is authorization of GNSS using new technologies, discussion to mitigate the risk of mixed traffic and information sharing about new technologies. In addition, current cybersecurity guidelines may not prevent cyberattacks on autonomous and unmanned ships. Therefore, the guidelines should be updated according to the latest research.

4.5 Conclusion

Because digitalization is considered to enhance maritime safety, the above six issues should be addressed. To further advance digitalization, this dissertation recommends the following actions:

Governments

- to cooperate with their maritime industries to develop appropriate business models for autonomous ships, including subsidies.
- to further facilitate R&D for digitalization, especially for space infrastructure
- to consider future skills for seafarers and operators in SCC, and to set such requirements for future MET
- to cooperate with their maritime industries to seek to establish appropriate liability, taking into account discussion of autonomous vehicles.
- to share and discuss information on the above items at IMO
- to discuss how to mitigate the risk of mixed traffic at IMO

Classification societies

- to develop appropriate risk assessment methods for autonomous ships and unmanned ships

Maritime Industries

- to introduce advanced design methods, such as SOA, to enhance reliability and eliminate data vulnerability

Research Institutes

- to research more on the risk of cyberattacks against autonomous or unmanned ships, safe navigation by SCC, and future skills for seafarers and operators in SCC.

The author believes that the major issues will be addressed in the future according to the above recommendations and shipping will make full use of digitalization, for enhanced safety and increased efficiency.

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Appendices

Appendix A: Terminology

In this section, this dissertation will give definitions for some basic words.

Digitization

Digitisation refers to the process which converts analogue information into digital data (Ma, 2020; Dalaklis et al., 2021).

Digitalization

Focusing on change of way of business, Kitada et al. (2019) defined that digitalization is the process for modernization of the shipping industry. On the other hand, WMU (2019a) defined digitalization focusing on system components. The author described that digitalization is a set of process to apply digital technologies to systems and processes, which improves functions of existing systems. WMU (2019b) also explained that digitalization is relevant to computerization of systems, possible fuel change and enhanced monitoring of navigational systems and engine. Sullivan et al (2020) focused on specific technologies relevant to digitalization of ships, and explained that digitalization in shipping from the perspective of the new concept “Maritime 4.0” (Industry 4.0 in the maritime domain). The key technologies include IoT, Robotics, Cloud Computing, Additive Manufacturing (3D Printing), Big Data, Intelligent Simulation and Augmented Reality.

Sanchez-Gonzalez et al. (2019) gave detail definition including both business and technical aspects. The authors showed that digitalization is to use digital technologies for transformation of business model and to suggest new opportunities to add value, referring to specific relation to the key technologies of Industry 4.0: Robotics, AI, Big

Data, Virtual Reality, IoT, Cloud Computing, Digital Security and 3D Printing. The authors also revealed that AI, Big Data and IoT are actively well researched in the field of shipping. Similarly, Dalaklis et al. (2021) defines digitalization as change of business model and creation of new revenue and business opportunity by using digital technologies (Figure A-1).

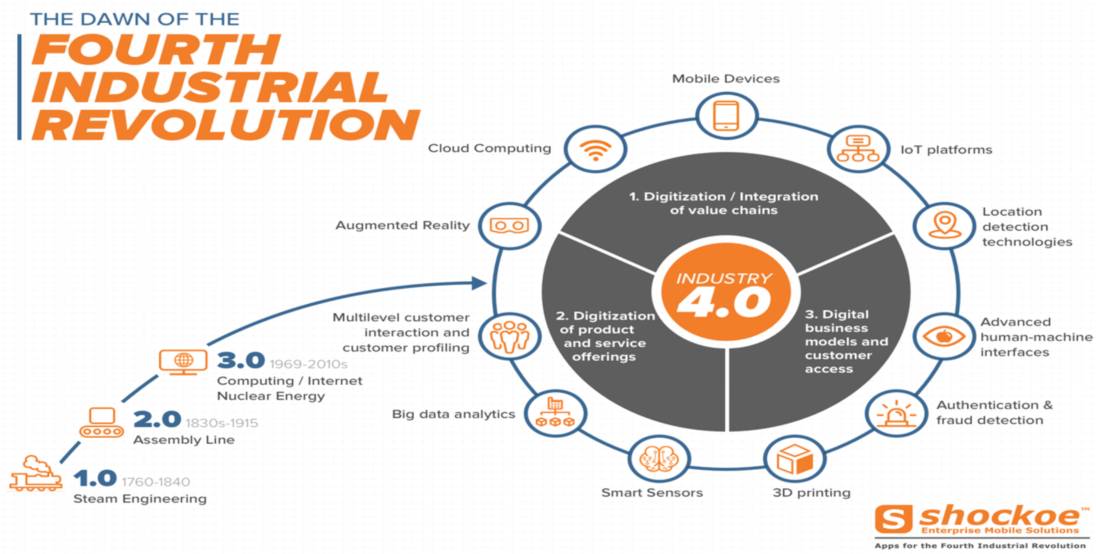

Figure A-1. Stages of the Industrial Revolution and key technologies of Industry 4.0. From "Stages of the Industry Revolution", by Dalaklis, 2021, p2.

Sullivan et al. (2019) illustrated that technologies of Industry 4.0 can have great influence on shipping, including real-time tracking, remote operations, collision avoidance, route optimization and surveillance of equipment.

Based on the above information, this paper defines "digitalization in shipping" as a change of way of business by introduction of the state-of-the-art technologies of Industry 4.0: Robotics, AI, Big Data, Virtual Reality, IoT, Cloud Computing, Digital Security and 3D Printing. Specifically, this dissertation will focus on the three technologies which are well researched fields in shipping as Sullivan et al. (2019) described (AI, Big Data and IoT). The definitions and impacts of AI, Big Data and IoT will be given in the item 2.1.1.1, 2.1.1.2 and 2.1.1.4 respectively.

Digital Transformation

Digital Transformation refers to cultural change created by increasing use of digital technologies. It focuses on human who adopt the technologies, instead of technologies themselves (Dalaklis et al., 2021).

Autonomous ship/vessel and unmanned ship/vessel

A number of literatures use "autonomous" and "unmanned" ships in the same meaning. However, unmanned vessels refer to ships without crew onboard, so these ships might be remotely controlled by facilities ashore or other mobile station, such as another vessel. An autonomous ship, on the other hand, is a vessel with appropriate systems which can manipulate the ship and make decisions on changes in control configuration without human intervention. Such decisions are delivered by AI. Autonomous ships can be both manned or unmanned and unmanned ships might be both autonomous or non-autonomous (Baldauf et al., 2017; Kitada et al., 2019). In some exceptional situations, autonomous ships may be controlled by shore. The feasibility study of autonomous ships called 'MUNIN' in Norway described that autonomous ships should be able to be controlled by shore because errors must occur during navigation of autonomous ships (Moræus et al., 2016). This implies that remote control supports and complements decisions of ASC onboard.

An example of autonomous ship and unmanned ship is *Yara Birkeland*. The ship is the first autonomous container ship in the world, owned by a Norwegian fertilizer make Yara (WMU, 2019b). The ship can also be manned and remotely controlled. The company revealed in November 2020 that the ship would be delivered soon and several test regarding cargo-handling and stability would be conducted (Yara, 2020). In July 2021, it is reported that several tests were conducting for the ship under the condition that crew are onboard ("SpaceX May Have", 2021). The first operation stage is expected to be manned and remotely controlled. Then, it will shift to remotely controlled without seafarers onboard (unmanned ship). Finally, autonomous and unmanned operation will be introduced (WMU, 2019b). To ensure safety, three remote control centres are planned to monitor operations of ships, so human interventions are expected in case of emergency and exceptional situations. The centres also deal with condition monitoring and decision support for the vessel (Kongsberg, n.d.). *ASOG*, described in section 1.1, can be also classified into both an autonomous ship and an unmanned ship. However, this ship is expected to operate without human intervention (Ralph, 2021), so the concept is more advanced than *Yara Birkeland*.

To summarize the discussion of 'autonomous' and 'unmanned' ships, it is possible to use the venn's diagram to classify all cases into the following seven patterns a to g in Figure A-2.

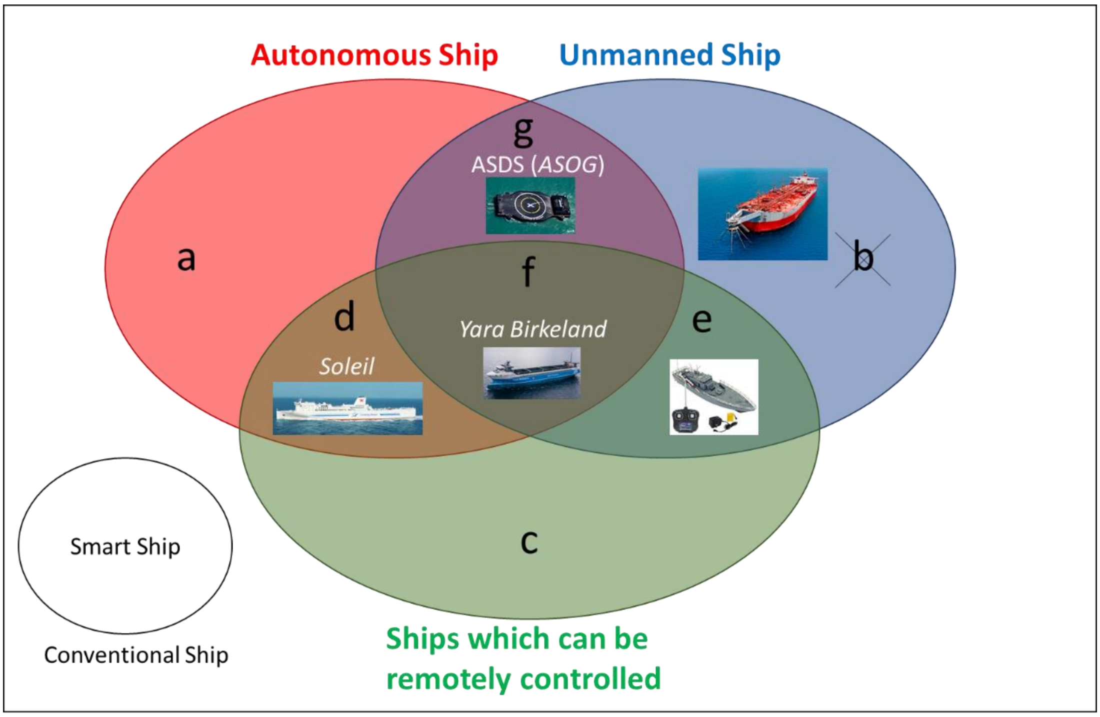

Figure A-2 Categorisation of future ships

Source: Created by the Author

There are sets of "autonomous ship", "unmanned ship", "Ship which can be remotely controlled" and "smart ship". The margin corresponds to a conventional ship. There are seven realms of sets (from a to g). Case a implies a ship which navigates autonomously with seafarers, but cannot be remotely controlled. Case b is a ship which is unmanned, but without an ASC nor remote control. It is difficult to imagine that ships can navigate without seafarers, ASC and remote control, so this type of ships may be static, such as a Floating Storage and Offloading unit (FSO). However, this is not relevant to digital technologies, so this dissertation will not focus on case b. That is, an unmanned ship refers to an autonomous ship without seafarers or a remotely controlled ship without seafarers. Case c refers to a remotely controlled ship which seafarers are onboard, and this corresponds to the degree two of MASS. Case d is an autonomous ship with seafarers onboard which can be remotely controlled. An example is a Japanese domestic ferry *Soleil*. This ferry realizes fully automation from undocking to docking and can be remotely controlled by shore. Test will be taken place after entering service, and the shipping company revealed that autonomous navigation will be used in daily operation if the ship shows high level of safety and efficiency in the test (The Nagasaki Shimbun, 2020). Case e means a remotely controlled ship without seafarers. Case f is an autonomous and unmanned ship which can be remotely controlled. The example is *Yara Birkeland*. Case g is an autonomous and unmanned ship which cannot be remotely controlled (no human intervention). The example is *ASOG*. In the case of *Yara Birkeland*, the ship is expected to firstly operate at the level of c., then try to navigate at the level of e. and finally seek to operate at the level of f. (WMU, 2019b). Thus, a ship can be both different levels.

Instead of defining an autonomous ship, the maritime industry and researchers have tried to clarify autonomous ships to give autonomous degrees, and many entities have tried to describe levels (Kitada et al., 2019; Pietrzykowski & Hajduk, 2019).

IMO uses the term MASS (Maritime Autonomous Surface Ship) to describe advanced ships, and IMO gives autonomous level as follows:

- **Degree one**: conventional ships which equip automated process and decision support systems.
- **Degree two**: remotely operated ships which seafarers are onboard.
- **Degree three**: remotely operated ships without seafarers onboard.
- **Degree four**: Fully autonomous ships (IMO, 2018; WMU, 2019b).

Hurley (2021) predicts that remotely controlled ships (Degree two or three) will start to navigate by 2030, and by 2035 autonomous ships which can be remotely controlled will navigate on high-sea.

Besides, Lloyd's Register gave seven degrees of autonomous levels (Lloyd's Register, 2017; Kitada et al., 2019). However, this clarification is too detailed, so WMU developed more simplified scale, taking into account the Lloyd's Registrs' levels:

- **Level 0** (no automation): human operators take all decisions and actions, and technical systems are passive. [Ships in 1960s to 1980s]
- **Level 1** (partially automated ships): human operators take most decisions and actions, and technical systems suggest useful information and possible actions. [Today]
- **Level 2** (highly automated ships): human operators take some decisions and actions, and technical systems take most decisions and actions. [Soon]
- **Level 3** (highly autonomous ships): human operators can monitor the systems and can override, and technical systems take autonomously all decisions and actions. [In the near future]
- **Level 4** (fully autonomous ships): human operators can only intervene if the system decides to do so, and technical systems take autonomously all decisions and actions [After 10 to 20 years] (Kitada et al, 2019).

Similar to WMU's definition, Munim (2019) explains the four key automation options: (1) conventional ships which equip automated decision support system, e.g. collision avoidance system (2) ships which are periodically fully automated depending on conditions (3) fully autonomous ships which facilitate crew in some areas, such as ports (4) fully autonomous ships which do not facilitate crew anymore. In case of the option two and three, the ships may be controlled by SCC.

Maritime Autonomous Surface Ship

MASS is a term produced by IMO to conduct regulatory scoping exercise (Baldauf et al., 2017; Kitada et al., 2019).

Shore Control Centre

In case of autonomous ships, assistance from shore will be enhanced, including remote control. Moræus et al. (2016) and Ramos et al (2019) described that fully autonomous ships without human intervention are not feasible because the required ship systems become very complex to realize it, and this is why control from shore is indispensable for autonomous ships. Such a control centre is called "Shore Control Centre (SCC)" or "Remote Control Centre (RCC)". The term RCC is used by the RSE of IMO, and SCC tends to be used in commercial activities or academic papers, and this dissertation will use SCC to describe such centres.

Yoshida et al. (2020) explained that most MASS requires SCC as a back-up function, and operators in SCC will play an ultimate role for safety in case of errors of autonomous navigational systems. Bastiaansen et al. (2019) explained that SCC can completely override ASC onboard and take over control when operators see that ASC may not able to avoid an accident or a critical error occurs. The author also suggested that SCC can play a role in not only remote monitoring and surveillance but also coordinator of information sharing of logistics. Ramos et al. (2019) also showed the two scenarios which operators of SCC should take over the control: (1) the ASC does not have any solution for surrounding situations; (2) the operator who monitors the ship does not agree with the course of action suggested by the ASC. At the level 4 autonomous ships of WMU's scale, the only above (1) may apply because the autonomous ship itself decide to give up control at the level in this case.

Smart Ship

A smart ship refers to one which adopts computerized systems, increased monitoring of navigational systems and engine, and possible fuel shift, resulting from continuous improvement of a conventional ship (WMU, 2019b). Such advanced systems may include AI, advanced sensors and communication technologies (Lloyd's Register, 2016; WMU, 2019a). A smart ship is usually manned, but the number of crew is limited due to automation. Digital systems on board are expected to improve working conditions of seafarers (WMU, 2019b).

Summary

Digitalization (utilization of AI, Big Data and IoT in the maritime field) may transform work at sea. Thanks to these new and advancing technologies, new seven types of ships which are classified into Figure A-2, are expected to be realized in the near future. However, this classification is complicated, so this dissertation is of the view that digitalization may create smart ships and autonomous ships as discussed in item 2.1.1.3 (Figure A-3).

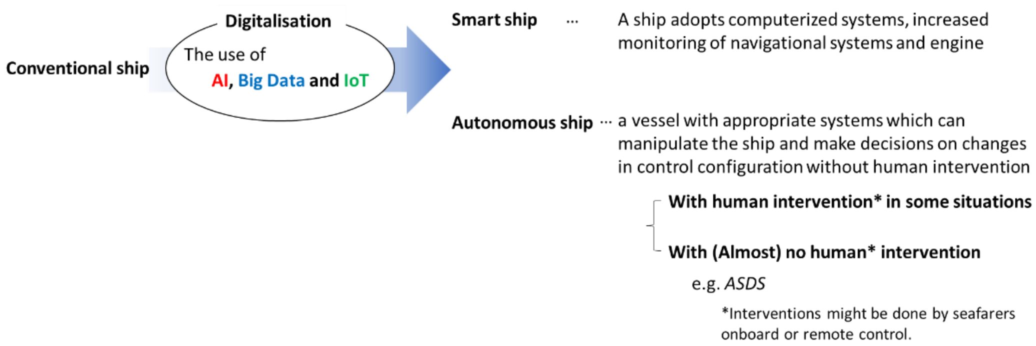

Figure A-3 Evolution of ships

Source: Created by the Author

Autonomous ships may require a certain level of human intervention. This intervention may be done by seafarers onboard in the case of manned autonomous ship or remote control in the case of unmanned autonomous ship. The most advanced autonomous ship may not require human intervention (Fully autonomous ship), such as ASDS.

Appendix B: Overview of national strategies

1. China

In 2019, seven Chinese ministries, including the Ministry of Transport and the National Development and Reform Commission, the Ministry of Science and

Technology, the Ministry of Education, the Ministry of Industry and Information Technology and the Ministry of Finance, jointly issued the guideline to further develop intelligent shipping (Huaxia, 2019; Si, 2019; The Media Telegraph, 2019; Wang, 2020). The author could not find the English source of the guideline, but some news media, including the Chinese official press Xinhua News Agency, revealed its digest (Huaxia, 2019). The aim of the plan is to enhance the integration of cutting-edge technology, such as AI, with the shipping industry to make the industry more intelligent (Si, 2019). The plan emphasises to integrate new and advancing technologies into the shipping industry, and aims to make China the centre of world shipping development and innovation by facilitating several key technologies by 2025. In addition, the plan describes that the shipping industry in China will seek to new business models regarding enough intelligence and a high-standard intelligent shipping system by 2050 (Huaxia, 2019; Si, 2019). The plan highlights 10 major tasks, such as improvement of the information and intelligence of shipping and port infrastructure, promotion of intelligent shipping technologies, and enhancement of technological innovation and cultivation of talent (Huaxia, 2019; Si, 2019; The Media Telegraph, 2019). The plan recommends local governments to well create such environment, establish pilot projects and promote cooperation to realize intelligent shipping (Huaxia, 2019).

2. Denmark

In May 2016, the Danish Maritime Authority (DMA) established the Maritime Strategy Team composed of senior officers of the DMA, shipping companies, ship machinery companies, port authority and trade union. The team developed eleven recommendations for DMA, and they were integrated into the national strategy for growth in Blue Denmark issued in January 2018 (DMA, 2017a; DMA, 2017b; DMA, 2018a). The strategy is constituted by four pillars: (1) a power hub for digitisation; (2) a power hub with attractive framework conditions; (3) a power hub of knowledge and know-how; (4) a power hub with a global outlook and attractiveness (DMA, 2018b).

Among these pillars, the former three pillars are specifically relevant to digitalization of ships.

Regarding the first pillar, the strategy aims to make Denmark a world laboratory of testing digital and autonomous technologies by using Danish unique marine geography towards 2025. Specifically, the Danish Government will tackle challenges of maritime cyber security, such as improvement of maritime ICT infrastructure under the EU and IMO regulatory framework. Furthermore, the Danish Government pledges to enhance the use of maritime data, such as publication of data, to facilitate maritime business and innovation. Moreover, the Danish Government will seek to cooperate with the maritime industry to enhance the entrepreneurial environment (DMA, 2018b).

Regarding the second pillar, the strategy explains that the Danish Government will investigate rules and legislation in many fields so that implementation of international regulation will not impose undue barriers which can undermine competitiveness of Danish companies, particularly in the field of digitalization (DMA, 2018b).

The third pillar emphasises on MET and R&D required for the future. Regarding MET, the Danish Government will provide appropriate training programme, taking into account recent technological development, to meet the needs of maritime industry (DMA, 2018). The strategy did not refer to details of "technological development", but digital technologies are considered to be included into this term. Regarding R&D, the Danish Government pledged to invest DKK 237m in such R&D of new technologies, including digitalization (DMA, 2018b).

3. Germany

The German Government published "Maritime Agenda 2025" in 2017 to make the maritime industry in the country a global hub. The strategy suggests nine courses of actions for the German Government, as well as measures to implement the strategy.

Within the nine actions, the pillar “Maritime 4.0 – use the opportunities of digitalization” describes the German Government’s actions for digitalization in the maritime field. The pillar firstly explains situation of digitalization of ships, and later suggests the German Government’s action until 2025. As analysis for digitalization, the pillar emphasises on the importance of data analysis, assessment and management, which can transform merchant shipping and port management, such as weather routing and just-in-time arrival. The pillar also emphasises on development and diffusion of cutting-edge communication technology such as 5G to cope with large amount of data transmission from machinery and equipment. To make the most use of 5G, the Federal Ministry of Transport and Digital Infrastructure (BMVI) has established the platform “5G Initiative”, which includes “The Dialogue Forum 5G” in charge of providing the maritime industry with opportunity to present 5G requirements. Furthermore, it explains that digitalization of ships requires new safety and security standard such as approval and certification of ship systems, equipment and digital network on board, so it is important to integrate German view on digital technologies into international regulations of IMO, ISO and IEC. Lastly, the pillar suggests the importance of MET to deal with rapid digitalization. As German Government’s action, the Government pledges to facilitate R&D through maritime funding programmes and targeted funding of collaborative projects, especially inter-discipline projects. The German Government further pledges to enhace collaboration among entire value chain, and create new international standards regarding digitalization through collaborative mechanism among German industry players. Finally, the German Government will improve MET of qualified employees taking into account digitalization.

After the specific Government’s actions, the strategy elaborates 10 measures to effectively implement the Maritime Agenda 2025. Within the measures, the third item “Promoting research, development and innovation on the sustainable use of the sea” suggests several funding projects for digitalization of ships. Firstly, R&D regarding Industry 4.0 and Big Data will be conducted under the Federal Government maritime funding programmes. Secondly, R&D on autonomous shipping, navigation tools for efficient routing, by using satellite data transmission, will be conducted under the Maritime Safety Programme. Other than that, the item six “Maritime Safety” describes that the Federal Government will facilitate e-Navigation (BMWi, 2017).

4. Greece

The Greek strategy for digitalization in the maritime field focuses on procedures. To further raise the attractiveness of Greek flag, the Greek Government pledges to develop modern information system to minimize and speed up administrative procedures such as ship registration, recruitment of seafarers, certification related to ships. To attain the goal, the ministry of shipping and island policy has launched several projects (The Greek Ministry of Digital Governance, 2021).

5. Japan

In Japan, there are several strategies which are dealing with about digitalization of ships. Among them, the document called “Shipbuilding policies to secure stable international maritime transport” developed by the experts committee in the Japanese maritime industry and authorized by the minister of Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is the most detailed. Therefore, this dissertation heavily relies on this document.

The document suggests several recommendations for the Japanese Government. Regarding digitalization. Firstly, it recommends the Japanese Government to introduce “DX shipbuilders”, which uses digital twin technologies and streamline total lifecycle cost of ships from design, operation to maintenance. In addition, the Ministry has developed the roadmap to realise the phase II autonomous ship in 2025, which can support navigators by remote control or proposal of decision by AI, so the document recommends the Japanese Government to further enhance tests of autonomous systems and development of necessary regulations at IMO. Furthermore, the document analyses that digitalization will enhance the power of ship machinery companies called “system integrator”, such as Wärtsilä and Kongsberg, which can integrate ship systems and equipment on board by software and network. Therefore, the document requests the Japanese Government to develop Japanese system integrator by standardization, facilitation of R&D and enhancement of education for technicians (MLIT, 2020).

6. Norway

In 2019, The Norwegian Ministry of Trade, Industry and Fisheries issued the ocean strategy called “Blue Opportunities”. The strategy is composed of six chapters: (1) Future-oriented ocean industries; (2) Education, skills and the labour market; (3) Research, technology and innovation; (4) Sound management and a predictable framework; (5) Clean and healthy oceans; and (6) International cooperation and ocean diplomacy (The Norwegian Ministry of Trade, Industry and Fisheries, 2019).

Regarding digitalization, Chapter 1 (Future-oriented ocean industries) emphasizes on the importance of new and advancing technologies, such as digitalization, autonomous technology and Big Data, in the maritime industry in Norway. For example, highly developed satellite communication can enhance the industry, and the Norwegian parliament gave Space Norway AS a conditional pledge of equity so that the company can create stable and broadband satellite communication system covering the high north. The project will be started when its profitability is determined to be clear (The Norwegian Ministry of Trade, Industry and Fisheries, 2019).

Chapter 2 (Education, skills and the labour market) explains that specialty on robotics, autonomous system, IoT, Big Data and AI will become more and more important, and it is possible for ocean industries to create a synergy effect. Therefore, the Norwegian Government will enhance digital skills in the industry by improving ocean-related education programmes (The Norwegian Ministry of Trade, Industry and Fisheries, 2019).

Chapter 3 (Research, technology and innovation) describes the actions taken by Norwegian government regarding R&D, such as establishment of test beds for experiments of autonomous ships in Trondheimsfjorden, Storfjorden and Oslofjorden.

The chapter also mentions that "The long-term plan for research and higher education 2019-2028" adopted by the Ministry of Education and Research describes the prioritized fields of R&D in Norway, and the plan suggests "seas and oceans" as one prioritized area (The Norwegian Ministry of Education and Research, 2018; The Norwegian Ministry of Trade, Industry and Fisheries, 2019). After the five chapters, the strategy suggests future priorities of Norwegian Government. Regarding digitalization, the Government will continue to support the establishment of research infrastructure including test facilities. The Norwegian Government will also support R&D and continue to prioritize autonomous operation and digitalization in the ocean industries (The Norwegian Ministry of Trade, Industry and Fisheries, 2019).

7. Singapore

In Singapore, the International Maritime Centre, founded by the Maritime and Port Authority (MPA) of the Singapore Government, made a strategic review report to MPA, aiming that Singapore will continue to be the centre of global maritime hub, innovation and talent (MPA, 2017).

Regarding digitalization, the report recommends MPA to facilitate the maritime industry in Singapore to enhance commercial and technical abilities, especially in the area of Big Data and risk mitigation including cyber risk management. In addition, it recommends to enhance collaboration between the maritime industry and pertinent communities in the area of digital solutions to facilitate cross-border cargo, financial, and information flows. To enable such pilot trials, the report recommends not to apply existing regulations to such projects (regulatory sandboxes). Furthermore, the report describes that Singapore can develop close relationships between local research and education institutes and other leading maritime clusters to collaborate in the field of digitalization, autonomous systems and Big Data. Regarding Big Data, the reports recommend the Government to develop data-sharing system between the maritime industry and research and education institutes. To attain the goal, the report recommends the Governments to create research bases and collaborations, such as joint research projects including start-ups and scale-ups, in order to make the country "Living Hub" in the world maritime industry. Regarding maritime education and training, the reports recommend to integrate emerging skills, such as automation skills, data analytics and cyber security skills into seafarer education and training (IMC, 2017).

8. The Republic of Korea

Ministry of Ocean and Fisheries (MOF) of the Republic of Korea has developed its maritime strategy to make the country global marine leader (MOF, 2021a). Under the strategy, MOF has created detailed annual work plan. The MOF's Work Plan for 2021, issued in January 2021, explains that ensuring digital transformation in the maritime and fisheries fields and promoting the growth of innovative industries are some of the prioritized areas of the ministry. Under the plan, the ministry pledges to develop key technologies for MASS. In addition, the Korean Government will enhance maritime safety by digital technologies and seek to create a Big Data platform in the maritime and fishery fields. Furthermore, the Korean Government will continue to support ventures and start-ups (MOF, 2021b).

9. The United Kingdom

In January 2019, the Department for Transport of the United Kingdom issued "Maritime 2050: navigating the future", representing the vision and ambitions of the Government for the future of the British maritime industry. The strategy is composed of seven topics: (1) competitive advantage of the UK; (2) technology; (3) people; (4) environment; (5) trade; (6) infrastructure; and (7) Security and resilience. Each topic has its own sub-topics and each sub-topic has vision in 2050 and course of actions for short-term (1-5 years), medium-term (5-15 years) and long-term (15 years or over). This dissertation will explain the overview of the topics, sub-topics and visions related to digitalization, and summarize the course of action by the UK government and the UK maritime industry in Table A-1.

Regarding digitalization, the sub-topic ‘safety’ in the first topic “UK competitive advantages” explains that overreliance on new technologies, such as GNSS, can weaken traditional seafaring skills such as navigation and seamanship, which has been one reason for many accidents. Therefore, the UK Government will review the regimes of maritime education, training and certification taking into account the realities of roles on modern ships as a medium-term action while retaining a basis in orthodox skills and enhancing successive improvement.

The second topic ‘technology’ is deeply related to digitalization. As the vision in 2050, the strategy mentions that autonomy and smart shipping will make the maritime sector safer, cleaner and more efficient. In addition, Big Data analysis and digitalization, and more resilient communications will enhance connectivity between ships and ports, which will improve business decisions. Furthermore, AI will ensure effective management of huge amount of data, which will save costs and make logistics and supply chains more efficient. Moreover, distributed manufacturing, such as 3D printing, will have great influence on design of ships and ports. The topic has four sub-topics: (i) future of shipping; (ii) smart ports; (iii) digitalization; and (iv) communication, navigation, and exploration, and each sub-topic has its recommendations. Among the sub-topics, ‘future of shipping’,’digitalization’ and (i), (iii), (iv) are relevant to digitalization of ships.

The first sub-topic ‘future of shipping’ aspires that the UK will be a global leader in the field of ship design, shipbuilding, integration, and utilization of autonomy and other cutting-edge technologies on board ships. The sub-topic also puts forward the nation that the UK will lead the development of international regulatory frameworks regarding new technologies so that UK companies will be able to enjoy benefits by exporting, using, and commercializing innovative technologies such as autonomous navigation. To attain this vision, the strategy also refers to enhancement of maritime cyber-security. The Government pledges in the sub-topic to subsidize the maritime industry for £1 million to develop innovative laboratories.

The third sub-topic ‘digitalization’ aims to make the UK maritime sector ‘digital by default’ by adopting accessible, user-friendly and secured processes. It also aims to realize paperless maritime governance and e-registration of the UK flagged vessels as well as electronification of seafarer certification of skill and competence. Furthermore, it aims to realize real-time open data sharing among all stakeholders in the supply chain to make it more efficient and cost-saving e.g. optimization of routes. To attain the above visions, the Government pledges to facilitate the sharing and publication of as much data as possible to make fully use of the benefits of open data, such as cost and efficiency, in conjunction with the maritime industry. In addition, the Government will support integration of cutting-edge digital technologies into the industry to generate, use and analyse data. Furthermore, the Government will proceed electronification of certification of seafarers and registration of ships by 2030.

The fourth sub-topic ’communication, navigation, and exploration’ aims to make the UK ships more connected by adopting next-generation of communication technologies such as resilient and high-bandwidth satellite communication covering worldwide. In addition, it also aims that navigational data gathered by the above communication systems will be used for safe navigation of autonomous ships around the world, which makes the UK continue to be a global leader in the field of hydrography. To attain this vision, the Government pledges to develop standards regarding data and communication technologies which can maximize bandwidth and resilience between ships and shore. In addition, the Government pledges to facilitate innovative satellite communication technologies, such as CubeSat (small and light satellite) which ensures worldwide coverage for new trade routes such as arctic. Furthermore, the Government will continue to retain the UK’s strong position in the area of geospatial data and hydrography in conjunction with pertinent national institutes, the industry and academia to create data requirements and commercialise data regarding navigational safety for autonomous ships. Moreover, the Government will map the EEZ of the country for autonomous ships by establishment of national data collection programme which can supplement existing geographical data with new data shared by vessels including autonomous ships, offshore platforms.

Within the third topic ‘People’, the first sub-topic “Maritime skills and promotion” is deeply related to digitalization. The vision in the sub-topic explains that new skills regarding IT, digital and new technology will be required in the future, so highly qualified seafarers who can create and manage autonomous and technological systems are needed. Therefore, the Government and the industry have tried to attract people who specialize in Science Technology Engineering and Mathematics (STEM) to secure enough workforce in the maritime field.

The second sub-topic “Considering the human in the face of technological change” is also related to digitalization. The sub-topic explains the necessity to reform the current retraining system to cope with emerging technologies. The sub-topic also describes that carrier path of seafarers should be more clarified so that experts of new technologies can join the maritime workforce.

Within the topic ‘security’, the sub-topic “Cyber – security of technology” describes that due to increasing automation and communication, systems will be susceptible to attacks by state and non-state players for financial, disruptive and violent results. (The Department for Transport of the United Kingdom, 2019).

Table A-1

The specific courses of actions by the UK Government and the UK maritime industry

Topic: UK's competitive advantage	
	Sub-topic: Though leadership [Short-term action] • facilitate maritime innovation
Topic: Technology	
	Sub-topic: Future of shipping [Short-term action] • launch three flagship projects to show technological proofs and demonstrate smart shipping [Medium-term actions]

	• develop a national legal framework for autonomous ships to lure international business and allow testing in the UK's waters • show leadership to contribute into the international regulatory framework for autonomous ships [long-term action] • cooperate with the industey to establish multi-modal autonomous freight movement at UK ports.
	Sub topic: Digitalization [Short-term action] • assess the benefits of new technologies and roles of the Government in facilitating development of these technologies and use in conjunction with the maritime industry. [Medium-term actions] • attain full paperless governance of the industry, especially the fully digitalized UK ship registry by 2025. • regulate and make standards the use of data to introduce data related technologies such as blockchain with transparent, competitive and efficient manners. [Long-term action] • make efforts to establish international standards related to digital technologies to secure interoperability
	Sub-topic: Considering the human in the face of technological change [Short-term actions] • conduct a study on the impact of 'Future Navigation' to assess what information the maritime industry wants and the capabilities of the State to provide it as a short-term action • create sea chart of seabed in the EEZ waters for autonomous ships [Medium-term action] • develop close relation with the UK space industry and integrate the capacity of R&D on satellite of the space industry into the maritime sector [Long-term action] • understand the wat to manage sustainably manage ocean, benefits from the world ocean environment and create technology and soft skill so that the UK will be the top-runner of charting the world seabed.
Topic: People	
	Sub-topic: Maritime skills and promotion [Short-term actions] • revise regulations to use new technologies, such as virtual reality for maritime education and training • establish the Maritime Skills Commission, which is composed of experts of leading maritime skills to review maritime skills needed on a 5-yearly cycle [Medium-term action] • create leading-edge training programme to maximize the use of future technologies including virtual reality [Long-term action] • lead the discussion at IMO and ILO to review the international regulatory framework of MET
	Sub-topic: Considering the human in the face of technological change

	[Short-term action] • establish the internet connectivity working group to assess internet connectivity at sea for social care and continuous education in conjunction with the industry and academia [Medium-term action] • the Maritime Skills Commission will consider how to make sure develop professional development plans are integrated into training programmes to make the carrier path more transparent in conjunction with maritime training institutes.
Topic: Security	
	Sub-topic: Cyber – security of technology [Short-term actions] • develop a model to which can support the industry because not all companies have enough resources to employ experts of cyber security • evaluate cyber threats through the National Cyber Security Centre to warn, inform and advice of cyber threats for the industry [Medium-term actions] • play a leading role in developing regulations for the security of autonomous ships and connected systems • provide warning and advice regarding cyber threats of autonomous ships and connected systems for the industry

10. The United States

In the US, the U.S. Maritime Administration (MARAD) and the United States Coast Guard are in charge of shipping. The former is engaged in shipping policy, and the latter is involved in maritime administration, such as ship inspection, MET, and qualification of seafarers. Each organization has its own strategy. MARAD has developed "Maritime Administration Strategic Plan" in 2017 with the targeted completion year in 2021. The strategy is composed of mission, vision, five strategic goals and their individual objectives. Regarding digitalization, the vision hoists "an innovative, competitive U.S. maritime system". The strategic goal 5 (Maritime Innovation) gives details about innovation in the vision. The goal 5 is composed of five objectives. The objective 5.1 describes that the organization will increase benefit of maritime/intermodal transportation by using existing Intelligent Transportation System technologies. The objective 5.2 suggests the use of cargo tracking, and the objective 5.4 explains facilitation of R&D for advancing technologies including automation (MARAD, 2017).

When compared with MARAD, USCG has developed more detailed strategy "Maritime Commerce Strategic Outlook". The strategy firstly analyses the situation of shipping in the US, and suggests the following three courses of actions: Facilitating Lawful Trade and Travel on Secure Waterways (Line of Effort 1); Modernizing Aids to Navigation and Mariner Information Systems (Line of Effort 2); and Transforming Workforce Capacity and Partnerships (Line of Effort 3). There are several objectives under each line of effort, and the specific USCG's actions are written under the objectives (USCG, 2018). The specific actions of USCG related to digitalization are summarized in Table A-2.

As well as the three lines of effort, USCG develops some additional overarching concepts to make sure long-term success. One of the concepts named "Situational Awareness" explains that USCG will give useful information for maritime operations in real-time. Such information sharing system will be developed taking into account technological trends, and, stakeholders can make better decisions by using the system (USCG, 2018).

Table A-2

The USCG's actions for digitalization

Line of Effort 1: Facilitating Lawful Trade and Travel on Secure Waterways	
	Objective 1; Mitigate Risk to Critical Infrastructure
	• enhance security related to information technology in the maritime domain including vessels, referring to recognized industrial cybersecurity standards.
	Objective 3: Enhance Unity of Effort in the MTS
	• empower and encourage the Area Maritime Security Committees (AMSCs) to continuously try to focus on the identification, prevention, mitigation, response, resiliency, and recovery efforts on high consequence risks to the national maritime transportation system to cope with cybersecurity, with a view to develop cyber information sharing for the shipping industry
Line of Effort 2: Modernizing Aids to Navigation and Mariner Information Systems	
	Objective 1: Improve the Nation's Waterways
	• transform the waterways in the US into the most technologically advanced network in the world by making USCG workforce able to meet the needs of new and advancing technologies including autonomous navigation • facilitate the use of electronic sea charts (paperless bridge) as long as they are accurate, reliable and cyber-resilient
	Objective 2: Optimize Maritime Planning

	• improve the information sharing system between interagency entities and the maritime industry to evaluate emerging technologies including autonomous navigation and robotic ships.
	Objective 3: Recapitalize Aging Assets
	• invest in data infrastructure, such as storage and processing capabilities, to utilize increasing maritime data.
	Objective 4: Streamline and Update Information Systems
	• conduct R&D for modernization of information systems to enhance the safe, secure and sustainable information flow of commerce. The goal of the system is to use data for risk-based decision-making by using different public and private data source. • reform its regulatory framework from the rule-based system to goal-based one to integrate new and advancing technologies including electronic and autonomous systems • collaborate with interagency partners in the field of IT solutions to improve surveillance, intelligence, and reconnaissance, intelligence analysis, and screening/identity management.
Line of Effort 3: Transforming Workforce Capacity and Partnerships	
	Objective 2: Sharpen High-Tech and Adaptive Service Competencies
	• optimize the utilization of new technology, such as cloud computing, Big Data analysis, and AI to improve the quality of ship inspection. • reform maritime education and training in the US to cope with emerging technologies, such as autonomous system, AI, Big Data and cybersecurity. • facilitate collaboration among industry, academia and the government in the field of emerging technologies
	Objective 3: Advance the Prevention and Response Operations Workforce
	• train its officers so that they have enough skills and expertise in cybersecurity • enhance its employees' skill to cope with emerging technologies by internships, continuing education and field studies. • make efforts to remove cultural and legal barriers which may prevent the use of leading-edge technology for mission execution in Prevention and Response.

Appendix C: Major liner shipping companies' strategy

CMA CGM

CMA CGM has published sustainability strategy, and the company refers to digitalization within the strategy. The company categorizes actions for sustainable development into three pillars: (1) Acting for People; (2) Acting for Planet; and (3) Acting for Responsible Trade, and digitalization is referred in the first and third pillars.

In the first pillar (People), the company pledges to introduce new digital platform for education and training for employees, such as virtual reality. In the third pillar (Responsible Trade, and digitalization), the company pledges to pay more attention to and grasp customers' needs by technological innovation, digital transformation and environmentally friendly innovation. As specific courses of actions, the company plans to support start-ups (CMA CGM, 2021). The company has also announced to collaborate with Shone, an IT company in San Francisco, in order to introduce AI into cargo ships and realize autonomous navigation (CMA CGM, 2018b).

Hapag-Lloyd

Hapag-Lloyd has developed "Hapag-Lloyd Strategy 2023 - Our journey starts now." since 2018. Within the strategy, the company pledges to further invest in digitalization because the company wants to simplify shipping and optimize the whole supply chain (Hapag-Lloyd, 2018).

The company does not mention the detail of the action for digitalization any more in the strategy, but the company gives detail on the company's website. It shows that the company will focus heavily on container trackers. With regard to autonomous shipping, the company states that there is no telling about the impacts of autonomous shipping, taking into account the fact that such technology is not widely used today although autonomous shipping has potential to reduce accidents and spare parts. Regarding Big Data, the company is discussing how to use and analyze data with customers in order to optimize the supply chain so that the customers can enjoy further monitor their goods by Big Data analysis (Hapag-Lloyd, 2019).

Ocean Network Express (ONE)

ONE revealed its policies for digitalization in the company's explanatory material for investors. It mentions that the objective of digitalization is to provide services which can meet the needs of customers by Big Data analysis and digitalization. The company explains that there are three domains of digitalization: channel, operation and assets. The former two domains are relevant to e-commerce, such as real-time freight estimate and automation of repetitive tasks e.g. booking. The digitalization of assets is optimization of the use of assets, such as operative analysis by using data from ships. Besides, ONE will establish joint research projects to gather all stakeholders of the supply chain on the one platform. Furthermore, ONE will standardize data and interface, cybersecurity, IoT container and blockchain technology (ONE, 2019).

Orient Overseas Container Line (OOCL)

OOCL describes its future vision for digitalization in the annual report. It explains that the company will enhance its ability to use AI to increase cost efficiency and to make the traffic network more visible. OOCL has established IQAX, a tech company, to enhance digitalization of ships and develop harmonized international trade environment. The company aims to drive digital transformation in the maritime industry by close collaboration with stakeholders in supply chain, such as forwarders, carriers, terminals and financial institutions, so OOCL expects IQAX to be a collaborative centre of innovation among stakeholders (OOCL, 2021).

Other companies

Yang Ming and MSC replied that their strategies are confidential and cannot provide them for outsiders. There were no responses from other companies (COSCO, Evergreen, HMM and Maersk).

Appendix D: Classification Societies' strategies

American Bureau of Shipping (ABS)

ABS has released its digital vision on its website under the notion that the fourth industrial innovation (digitalization and connectivity) is transforming the maritime industry through sensors, data and autonomous systems. According to the strategy, the goal of digitalization for ABS is to support clients to make better decisions through digital transformation driven by data and obtain better business outcome. Specifically, ABS will use its data scientists and advanced data analysis, global cloud-based platform, digital twins and connectivity tools which can acquire data from ship sensors to provide automation, predictive maintenance, asset performance and cyber security. In addition, through machine learning and AI, data scientists of ABS are developing models which support failure prediction, pinpoint issues and identification of areas of risks. Furthermore, ABS will work with clients to offer condition-based class and optimize supply chain logistics, fleet management and workforce productivity with software and business intelligence tools (ABS, 2018).

Nippon Kaiji Kyokai (Class NK)

Class NK has published "Class NK Digital Ground Design 2030" to cope with digitalization in 2020. The objective of the strategy is to support sustainable development of the maritime industry by creating appropriate business environment and facilitating collaboration among stakeholders. The strategy is composed of three functional pillars and two bases (development of 'domain × IT' personnel; and collection of data/knowledge).

The first functional pillar (fair and transparent certification) includes enhancement of transparency by electronic certificates. The second functional pillar (development of advanced business environment) is relevant to diffusion of IoT and maritime cyber security. The third functional pillar (advanced survey and inspection) includes remote inspection, inspection by image recognition technique, condition-based inspection and digital-twin (ClassNK, 2020a). Based on the strategy, the organization has launched evaluation service called "Innovation Endorsement (IE)" for ships which integrate digital technology, such as autonomous navigating system (ClassNK, 2021). Besides, the organization has released guidelines for automated/autonomous operation on ships in 2020 to certify autonomous vessels (ClassNK, 2020b).

Indian Register (IRClass)

IRClass has launched "IRClass Digital" initiative in May 2021 to develop a world class digital framework. The strategy is composed of four important pillars: (1) technology, (2) people, (3) process, and (4) open innovation. To proceed the strategy, the organization established a new team, focusing on connected ship and smart infrastructure, online information and access management, smart emergency response system, automated immersive design simulation and validation, use of Digital Twin concept, and real-time condition-based monitoring. The organization plans to offer remote-controlled ships, remote monitoring, optimization of performance and voyage, remote maintenance support, condition monitoring, predictive maintenance and improvement of other services (IRClass, 2021).

Other classification societies

DMV and Lloyd’s Register replied that the organizations do not have strategy which can be shared outside the organization. According to an officer of DNV, the very rough overview of the strategy is as follows:

- position DNV as a thought leader in Digital Assurance
- develop capabilities for digital assurance
- explore and develop capabilities for AI and emerging technologies

There were no replies from other classification societies (BV, CCS, RINA and RS).