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Analysis on collision accidents and maritime autonomous surface ships

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WORLD MARITIME UNIVERSITY
Malmö, Sweden

ANALYSIS ON COLLISION ACCIDENTS AND MARITIME AUTONOMOUS SURFACE SHIPS

KO TAGUCHI
Japan

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

MASTER OF SCIENCE
in
MARITIME AFFARS

(MARITIME SAFETY AND ENVIRONMENTAL ADMINISTRATION)

2022

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.

(Signature):

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(Date):

20 September 2022

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Abstract

Title of Dissertation: **Analysis on collision accidents and maritime autonomous surface ships**

Degree: **Master of Science**

Human factors contribute to the occurrence of maritime accidents to the large extent. Therefore, the importance of human factors has been addressed in the area of accident investigation. On the other hand, recently, maritime autonomous surface ships (MASS) have been developed due to the rapid growth of relevant technologies. One of the expectations of MASS is to improve the safety of shipping by reducing human errors. In this context, this dissertation analysed human factors in collision accidents and assessed the effects of the introduction of MASS to collision accidents. Firstly, 98 collision accident reports from Japan and other countries were analysed utilising Human Factors Analysis and Classification System (HFACS) and SHEL (Software, Hardware, Environment, and Liveware) model. HFACS results showed a large number of observations on unsafe acts which directly lead to the accident and its preconditions. In addition, SHEL results showed a large number of human factors which is the seafarer itself and related to the environment and other humans. Secondly, a literature review on collision avoidance issues on MASS was conducted and several challenges in terms of hardware, software and human factors were found. Finally, the effects of different degrees of autonomy of MASS on human factors identified through the analysis on collision accidents were assessed utilising a Likert scale likelihood taking into account the findings from a literature review. The result showed the likelihood of each human factor generally decreased with the increased degree of autonomy of MASS.

KEYWORDS: Human factor, HFACS, SHEL model, Maritime Autonomous Surface ships

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List of Abbreviations

AIS	Automatic Identification System
BRM	Bridge Resource Management
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
CPA	Closest Point of Approach
ECDIS	Electronic Chart Display and Information System
GEMS	Generic Error Modeling System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HFACS	Human Factors Analysis and Classification System
ICT	Information and Communication Technology
IMO	International Maritime Organization
ISM Code	International Safety Management Code
JTSB	Japan Transport Safety Board
MASS	Maritime Autonomous Surface Ships
MSC	Maritime Safety Committee
RSE	Regulatory Scoping Exercise
SCC	Shore Control Centre
SHEL	Software, Hardware, Environment, and Liveware
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea
SRM	Ship Resource Mismanagement
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
VHF	Very High Frequency
VTS	Vessel Traffic Services

1. Introduction

1.1. Background

Traditionally, maritime safety has been improved by lessons learned from maritime accidents, such as the accident of the *Titanic* in 1912, which led to the development of the first version of the International Convention for the Safety of Life at Sea (SOLAS) in 1914. In addition, the traditional approach adopted technical countermeasures to address identified safety issues. However, the accident of the *Herald of Free Enterprise* in 1987 revealed the limitation of the technical approach and the necessity of considering human and organizational factors (Schröder-Hinrichs et al., 2013). Currently, it is well known that human factors play an important role in maritime accidents. Although the original justification has been unclear, it has been widely believed that about 80% of maritime accidents were contributed by human factors (Wróbel, 2021).

The importance of human factors is acknowledged in a wide range of industries, and several studies have been conducted. Firstly, studies addressed individual failures, such as Rasmussen's Skill-Rule-Knowledge classification and Reason's Generic Error Modeling System (GEMS), then linkage of individual, systematic and organizational failures was focused on, such as Reason's Swiss Cheese Model and Howkin's SHEL (Software, Hardware, Environment, and Liveware) model (Chen et al., 2013a). In the fields of research on maritime accidents, the focus was shifted from naval architecture to human factors from the 1960s to the 2010s and may continue to be socio-economic matters (Luo & Shin, 2019).

The International Maritime Organization (IMO) started to address human and organizational factors in maritime safety in a detailed and holistic way after the accident of the *Herald of Free Enterprise* (Schröder-Hinrichs et al., 2013). In 1993, the IMO adopted the International Safety Management Code (ISM Code), which became mandatory in 1998 (IMO, 1993). In brief, the ISM Code was developed to deal with human errors and related maritime accidents and introduced a self-regulation approach in the shipping industry that changed from previous command-and-control practices (Dalaklis, 2017). The ISM Code requires companies to develop an integrated Safety Management System (SMS), and the Code consists of several sections dealing with different aspects (Batalden & Sydnes, 2014). In addition, other publications of IMO work related to human factors can be found in the guidelines for the previous casualty investigation code (Resolution A.849(20)) that was adopted in resolution A.884(21) in 1999. To assist effective analysis and identification of preventive action by providing practical advice for the systematic investigation of human factors in a maritime accident, the guidelines included a detailed investigation process for human factors by the approach of integration and adoption of several frameworks, namely Hawkins's SHEL and Reason's GEMS as well as Rasmussen's Taxonomy of Error (IMO, 1999). However, resolution A.849 (20) was revoked by the new resolution A.1075 (28), and there is no specific mention of a particular method in the current guidelines.

On the other hand, the recent rapid growth of technological developments has led to the development of Maritime Autonomous Surface Ships (MASS), and various pieces of work from various aspects, such as industrial, scientific, and regulatory projects have been conducted. For example, on the industrial side, it was reported that the world's first electronic autonomous container ship would start commercial operation in 2022 (Yara International, 2021). Furthermore, it was reported that the world's first ocean passage of LNG carriers with autonomous navigation was initiated in 2022 (Hyundai Heavy Industries Group, 2022). Furthermore, at a national level, Japan developed a roadmap that includes the practical realization of Phase II MASS, which partly supports the seafarer who is the final decision maker through shoreside control and action recommendation by Artificial Intelligence, by 2025 in its one of maritime policies in 2018 (Ministry of Land, Infrastructure, Transport and Tourism [MLIT], 2018). From this, several demonstration projects have been conducted for the early demonstration of three core technologies, namely automated manoeuvring, distanced manoeuvring, and automated berthing/un-berthing (MLIT, n.d.). In addition, the Safety Guidelines for Maritime Autonomous Surface Ships were developed in 2022, which include matters taken into account in terms of design, installation, and operation to ensure the safety of Phase II MASS (MLIT, 2022).

At the international level, at the IMO, based on the view of a lack of clarity about the application of existing IMO instruments to MASS, the work program of the regulatory scoping exercise (RSE) on MASS was proposed to the Maritime Safety Committee (MSC) on its 98th session (IMO, 2017a) and it was agreed to include to the agenda of the MSC to RSE on MASS (IMO, 2017c). After discussions at several sessions of the MSC, the outcome of the RSE was approved at MSC 103, which includes key issues such as the development and clarification of terminologies and addressing the functional and operational requirements for remote-control stations/centres (IMO, 2021). In addition to the work for the RSE, to ensure the safety, security, and environmental protection regarding the trial of MASS, the Interim Guidelines for MASS Trials were adopted at MSC 101, and the guidelines include the basic principle that the trial should ensure at least the same degree of safety, security and environmental protection provided by existing instruments (IMO, 2019). Currently, the development of a non-mandatory code that regulates the operation of MASS in a goal-based way with a view to adoption in 2024 has been conducted (IMO, 2022).

It is said that one of the advantages of MASS is the reduction of human errors. In Japanese policy, one of the objectives of introducing MASS is to improve maritime safety to reduce human errors, along with other objectives such as ensuring the competitiveness of the maritime industry. However, it is expected that the degree of involvement of human factors depends on the type of accidents, for example, fire and collision. Furthermore, at the time this study was conducted, there was no specific estimation of how the introduction of MASS will affect maritime accidents in Japan. However, according to Japan Transport Safety Board (JTSB) (2022), 736 maritime accidents were newly subjected to investigation by JTSB, and collisions occupied 192 cases, followed by 165 cases of grounding in 2021. Furthermore, although there are some exceptions, collisions have been the most frequent accident type in Japan in recent years. Therefore, to estimate the effects of the introduction of MASS on maritime accidents, this study addresses collision as an example of a frequently observed accident type.

1.2. Aim and objectives

The aim of this dissertation is to evaluate the effectiveness of introducing MASS in the context of collision accidents. Generally, human factors in maritime accidents are a complex issue, and it is useful to analyse accident investigation reports since these reports are made by experts. This study mainly relies on the reports from Japan, but several reports from other countries are also analysed. In addition, taking into consideration the time constraint, addressing collision accidents is limited to involving container ships since it is expected that MASS will be actively introduced to container ships as an example of the Yara. In fact, automated container handling is already realized in some terminals due to two main reasons. Firstly, tasks are repetitive, routine, and rule-based, and secondly, the predictable environment of operation (Ma, 2021). Therefore, together with the characteristics of liner shipping such as high demands for on-time performance, it is expected that autonomous container ships will be introduced to shipping industries.

1.3. Research questions

To achieve the objectives stated in section 1.2, the following research questions are set:

I. What are the characteristics of human factors in collision accidents?
II. What are the characteristics of MASS in collision accidents?
III. How does the introduction of MASS affect collision accidents?

1.4. Research methodology

To answer the research questions presented in section 1.3, qualitative and quantitative methods are adopted. For research question I, Human Factors Analysis and Classification System (HFACS) are utilized to analyse human factors in accident investigation reports. Then, the SHEL model is utilized to analyse identified human factors quantitively, especially extracting the interactive relationship between identified factors. For research question II, literature review is adopted to analyse the expected characteristics of MASS in collision accidents. Finally, for research question III, a Likert scale likelihood scale of 5 has been adopted to assess the effects of different degrees of autonomy of MASS on identified human factors for research question I, taking into account the result of research questions II with the validation by the experts within WMU.

1.5. Expected result

This study assumes the following information as a result:

- Major human factors contribute to the occasion of collision accidents and their relationship
- Advantages and disadvantages of MASS in terms of collision-related issues
- Effect of introduction of MASS in terms of human factors identified by analysis of accident investigation reports

2. Analysis of collision accidents

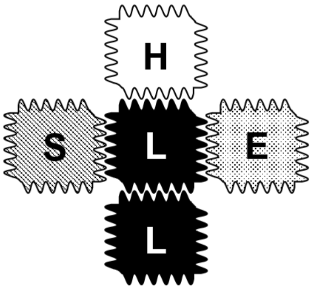
2.1. Human Factor analysis methods

2.1.1. SHEL and HFACS

There is a number of human factor-related theories utilised in various area. As mentioned in the previous chapter, some methods were adopted in the former IMO guidelines for the casualty investigation code. The first method is the SHEL model, which addresses human factors from a system perspective. The SHEL model was originally developed by Edgar (1972, as cited in Hawkins, 2017) and lately modified by Hawkins (1984, as cited in Hawkins, 2017) based on the building block model. As indicated in its name, the model has four components, namely, Software (S), Hardware (H), Environment (E), and Liveware (L, Human), and represents interactions of them, as shown in Figure 2-1.

Figure 2-1.

SHEL model



Note. Adopted from "Human Factors in Flight", by F. H., Hawkins, 2017, p.25. Copyright 1987 by F. H., Hawkins

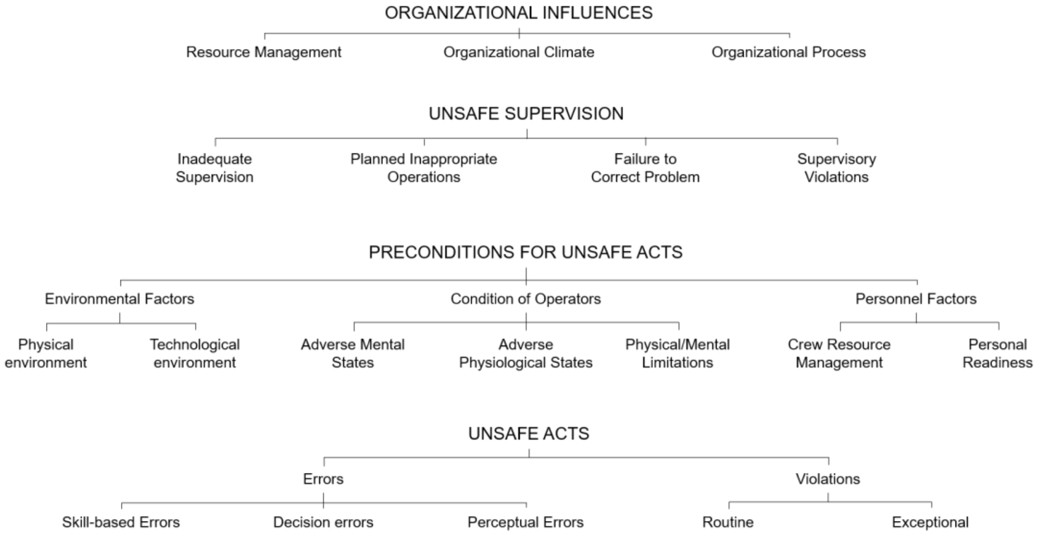
Liveware is located in the hub of the model and has various characteristics and aspects, such as physical characteristics, information processing, environmental tolerances, and other components connected to Liveware (Hawkins, 2017). Focus on interfaces, L-H interface is one of the most common sources of the error in man-machine systems, such as an inappropriate seat and pilot/passenger. The L-S interface includes nonphysical items of the systems such as procedures, manuals, and computer programs. This interface is generally less definite but more difficult to solve compared to L-H interface. The L-E interface includes noise, heat, and violation that increase errors or reduce performances, which leads to the occurrence of errors. The L-L interface is addressing factors between people such as teamwork and leadership (Hawkins, 2017). Therefore, some modification to the SHEL model has been proposed. For example, the m-SHEL model introduced management factors based on human factor activities at a nuclear power plant in Japan (Kawano, 1997), and the SHELLO model was developed to better categorise organisational factors for human factor evaluation of aircraft maintenance technicians (Chang & Wang, 2010). The SHEL model has advantages in its simpleness, understandability, and usefulness for reducing errors and preventing accidents in the systems; however, the model has a limitation in that it does not have interfaces outside human factors such as hardware-environment and hardware-software (Kaptan et al., 2021).

Another method is the GEMS, which is an error classification system focused on cognitive factors proposed by Reason (1990). The GEMS is mainly based on Rasmussen's skill-rule-knowledge classification of human performance and consists of three basic error types, ie skill-based slips and lapses, rule-based, and knowledge-based errors. These can be divided into two operational areas. Skill-based mistakes and lapses are seen mainly associated with monitoring failures, while rule-based and knowledge-based errors appear in problem-solving failures. Skill-based slips and lapses usually involve inattention, such as omitting checks, and over-attention, such as checking at an inappropriate time. Rule-based errors consist of misapplication of good rules, such as inappropriate application of the proven utility of rules in a certain condition, and application of bad rules, such as deficiencies from active components. Knowledge-based errors are due to human cognition, such as inaccurate understanding of systems, confirmation bias, and overconfidence. The GEMS is a useful taxonomy technique for cognitive errors; however, the guidance for how to apply these errors is limited, and it highly relies on the assessor's own judgments (Kirwan, 2017).

In addition to the GEMS, Reason (1990) also developed the model of accident process that is well known as the "Swiss cheese model". In the Swiss cheese model, there are two categories of errors: active failures (unsafe acts) that affect the system immediately and exist in front-line workers, and latent failures that exist in long time systems and are only evident when combined with other factors and these exist at a high level such as designer and decision maker in the systems. Latent failures consist of three layers: 1) preconditions for unsafe acts, 2) unsafe supervision, and 3) organisational influences. Each layer has small holes that mean deficiencies at each level of the system, and an accident happens when the trajectory exists that penetrates layers as a result of complex interactions of latent failures and local triggering events. According to the model, for the purpose of fully understanding the accident, the accident investigator needs to investigate all levels of the system. One of the advantages of the Swiss cheese model for use in accident investigations is that it forces the investigator to address latent failures within the accident causation process (Wiegmann & Shappell, 2017). Although the Swiss cheese model provides an explanation of accident occurrence with a simple diagram and general framework that helps data collection (Kaptan et al., 2021), the model does not define details about holes in each layer; therefore, it is difficult to apply the model to real-world cases (Shappell & Wiegmann, 2000).

Based on the Swiss cheese model, Shappell and Wiegmann developed the HFACS, specifically for defining the active and latent failures of the Swiss cheese model (Wiegmann & Shappell, 2017). The HFACS was originally developed for the purpose of systematically analysing human factors and improving accident investigation in the area of aviation based on accident data in the military, commercial, and general aviation sectors (Shappell & Wiegmann, 2000). The overview of the HFACS is shown in Figure 2-2.

Figure 2-2.
HFACS



Note. Adopted from *"*A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*"* by D. A., Wiegmann, and S. A., Shappell, 2017, p.71. Copyright 2003 by D. A., Wiegmann, and S. A., Shappell

The HFACS consists of four layers; 1) Organisational influences, 2) Unsafe supervision, 3) Preconditions for unsafe acts, and 4) Unsafe acts, with a total of 19 sub-categories that are categorised in the above four layers. Although the HFACS was originally applied to the aviation sector, it has been widely applied in various areas such as rail transport (Baysari et al., 2008; Madigan et al., 2016), mining (Patterson & Shappell, 2010; Lenné et al., 2012), and nuclear (Kim et al., 2014), and the HAFCS is considered as one of the most commonly used accident analysis methods in terms of human factors (Hulme et al., 2019). The application of the HFACS to maritime accidents will be addressed in the next section.

2.1.2. Previous studies on the analysis of maritime accidents utilised HFACS

According to Kaptan et al. (2021), HFACS was first used in the maritime sector by Rothblum et al. (2002). They proposed to use HFACS as a tool for the incident investigation program for addressing human errors in the offshore and maritime industries as HFACS is relatively simple to use and learn and has achievements of effective safety programs in the aviation sector. Several studies on maritime accident analysis utilised HFACS were conducted with some modifications from the original HFACS that was developed by Shappell and Wiegmann for the purpose of improving the applicability of their specific area (Kaptan et al., 2021).

Schröder-Hinrichs et al. (2011) developed HFACS-MSS for the purpose of reviewing accidents related to machinery space fires and explosions. The most significant modification from the original HFACS is the adoption of the fifth level, namely the outside factors, which is above the fourth level, organisational influences, for the purpose of capturing the effects of safety regulations on shipping and their enforcement. The results of reviewing 41 accident investigation reports developed by several countries between 1990 and 2006 showed that few organisational factors were identified from the reports although organisational factors have been considered as major safety factors by the IMO, while the investigation reports mainly focused on technical components of the socio-technical system.

Chen et al. (2013b) proposed the Human Factors Analysis and Classification System for Maritime Accidents (HFACS-MA) for the purpose of analysing maritime accidents in accordance with the (previous) IMO guidelines for a casualty investigation code. Three major modifications were adopted to HFACS-MA from the original HFACS. Firstly, the first level, unsafe acts, was modified to adopt the Generic Error Modelling System (GEMS) with three sub-categories of errors, ie Skill-based errors, Rule-based errors, and Knowledge-based errors. Secondly, the second level, originally named preconditions for unsafe acts, was modified to adopt the SHEL model and named as Preconditions (SHEL). These modifications were to comply with the IMO guidelines. Thirdly, the fifth level, namely external factors, which consist of three sub-categories: legislation gaps, administration oversights, and design flaws, was added above the level of organisational influences for the purpose of capturing safety deficiencies beyond the scope of organisations. Chen et al. (2013b) presented a method that integrated HFACS-MA and Why-Because Graph and showed an advantage in gaining insight into an accident through a case study of the *Herald of Free Enterprise* accident.

Focusing on the HFACS applications to collision accidents, Chauvin et al. (2013) developed HFACS-Coll based on 27 collision accidents between 1998 and 2012 investigated by the Transport Safety Board of Canada and the Marine Accident Investigation Branch of the United Kingdom. The additional level, namely Outside, consists of regulatory factors and others added above the level of organisational influences for the purpose of capturing factors such as the regulatory, economic, political, and social environment that have become a constraint for other levels, for example, international regulations and the Vessel Traffic Services (VTS) related matters. In addition, the level of precondition for unsafe acts was modified from the original HFACS, in which the sub-category of crew resource management in the personnel factors was updated to the ship resource management containing inter-ship communications and bridge resource management (BRM). This was done for the purpose of adopting HFACS to the collision avoidance activity and bridge space. Chauvin et al. (2013) combined HFACS-Coll and Multiple Correspondence Analysis, and the results showed three typical patterns of collision occasion; 1) restricted waters with the pilot and problems on personnel factors (inter-ship communication and BRM); 2) combinations of factors in different levels, visibility and inappropriate instruments (precondition level), deficiency of attention (conditions of operators), inappropriate operations (leadership level), and insufficient SMS (organisational level); and 3) non-compliance with SMS.

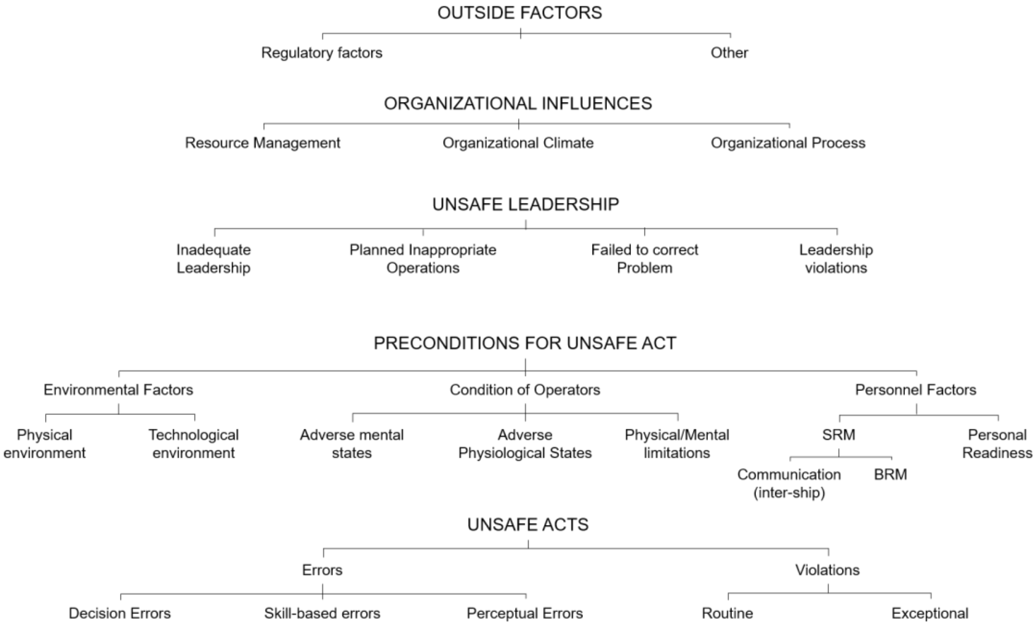
For the purpose of analysing passenger ship accidents, HFACS-PV was developed by Uğurlu et al. (2018) based on 70 collision and contact accidents involving passenger ships between 1991 and 2015 investigated by 22 different organisations. The most significant modification of HFACS-PV from the original HFACS was the adoption of the additional level, namely operational conditions, below the level of unsafe acts for the purpose of catching the situation that even if all necessary factors existed, the accident would not happen without a presence of the key operational condition. Other modifications were adopted to the level of preconditions for unsafe acts and consisted of sub standard team members and technology and interface malfunctions. The former is based on the concept that the accident analysis should focus on all bridge members, not only the master. The level of unsafe acts was also modified in the sub-categories of violations. The results showed that operational conditions, unsafe acts, and preconditions for unsafe acts occupied 19.92%, 35.01%, and 30.37% of all identified factors, respectively. The significant factors within the unsafe acts were violations of the Convention on the International Regulations for Preventing Collisions at Sea (COLREG) rules 5 (lookout) and 6 (speed), and the importance of preventing preconditions for unsafe acts was also highlighted.

2.2. Results

2.2.1. Methodology

Taking into account the scope and the purpose of this study, specifically, analysing human factors in collision accidents involving container ships, the HFACS-Coll (see Figure 2-3) was adopted as a human factor analysis method.

Figure 2-3.
HFACS Coll.



Note. Adopted from "Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS" by C., Chauvin, S., Lardjane, G., Morel, J.-P., Clostermann, and B. Langard, 2013, *Accident Analysis and Prevention*, 59, p.29. Copyright 2013 by Elsevier Ltd.

A total of 98 collision accidents involving at least one container ship occurring between 2011 to 2020, investigated by JTSB and other organisations, and opened to the public on their web pages, were analysed. The whole list of analysed reports is shown in Appendix 1. The breakdown of organisations and the number of analysed reports are as follows: Australian Transport Safety Bureau (1), Danish Maritime Accident Investigation Board (1), Federal Bureau of Maritime Casualty Investigation (8), Marine Accident Investigation Branch (7), National Transportation Safety Board (4) and JTSB (77). Thirty-one reports including 10 reports from JTSB were written in English and the rest of the 67 reports from JTSB were in Japanese; therefore, the HFACS coding process was mainly conducted by the author with the review by experts on the HFACS analysis at WMU. For the purpose of reducing the subjectivity of the author, the coding was conducted with attention to avoiding re-investigation of each accident in the way referring to the method that was adopted by Schröder-Hinrichs et al. (2011) Specifically, the analysis part of the report was utilised for the coding process, while the conclusions or the equivalent part of the report was utilised for confirmation purposes.

After identification and classification of the human factors utilised by HFACS Coll, the SHEL model was utilised for further classification of human factors focusing on interaction. Since categorisation for organisational and management factors has been completed by HFACS Coll, and for the purpose of simplification, the original SHEL model was adopted instead of the modified SHEL model, such as m-SHEL and SHELLO.

2.2.2. HFACS results

A total of 532 (human) factors were identified through reviewing 98 accidents utilising the HFACS Coll, and the overview of the results that include the 3rd Tier of the HFACS Coll is shown in Table 2-1.

Table 2-1.
Overview of the HFACS result

1st Tier	2nd Tier	3rd Tier	Observations
Outside factors			11
	Regulatory factors		3
	Other		8
Organisational influence			22
	Resource Management		5
	Organisational Climate		2
	Organisational Process		15
Unsafe leadership			39
	Inadequate Leadership		24
	Planned Inappropriate Operations		9
	Failed to correct problem		2
	Leadership violations		4

1st Tier	2nd Tier	3rd Tier	Observations
Preconditions for unsafe act			186
	Environmental Factors		53
		Physical environment	37
		Technological environment	16
	Condition of operators		76
		Adverse mental state	52
		Adverse physiological state	13
		Physical/Mental limitations	11
	Personnel Factors		57
		SRM-BRM	21
		SRM- Communication (Inter-ship)	31
		Personal readiness	5
Unsafe acts			274
	Errors		239
		Decision errors	104
		Skill-based errors	66
		Perceptual errors	69
	Violations		35
		Routine	34
		Exceptional	1
Total			532

It should be noted that in the six cases, only environmental factors, such as weather conditions, were identified, and no other human factor was identified. In addition, even though all accidents involved at least two ships, human factors were only identified in one ship, and no human factor was identified in the other ship in some cases since the investigator could not obtain detailed information on the ship due to the reasons such as the death of the crew, limitation of the investigation, or refusal to cooperate for the investigation. Consequently, human factors were identified for a total of 158 ships. The results within each layer (1st tier) will be shown in the following section.

Eleven factors were identified at the level of outside factors, with the lowest number of observations occupying about 2.1% of the total 532 observed factors. Outside factors consist of regulatory factors and others. Three factors were categorised in the regulatory factors, specifically, lack of the provision in the COLREG about the use of Automatic Identification System (AIS), easing the requirement for mandatory pilotage in the national legislation, and a national guide that did not reflect current technological characteristics of AIS. In addition, eight factors were categorised in others. Among these, six were related to VTS matters such as training of VTS operators, procedures for information providing, and errors of the VTS operators, and rest two factors were the arrangement of the passage and maintenance of the canal infrastructure.

Twenty-two factors were identified at the level of organisational influence and this accommodated 4.1 % of the total observed factors. Although there were no sub-categories in the 3rd Tier in the original HFACS Coll, sub-categories were added by the author based on the description by Chauvin et al. (2013), as shown in Table 2-2.

Table 2-2.
Result of Organisational influences

1st Tier	2nd Tier	3rd Tier	Observations
Organisational influence			22
	Resource Management		5
		Human resource management	4
		Maintenance of equipment	1
	Organisational Climate		2
		Organisational culture	2
	Organisational Process		15
		Organisational procedure	5
		Oversight within the organisation	4
		Formal process	6

In resource management, human resource management includes crew training and crew duty, and maintenance of equipment related to maintenance of onboard equipment. The organisational climate had two factors categorised as organisational culture, specifically, addressing fatigue and the use of AIS. Organisational procedures include four factors related to the documentation and one factor concerning briefings. Oversight within the organisation includes factors related to SMS and risk management. The formal process includes factors concerning time pressure, operational tempo, and maintenance schedule.

Thirty-nine factors were observed at the level of unsafe leadership, which occupied 7.3% of the total identified factors, and the result with an added 3rd Tier is the same as organisational influences shown in Table 2-3.

Table 2-3.
Result of Unsafe leadership

1st Tier	2nd Tier	3rd Tier	Observations
Unsafe leadership			39
	Inadequate Leadership		24
		Failure to provide guidance	12
		Failure to provide oversight	7
		Failure to track performance	2
		Failure to track qualification	3
	Planned Inappropriate Operations		9
		Inappropriate operational planning	6
		Inappropriate crew changing	1
		Failure to provide correct data	2
	Failed to correct problem		2
	Leadership violations	Master's violation	4

Inadequate leadership consists of four sub-categories (3rd Tier). Failure to provide guidance is the most common sub-categories in the 3rd Tier of unsafe leadership, and it involves the master's inappropriate instructions and the absence of the master/pilot on the bridge. Failure to provide oversight involves the master's failure to have oversight of the pilot, the risk assessment, and the passage plan. Failure to track performance includes failure in tracking ship and crew performance. Finally, failure to track qualification includes failure in tracking crew competency. The planned inappropriate operation consists of three sub-categories. Inappropriate operational planning includes problems with bridge member assignment, voyage plan, and planning on the port entry. Inappropriate crew changing refers to the case that crew changing did not take into account the expected voyage situation. Failure to provide correct data refers to cases the company manager failed to provide correct data to the ship. Failed to correct problem refers to cases that failed to implement measures identified in previous accident investigations and failure to recover the problem on equipment. Finally, the master's violation refers to the case the master violated the company's procedures or SMS.

One hundred eighty-six factors were categorised as preconditions for unsafe acts, and they occupied 35.0% of the total observed factors. The result with an additional 4th Tier that represents frequently observed cases is shown in Table 2-4.

Table 2-4.
Result of Preconditions for unsafe acts

2nd Tier	3rd Tier	4th Tier	Observations
Environmental Factors			53
	Physical environment		37
		Low visibility	9
		Strong current	2
		Bright background	4
		Adverse traffic condition	3
		Hydrodynamic phenomenon	3
		Heavy weather	16
	Technological environment		16
		Limitation of equipment	9
		Design of equipment	3
		Failure of equipment	4

2nd Tier	3rd Tier	4th Tier	Observations
Condition of operators			76
	Adverse mental state		52
		Overconfidence	2
		Distraction	25
		Loss of situational awareness	10
		Preconception on traffic situation	7
		Other adverse mental state factors	8
	Adverse physiological state		13
		Doze	5
		Physical fatigue	5
		Other adverse physiological state factors	3
	Physical/Mental limitations		11
		Slow movement of ship	1
		Lack of knowledge	8
		Lack of time to respond	2
Personnel Factors			57
	SRM		52
		BRM	21
		Communication (Inter-ship)	31
	Personal readiness		5
		Insufficient rest hours	4
		Chronic sleep shortage	1
Total			186

It should be noted that BRM and Communication (Inter-ship), which were sub-categories of Ship Resource Mismanagement (SRM), were already included in the original HFACS Coll. The physical environment consists of sub-categories that affected the perception of other ships, such as low visibility and bright background. In addition, there were other factors that contribute to an obstacle or restrict the ship's manoeuvre, such as heavy weather and strong currents. These contain adverse traffic situations that refer to the situation, such as congested traffic that restricts manoeuvring options. The technological environment had sub-categories of limitation of equipment such as delay in refreshing information on navigational equipment and restricted radar angle, design of equipment such as difficult to use, and failure of the equipment such as failure on machinery and failure of the doze warning equipment.

Conditions of operator are the most common sub-categories within the level of preconditions for unsafe acts, and among these, adverse mental state was the most common. Distraction and loss of situational awareness were two common sub-categories within the adverse mental state that led to errors in decision and perception. In addition, other adverse mental state factors include panic, mental fatigue, and cultural effects that lead to hesitation to act. Adverse physiological state involves physical fatigue, doze off, and others such as illnesses. Physical/mental limitations had sub-categories of lack of knowledge, including characteristics of equipment and rules that led to errors in the decision making, lack of time for response, and slow movement of the ship that was difficult to be recognised.

SRM is the most common sub-categories within the personnel factors and consists of BRM and Communication (inter-ship). BRM includes the issue of teamwork among the bridge member, inappropriate task allocation, and information sharing within the ship. Communication (Inter-ship) includes misinterpretation of manoeuvring intention done by communicating and taking time to establish communication. Personnel readiness had relatively low observations within personnel factors and included insufficient rest hours and chronic sleep shortage that affected the mental and physiological conditions of the crew.

Two hundred seventy-four factors were categorised as unsafe acts, and they had the largest number of observations accounting for 51.5% of total observed factors. The result of unsafe acts is shown in Table 2-5.

Table 2-5.
Result of Unsafe acts

2nd Tier	3rd Tier	4th Tier	Observations
Errors			239
	Decision errors		104
		Failure of traffic assessment	17
		Inappropriate collision avoidance manoeuvre	30

2nd Tier	3rd Tier	4th Tier	Observations
		Inappropriate manoeuvre	16
		Late collision avoidance manoeuvre	13
		Other decision error	28
	Skill-based errors		66
		Inappropriate monitor/lookout	36
		Inappropriate use of navigational equipment	18
		Other skill-based error	12
	Perceptual errors		69
		Late notice of other ship	29
		Failure of notice of other ships	19
		Other-perceptual errors	21
Violation			35
	Routine		34
		Manoeuvre violating COLREG	7
		Other COLREG violation	8
		Violation of STCW	6
		Violation of master's order/SMS	5
		Other violations	8
	Exceptional		1
		Use of VHF violating SMS	1
Total			274

Decision errors were the most common sub-categories within the errors and consisted of four sub-categories. Failure of the traffic assessment includes errors in assessing other ships' movement that influence the decision on own ship's manoeuvring. Inappropriate collision avoidance manoeuvre includes cases of manoeuvre that resulted in the collision with a specific intention to avoid collision and did not manoeuvre to avoid a collision. Inappropriate manoeuvres included cases that led to collision without the intention of the collision avoidance, such as position while passing a canal, approach during the entry, and fishing operations. Other decision errors include misjudgement of health conditions, inappropriate collision avoidance actions such as the use of the searchlight, and over speed. Within the skill-based error, inappropriate monitor/lookout was the most common factor. Inappropriate use of navigational equipment includes errors in radar setting and AIS. Other skill-based errors include failure to manoeuvre and use of equipment other than navigational equipment. Among perceptual errors, a late notice of other ships is the most common factor and refers to the cases the notice of other ships was too late for collision avoidance. While the failure of notice of other ships refers to the cases in which the ship did not recognise the other ship until the collision. Other perceptual errors include errors in recognising the collision risk and environmental conditions. Violations were observed relatively lower than errors, and most of them are categorised as routine. Among them, manoeuvre violating COLREG, such as manoeuvring head-on and the crossing situation, and other violations of COLREG, such as over speed and use of the ship's whistle, were common. In addition, violations of International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), such as the assignment of a lookout and watch handover, and violation of master's order/SMS, including violation of master's standing and night order and company's procedure, were also common. Other violations include violation of the local traffic rule and national legislation. Finally, an exceptional violation was identified in only one case, namely the use of Very High Frequency (VHF), which violates the company's internal rule based on SMS.

Focusing on sub-categories in 3rd Tiers, decision errors (104), perceptual errors (69), skill-based error (66), adverse mental states (52), and SRM (52) were the five common factors that accounted for 65.3% of the total identified factors. Therefore, although it is important to consider the relations of each factor, especially looking into the higher level, it is effective to consider the effects of introducing MASS on these factors when analysing the effects of MASS on collision accidents.

In terms of the distribution of the levels of factors, outside factors, organisational influences, and unsafe leadership were observed in relatively low numbers compared to the other two levels. This distribution of the levels also seems common in studies addressing other domains that utilised HAFCS and it might be due to characteristics of available data sources rather than the features of accident causation (Hulme et al., 2019). Focusing on organisational factors, although the importance of organisational factors has been highlighted, accident investigation might not be conducted at this level (Schröder-Hinrichs et al., 2011; Chauvin et al., 2013; Uğurlu et al., 2018). Although this study is not intended to evaluate the quality of the accident investigation report, the volume of each report had a broad range from several to dozen pages.

2.2.3. SHEL results

The identified (human) factors were also categorised by the SHEL model. Each SHEL category's number of observations with the distribution within the level of HFACS, such as unsafe acts, is shown in Table 2-6.

Table 2-6.
Overview of the SHEL result

SHEL categories	Observations					
	Total	OF	OI	UL	PU	UA
L-S	34	1	20	8	5	0
L-L	95	0	0	22	56	17
L-H, (H)	9	0	0	0	9	0
L-H	36	0	1	2	4	29
L-E, (E-H)	21	0	0	0	21	0
L-E	119	6	0	0	34	79
L	202	0	0	0	53	149
(S-H)	4	3	1	0	0	0
(S)	6	0	0	6	0	0
(H)	6	1	1	0	4	0

Note. Abbreviations in the table are the following; OF: Outside factors, OI: Organisational influence, UL: Unsafe leadership, PU: Precondition for unsafe acts, and UA: Unsafe acts.

Categories with brackets mean that these are not originally defined in the SHEL model. This is because some factors seem not comfortable for original categories, and it would be more applicable to add some categories than using only original categories. L is the most common category, followed by L-E and L-L, respectively. Compared to these categories, L-S and L-H are relatively less frequently observed. The detailed results of each category will be shown in the following sections.

The first category is software related factors. Among all identified factors, 34 factors and six factors were categorised as L-S and S, respectively. The result of L-S factors is shown in Table 2-7.

Table 2-7.
L-S result

HFACS	Factors	Observations
Outside factors		
	Relived requirement for mandatory pilotage	1
Organisational influence		
	Training, crew duty	4
	Safety culture (fatigue)	1
	Problem on documentation	5
	Time pressure/operational tempo	5
Unsafe leadership		
	Lack of risk assessment	3
	Didn't have the master onboard	1
	Inappropriate crew changing	1
	Master's violation	4
Preconditions for unsafe acts		
	Insufficient rest hours	5

L-S factors were most frequently observed at the organisational influence level, while no factors were observed at the level of the unsafe acts. In addition, all factors that were categorised as S were unsafe leadership and involved inappropriate voyage planning, failure to provide correct data, and failure to implement measures identified from the previous accident investigations. These factors seem to be more software-related, such as procedures, than the interaction between software and liveware; therefore, these were categorised as S in this study.

The second category is hardware-related factors. Thirty-six factors were categorised as L-H; in addition, nine and six factors were categorised as L-H, (H), and H, respectively. Furthermore, four factors were categorised as S-H. The result of L-H factors is shown in Table 2-8.

Table 2-8.
L-H result

HFACS	Factors	Observations
Organisational influence		
	Safety culture (equipment)	1
Unsafe leadership		
	Failure to track ship performance	1
	Failure to correct problem on equipment	1
Preconditions for unsafe acts		
	Design of equipment	3
	Preconception on equipment	1
Unsafe acts		
	Failure to manage equipment	3
	Inappropriate use of navigational equipment	22
	Inappropriate use of equipment	4

L-H factors were most frequently observed at the level of unsafe acts level, such as inappropriate use of navigational equipment, while no factors were identified at the level of the outside factors. In addition, a new category named L-H (H) was adopted with nine observations. This category was found at the level of the precondition for unsafe acts and consists of technical limitations of equipment, for example, data update periods of AIS and limitation of radar angle. These affect the liveware and have L-H characteristics; however, these are also issues on the hardware itself; therefore, these factors are categorised as L-H (H). Furthermore, six factors consist of failure of equipment such ss blackout of the ship and machinery failure whose causes were unknown, were categorised as H since these seem a purely Hardware aspect. Finally, three factors at the level of outside factors and one factor at the level of organisational influence were categorised as S-H. These consist of regulatory issues related to hardware, arrangement of passage, and resource management issues related to equipment There seems to be an interaction between software and hardware; therefore, these were categorised as S-H.

The third category is environment-related factors. One hundred nineteen factors and 21 factors were categorised as L-E and L-E (E-H), respectively. The result of L-E factors is shown in Table 2-9.

Table 2-9.
L-E result

HFACS	Factors	Observations
Outside factors		
	Issues on VTS operation	6
Preconditions for unsafe acts		
	Visibility	16
	Loss of situational awareness	17
	Slow movement of ship	1
Unsafe acts		
	Failure of traffic assessment	17
	Late notice of other ships	62

L-E factors were most frequently observed at the level of unsafe acts, such as late notice of other ships, while no factors were identified at the levels of organisational influence and unsafe leadership. Although VTS issues contain several aspects such as the issues on the officer in VTS, procedure, and coordination, in this study VTS related issues on the VTS side were simplified and categorised as L-E since these are surroundings that affect the seafarers' actions (Hasanspahić et al., 2021). In addition, 21 factors at the level of the precondition for unsafe acts, such as heavy weather and strong currents, were categorised as L-E (E-H). These factors are natural phenomena that mainly affect the ship's manoeuvrability and seem to have characteristics such as interaction issues between environment and hardware as well as the interaction between environment and liveware; therefore, these were categorised as L-E (E-H).

The final category is liveware. This consist of liveware (human) itself and its interaction. Two hundred two factors were categorised as L, and the result is shown in Table 2-10, and 95 factors were categorised as L-L, and the result is shown in Table 2-11.

Table 2-10.
L result

HFACS	Factors	Observations
Preconditions for unsafe acts		
	Distraction, stress	30
	Fatigue, dozing off	13
	Lack of knowledge	10
Unsafe acts		
	Inappropriate collision avoidance manoeuvre	78
	Inappropriate monitor/lookout	42
	Actions violating COLREG and other rules	29

L factors were only observed at the levels of the precondition for unsafe acts and unsafe acts, involving factors that seem to directly contribute to the occurrence of collision accidents.

Table 2-11.
L-L result

HFACS	Factors	Observations
Unsafe leadership		
	Inappropriate instruction	12
	Failure to check crew condition	4
	Failure to track crew performance/competency	4
	Inappropriate bridge member assignment	2
Preconditions for unsafe acts		
	Cultural effect of bridge member	4
	BRM, Inter-ship communication	52
Unsafe acts		
	Inappropriate passage agreement	6
	Failure to communicate VTS	2
	Master was not called	8
	Watch handover	1

L-L factors were most frequently observed at the level of Preconditions for unsafe acts such as BRM and Inter-ship communication, while there were no factors at the levels of Outside factors and Organisational influence.

3. Capability of MASS on collision avoidance

3.1. MASS architecture

3.1.1. Degree of autonomy of MASS

The characteristics of MASS highly depends on its degree of autonomy, which is the role of humans and the system in decision-making and control. Several definitions of the degree of autonomy have been proposed by classification societies such as DNV GL (DNV GL, 2018) and Lloyd's Register (Lloyd's Register, 2017) and the industry sector. The IMO also adopted the definition of the degree of autonomy for the purpose of the RSE (IMO, 2021), which is shown in Table 3-1.

Table 3-1.
Degree of autonomy adopted by the IMO for RSE

Autonomy	Seafarer on board	Control
Degree 1 (D1): Ship with automated processes and decision support	Yes	On board, seafarers operate and control the ship, while some processes are automated.
Degree 2 (D2): Remotely controlled ship with seafarers on board	Yes	The ship is remotely controlled from another location, and seafarers are on board to take control.
Degree 3 (D3): Remotely controlled ship without seafarers on board	No	The ship is remotely controlled from another location, and no seafarers are on board.
Degree 4 (D4): Fully autonomous ship	No	The action of the ship is decided by its operating system.

It should be noted that the level of autonomy can be varied during the voyage or operation (Ramos et al., 2019). For example, the ship without onboard seafarers navigates fully autonomously in open water but is remotely controlled from shore when the ship navigates in a certain challenging condition, such as navigating in a high traffic density area, which in this case, the level of autonomy of the ship is D3 or D4 depending on the situation. In this study, the degree of autonomy that was adopted by the IMO is adopted.

3.1.2. Collision avoidance system of MASS

A ship is composed of complex systems, in which each has a function, such as navigation, communication, and cargo storage/handling. Regarding systems that are related to collision avoidance, Zhang et al. (2021) highlighted five systems: global route optimization, navigational situational awareness, navigation behavioural decision making, motion control and execution, and communication. The global route optimization system refers to the system used to find the route from the starting point to the destination, which is collision-free and shortest based on acquired environment information such as obstacles and bad weather. The navigational situational awareness system consists of several means of sensors and equipment to attain internal and external information, which is the basis for navigational behavioural decision-making and motion control. The navigational decision-making system is the core of the MASS system, which receives input from the navigational situational awareness system and gives the instruction to the motion control and execution system as the output. The control and execution system executes the instruction from the decision-making system mainly through the control engine and rudder. Finally, communication systems share data and information between MASS, other ships, and shoreside facilities, which are necessary for systems to work properly. In addition to the above systems, the Shore Control Centre (SCC) has an important system. SCC has functions that the operator can monitor, supervise or control MASS from there (Wróbel et al., 2018a). Furthermore, the system of SCC allows the operator to monitor multiple ships (Burmeister et al., 2014).

3.2. Collision-related issues on MASS

3.2.1. Hardware

The first category that has challenges in terms of collision-related issues of MASS is hardware. This includes equipment utilized for the perception of other ships and the ship itself, communication, and other equipment. Except for D1 of MASS, the perception of other ships mainly relies on onboard sensors, even the D2 and D3 of MASS in which the final decision maker is a human, and the decision is taken by the person who is present in a place other than the onboard ship where the situation is not directly observed. This lack of the multi-sensory experience of living humans brings uncertainties to the safety of MASS navigation (Hogg & Ghosh, 2016). Data acquired by sensors is used for developing the situational awareness of the onboard system or the shoreside operator. Therefore, the failure of sensors lead to the system or operator ‘blind’ and hinder them from performing the navigation process safely and efficiently (Wróbel et al., 2018b). Therefore, sensors are one of the critical elements for collision avoidance abilities of MASS in terms of hardware.

Sensors are categorized mainly into two depending on target data, firstly, data related to the external condition, which consists of lookout data and external environment data, and, secondly, data related to the internal state of the ship (Dreyer & Oltedal, 2019). Lookout data involves data used for the observation of the other ships, land, and wreckages and is used for collision avoidance. This data will be obtained by several sensors such as radar, video camera, AIS, and infrared camera and integrated by the system as a perceived model containing various information such as the track and navigational status (Burmeister et al., 2014). External environment data such as weather conditions are also important data since these influence the Closest Point of Approach (CPA), which is the critical value for collision avoidance (Wróbel et al., 2018b). Weather data can be obtained by onboard sensors (Burmeister et al., 2015) and also be provided by outside sources for the purpose of enhancing situational awareness (Wróbel et al., 2018a). Internal system data involves data obtained by sensors for machinery, rudder angle, tank gauges, and fire (Dreyer & Oltedal, 2019; Wróbel et al., 2018b). One of the concerns is the accuracy of the onboard sensor system to detect small objects such as a life raft, wreckage, or people in all weather conditions (Hogg & Ghosh, 2016).

In addition to sensors, the Global Navigation Satellite System (GNSS) is also important hardware that is related to perception. MASS is expected to gain its position information from GNSS, which is known as an accurate and reliable position system; however, threats to GNSS have been raised recently (Felski & Zwolak, 2020).

Although there are several types of threats to GNSS, jamming is considered a major threat that is mainly caused by military and illegal fishery activities (Medina et al., 2019). This is also related to cyber security issues, which will be addressed in this section. In addition to intentional malicious interference, unintentional radio frequency interference can also be caused by equipment such as commercial high-power transmitters, ultra-wideband radar, television, VHF, mobile satellite services, and personal electronic devices (Felski & Zwolak, 2020). Although it is an area-specific issue, the Arctic region, which is currently attractive as a new maritime traffic route connecting the Atlantic and the Pacific, is a challenging area for the use of GNSS because of signal blockage caused by the low elevated angle of satellite position, and signal scintillation and delay caused by ionospheric disturbance (Yastrebova et al., 2020).

The second category which involves challenges within the hardware aspect is communication. The architecture of communication of MASS needs to be safe and reliable and mainly be categorized into “ship-to-shore” and “ship-to-ship” (Dreyer & Oltedal, 2019). Ship-to-shore communication includes both-way communication between MASS and SCC mainly utilizing satellite communication links with other short-range communication links as supplementary (Rødseth & Burmeister, 2015; Wróbel et al., 2018b); in the case of D2 or D3 of MASS, MASS sends the observed data to SCC and the operator in SCC makes the decision and sends the controlling signal to MASS. The communication link should have a fail-safe backup in case of communication failure and other reasons (Wróbel et al., 2018b). Ship-to-ship communication includes communication between MASS and conventionally manned ships (Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015) and others such as VTS (Thieme et al., 2018).

One of the challenges in communication is bandwidth and the qualities of communication. Although the communication from MASS to SCC is mainly status update, including radar, Global Positioning System (GPS), and rudder data which needs relatively low-quality communication architecture, high bandwidths and high-quality communication architecture are essential to in case such as SCC requires high-definition video images or SCC takes control of MASS (Hogg & Ghosh, 2016). In addition, satellite communication systems and other communication-related systems, such as communication devices in SCC, have a high potential to be affected by cyber threats (Tusher et al., 2022). On the other hand, communication between MASS and conventionally manned ships may also have a challenge since communication has been traditionally executed by humans on each bridge (Dreyer & Oltedal, 2019).

Finally, the reliability of the equipment can also be a challenge in the hardware aspect. This is not only for collision avoidance but also for the safety of navigation of MASS in general. In particular, there will be no crew on board for D3 and D4 of MASS, which means that onboard repair by the crew cannot be executed as well as emergency response activities for the event such as in case of fire. This can bring severe consequences than that of conventionally manned ships (Wróbel et al., 2017). Therefore, more reliability is required for equipment used in MASS compared to conventionally manned ships (Hogg & Ghosh, 2016). In addition, self-monitoring is also important for D3 or D4 of MASS since there is no crew on board who checks the condition of the system on board (Felski & Zwolak, 2020).

3.2.2. Software

There are also challenges in the software aspect. These involve decision-making, cyber security, and validation. Firstly, decision-making is the major challenge that involves collision avoidance manoeuvres such as head-on or crossing situations with other ships and avoidance of unfavourable weather conditions as weather routine (Burmeister et al., 2015). Decision-making of MASS for collision avoidance is one of the major research areas of MASS. There are mainly two categories of collision avoidance algorism: rule-based and learning-algorism based. Rule-based algorisms divide actions of MASS into each behaviour which is determined by rule logic based on CORLREGs, other traffic rules, knowledge, and experience. Learning-algorism-based methods include deep-learning-related methods and machine learning-based methods.

The rule-based algorism has advantages such as clear logic, strong interpretability, and ease of model, while it has disadvantages such as concerns in the overlapping of trigger conditions which lead to system failure, and bottleneck for complex conditions. On the other hand, the learning-algorism-based method has the advantage of its applicability to various situations through big data systems and possible simplification with a network structure, while it has disadvantages in poor interpretability. This will lead to difficulty in modifying the model and the quality of the model depends on data quality. Currently, the rule-based algorithm is widely adopted, and a combination of the rule-based and the learning- algorithm based will be more used (Zhang et al., 2021).

Although the future application of existing regulations to MASS is under discussion, COLREGs should still be referred to collision avoidance manoeuvres of MASS (IMO, 2021). Therefore, irrespective of algorithms, the decision-making should align with COLREGs. COLREGs consist of 41 regulations that are divided into six parts: Part A - General; Part B - Steering and Sailing; Part C - Lights and Shapes; Part D - Sound and Light signals; Part E - Exemptions; and Part F - Verification of compliance with the provisions of the Convention (IMO, 1972). Among these, Part B deals with collision avoidance actions applied in all conditions and certain conditions, such as overtaking (Rule 13), head-on (Rule 14), and crossing (Rule 15), and plays an important role in decision-making for collision avoidance; therefore, the collision avoidance algorithms have mainly been discussed in Part B of COLREGs (Burmeister & Constapel, 2021).

Challenges in decision-making for collision avoidance are mainly divided into two categories: interaction against ships whose intentions are unclear or do not act per COLREGs, and interpretation is derived from the text of COLERGs. The first category is significant for the situation where MASS and conventionally manned ships co-exist. Since MASS is always expected to follow a collision avoidance algorithm if the system works properly, conventionally manned ships might act unpredictably and violate rules (Felski & Zwolak, 2020). For example, even the system that shows good capability for collision avoidance in several situations, the unclear intention of the other ship under high-speed and close range is a challenging situation for the system (Kufoalor et al., 2020).

The second category, interpretation derived from the text of COLERGs, is challenging in the stage of software development for collision avoidance. In general, COLREGs have a qualitative nature, and the application of COLREGs is judged by seafarers taking into account not only the actual situation but their knowledge, experience, and culture (Porathe, 2019); therefore, the application of COLREGs has some subjectivity (Ramos et al., 2019). One of the examples is Rule 2, which requires seafarers to adhere to regulations of COLREGs, while it also regulates seafarers to deviate from rules if it is necessary to avoid accidents. However, there is no clear indication about the condition, such as distance or time, which should deviate from the rules in the COLREGs (Porathe, 2019).

The second category of challenge in decision-making is avoiding unfavourable weather conditions. As shown in the result of the HFACS coding of accident reports in chapter 2, heavy weather can be one of the contributing factors to collisions. In addition, this is also related to comprehensive navigation safety of MASS since if MASS encounters unfavourable weather conditions, damages to the hull, cargo, and environment may happen (Acanfora et al., 2018). The decision-making for avoiding unfavourable weather conditions consists of two stages, planning and operation. The planning stage mainly considers the route based on the weather forecast provided by the shoreside, while the operational stage mainly considers manoeuvres that try to reduce negative effects from the external environment based on locally observed environment data (Acanfora et al., 2018; Burmeister et al., 2015). It should be noted that the manoeuvre for collision avoidance and the manoeuvre for unfavourable weather conditions cannot be solved independently, and contradiction may happen (Burmeister et al., 2015).

The second major challenge in the software aspect is cyber security. Recently, cyber security is one of the major issues in the maritime industry, and it can also be a major threat to MASS (Ghaderi, 2019; Hogg & Ghosh, 2016). Furthermore, not only MASS but also threats to infrastructures exist in the offshore and coastal areas since hijacked MASS can be used for attacking these infrastructures (Vinnem & Utne, 2018). Regardless of its degree of autonomy, MASS increases dependencies on Information and Communication Technology (ICT) for ship control and monitoring connectivity between the ship and shore, and accessibility to the ship system through the internet also increases (Katsikas, 2017).

Several threats to MASS both on board and shoreside exist, and previous studies on cyber security in the maritime domain mainly categorize it into five; “navigational systems, propulsion control systems, port operations, shore control centre and shore-based management offices” (Tusher et al., 2022, p. 5). Navigational equipment includes GNSS, AIS, and Electronic Chart Display and Information System (ECDIS), which are widely used on board and can be subjected to cyber-attacks since these work based on signal processing and transmission (Dyryavyy (2015) as cited in Tusher et al., 2022). Jamming and spoofing are major types of cyber-attacks on navigational equipment. While it requires a relatively higher level of technologies than jamming, spoofing, which introduces false signals to equipment and leads to faults such as calculating incorrect position or timing, can bring more severe consequences since spoofing confuses even the alarm system for jamming (Androjna et al., 2020). Since the dependency on navigational equipment of MASS is higher than on conventionally manned ships, the consequences of cyber-attacks also become severe. Propulsion systems also have a vulnerability against cyber-attacks since advanced propulsion systems utilize information and communication technologies (Tusher et al., 2022). Although the estimated risk for the cyber security of the engine-related system is relatively lower than that of the bridge system (Kavallieratos et al., 2019), the effect of propulsion failure on collision avoidance should be considered. Port operations are also exposed to cyber threats in the area, such as Port Community Systems and Maritime Single Window. In addition, mooring operations can also be subjected to cyber threats since modern mooring technologies utilize remote radio control (Tusher et al., 2022). Although these are less significant for collision avoidance, they still possibly contribute to collision accidents during port entry/departure in terms of information sharing. The SCC is the core of the MASS operation. However, due to the lack of a common understanding of the necessary system architecture for future MASS, identifying cyber threats on SCC is challenging (Tusher et al., 2022). Some potential cyber threats on SCC were identified, such as compromising credential or administration access and losing connection capability (Kavallieratos et al., 2019). Since SCC has a critical role, ensuring safety and redundancy on SCC is important for collision avoidance. The final category of cyber threats is threats in shore-based management offices. The reliance on the internet has also increased in shoreside management offices, and potential vulnerability also exists in shore-based management offices. Furthermore, major shipping companies and the IMO have in fact suffered from cyber-attacks (Tusher et al., 2022). The same as the cyber threats in port operations, cyber threats in shoreside management offices are less significant in collision avoidance in direct aspects; however, these might have an effect on collision accidents as “latent factors” in the Swiss cheese model.

Finally, validation of the system is also a challenge in the software aspect. This can also be a challenge in the hardware aspect in terms of the overall collision avoidance system. MASS needs high reliability in all expected circumstances; therefore, validation of the system is very important. According to a recent review (Burmeister & Constapel, 2021), recent studies on collision avoidance of MASS have mainly adopted special simulation environments as validation methods which might be different from a commercial ship-handling simulator or field test in terms of hydrodynamic characteristics in manoeuvre. In addition, while the developments of preliminary classification society rules were acknowledged, the lack of internationally accepted or standardized process methods was also highlighted.

3.2.3. Human factor

Human factors are also a challenge for collision avoidance of MASS. Even with an increased degree of autonomy of MASS, which means reduced human involvement, human factors still exist, such as SCC and the navigation environment where MASS and other ships are mixed. For SCC, human factor-related challenges involve the operator and human-machine interaction. Although the operator in SCC will be free from fatigue and other adverse working conditions, which are expected to mitigate human errors compared to working onboard (Burmeister et al., 2014), operational errors can still happen with the operator. For example, Liu et al. (2022) highlighted that performing continuous collision avoidance during the voyage, system setting and updating before departure, and reporting to relevant authorities when arrival as the critical tasks of the operator which expects high error probability for the operation of degree three of autonomy of MASS. In addition, the risk of monitoring several ships by one operator is also highlighted (Zhang et al., 2020). Even for a high degree of autonomy of MASS, the human operator in SCC is still important as a safety barrier for collision avoidance systems of MASS. For example, intervention in the system by the operator can happen when the system cannot find a solution for collision avoidance and warns to the operator or the operator noticed the failure of systems (Ramos et al., 2019). Therefore, errors with the operator can lead to severe consequences. With regards to this, training and qualification for the operator are also challenges. The operator will be required new skills to manage the ship and analyse the data in addition to the experience at sea (Hogg & Ghosh, 2016) Therefore, the qualification for the operator needs to be regulated through open discussion between stakeholders (Felski & Zwolak, 2020).

Another challenge is Human-machine interaction. This contains several types of negative effects. One of the examples is automation-induced complacency, which means the inability of the operator to perceive an automation malfunction of the system, which is affected by the training and workload experience of the operator and the reliability of the automation system. This is also related to the optimization of trust and dependency on the system. Excessive trust leads to over-reliance, while lack of trust leads to the disuse of the system (Hogg & Ghosh, 2016). Another example is the situational awareness of the operator. There is a concern that the situational awareness of the operator might be limited due to the lack of sense of the ship, together with information overload from multiple sensors on board the ship (Ghaderi, 2019).

In addition to issues on SCC, the interaction between MASS and conventionally manned ships is one of the major challenges of MASS operation (Chang et al., 2021). Although the automated system has an advantage in performing repetitive tasks in terms of reliability compared to a human, there is a concern that the automated system may not make the decision that is adopted to complex and unpredictable situations as humans do (Kim et al., 2022). In terms of collision avoidance, the violation of COLREGs and other rules by conventionally manned ships (with the assumption that MASS always adheres to these), which is also found in the results of the HFACS coding of accident investigation reports, helps make the situation more complex and unpredictable. In addition, not only inter-ship relations but also the relation to VTS under a mixed navigational environment need to be taken into account (Baldauf et al., 2019). Furthermore, according to Kim et al. (2022), the risk matrix for the mixed navigational environment, which involves conventionally manned ships and MASS, shows that an increase in diversity of degree of autonomy leads to more likelihood and severity. Therefore, navigational situations in the near future can be more challenging.

4. Effects of introduction of MASS on collision accident

4.1. Methodology

Based on the analysis of collision accident investigation reports and a literature review on the capability of collision avoidance of MASS, the effect of the introduction of MASS on collision accidents was evaluated. More specifically, for each identified and categorized human factor, the likelihood was evaluated corresponding to the degree of autonomy of MASS which was adopted by the IMO. In addition, the Likert scale was adopted for the evaluation of the likelihood since it is a widely adopted method for quantifying subjective thinking in a reliable manner (Joshi et al., 2015). The original likelihoods were developed by the author and were validated by the three experts of the WMU. The experts are faculty members, have experience working at sea, and have engaged in research areas which are related to this study such as maritime safety and MASS. The opinions of the experts were equally considered since the number of the experts was low and they belonged to the same organization.

4.2. Result

In this section, the result of likelihood is presented after a brief introduction to basic considerations which lead to the result. Firstly, the likelihood was set from 1 to 5, 1 means very rare and 5 means very often, and 3 means as usual as the conventionally manned ship. The result of the likelihood of each factor corresponds to each degree of autonomy of MASS, D1 to D4. Secondly, the likelihood was developed for each ship and related outside facilities. In other words, the likelihood was developed as a “ship perspective” in general; therefore, matters such as the effects of MASS and conventionally manned ships mixed navigational environment on VTS operation were not taken into account. Thirdly, it should be noted about the overall assumption that MASS should be at least as safe as conventionally manned ships (Thieme et al., 2018). Therefore, human factor related issues should also be reduced in general. For example, matters related to the onboard crew’s health will completely be eliminated with D4 of MASS which is a completely automated ship. In addition, the operator in SCC will be provided with a better environment than that of an onboard bridge and it will be expected to mitigate adverse conditions such as stress (Burmeister et al., 2014).

However, factors related to the outside of MASS and SCC such as the company and other shore authorities will not be significantly affected by the introduction of MASS. This will also be applicable for matters not directly related to humans such as procedures and equipment. Finally, the reliability of systems utilised in MASS was assumed relatively high compared to conventionally manned ships. Although there are several challenges on MASS systems as highlighted in chapter 3 of this study, the measure to ensure redundancy of the system or the highly reliable system will be adopted as the risk control measures (Wróbel et al., 2018b). Therefore, factors related to the system reliability were considered as very rare to happen. In other words, the system will not make a mistake on decision or violate rules in general. Based on the above consideration, the result of developed likelihood is shown in Table 4-1 with the referencing HFACS Coll and SHEL categories.

Table 4-1.
Likelihood of each factor

HFACS			SHEL	Factors	Likelihood			
1st Tiers	2nd Tiers	3rd Tier			D1	D2	D3	D4
Outside factors								
	Regulatory factors							
			(S-H)	No provision exists for AIS data	3	3	3	3
			L-S	Relived requirement for mandatory pilotage	3	3	1	1
			(S-H)	Not reflect current technical situation	3	3	3	3
	Other							
			(S-H)	Inappropriate arrangement of passage	3	3	2	2
			(H)	Insufficient maintenance of canal infrastructure	3	3	2	2
			L-E	Issues on VTS operation	3	3	3	2
Organizational influence								
	Resource management							
			L-S	Training, crew duty	3	2	2	1

HFACS					Likelihood			
1st Tiers	2nd Tiers	3rd Tier	SHEL	Factors	D1	D2	D3	D4
			(S-H)	Insufficient maintenance of equipment	3	3	2	2
	Organizational climate							
			L-S	Safety culture (fatigue)	3	3	2	1
			L-H	Safety culture (equipment)	3	3	3	3
	Organizational Process							
			L-S	Problem on documentation	3	3	3	3
			L-S	Ineffective SMS/oversight	3	3	3	3
			(H)	Inappropriate repair/maintenance	3	3	2	2
			L-S	Time pressure/operational tempo	3	3	3	2
Unsafe leadership								
	Inadequate Leadership							
			L-L	Inappropriate instruction	2	2	2	1
			L-S	Lack of risk assessment	2	2	2	1
			L-L	Failure to check crew condition	2	2	1	1
			L-H	Failure to track ship performance	2	2	2	1
			L-L	Failure to track crew performance	2	2	2	1
			L-L	Failure to track crew competency/qualification	2	2	1	1
	Planned Inappropriate Operations							
			L-L	Inappropriate bridge member assignment	3	2	1	1
			(S)	Inappropriate voyage plan	3	2	2	1
			L-S	Didn't have the master onboard	3	2	1	1
			L-S	Inappropriate crew changing	3	1	1	1
			(S)	Failure to provide correct data	3	3	2	2

HFACS					Likelihood			
1st Tiers	2nd Tiers	3rd Tier	SHEL	Factors	D1	D2	D3	D4
	Failed to correct problem							
			(S)	Failure to implement measures identified previous accident investigation	3	3	3	3
			L-H	Failure to correct problem on equipment	3	3	2	2
	Leadership violations							
			L-S	Master's violation	3	2	2	1
Precondition for unsafe acts								
	Environmental Factors							
		Physical environment						
			L-E	Visibility	2	1	1	1
			L-E, (E-H)	heavy weather, strong current	2	2	1	1
		Technological environment						
			L-H, (H)	Limitation of equipment	3	3	3	3
			L-H	Design of equipment	3	2	2	1
			(H)	Failure of equipment	3	3	2	2
	Condition of operators							
		Adverse mental state						
			L	Distraction, stress	3	2	2	1
			L-L	Cultural effect of bridge member	3	1	1	1
			L-E	Loss of situational awareness	3	2	2	1
			L-H	Preconception on equipment	3	2	2	1
		Adverse physiological state						
			L	Fatigue, doze off	3	2	2	1
		Physical/Mental limitations						
			L-E	Slow movement of ship	3	2	2	1
			L	Lack of knowledge	3	2	2	1
	Personnel Factors							
		SRM						
			L-L	BRM	3	2	2	1
			L-L	Inter-ship communication	3	3	3	4
		Personal readiness						
			L-S	Insufficient rest hours	3	2	2	1
Unsafe acts								

HFACS			SHEL	Factors	Likelihood			
1st Tiers	2nd Tiers	3rd Tier			D1	D2	D3	D4
	Errors							
		Decision error						
			L	Inappropriate collision avoidance manoeuvre	3	2	2	1
			L-E	Failure of traffic assessment	3	2	2	1
			L-L	Inappropriate passage agreement	3	2	2	1
			L-H	Failure to manage equipment	3	2	2	1
		Skill-based error						
			L	Inappropriate monitor/lookout	3	2	2	1
			L-L	Failure to communicate VTS	3	3	1	1
			L-H	Inappropriate use of navigational equipment	3	2	2	1
		Perceptual error						
			L-E	Late notice of other ships	3	2	1	1
			L-L	Master was not called	3	2	1	1
	Violation							
		Routine						
			L	Actions violating COLREG and other rules	3	2	2	1
			L-H	Inappropriate use of equipment	3	2	2	1
			L-E	Late perception of other ships	3	2	2	1
			L-L	Watch handover	3	2	2	1
		Exceptional						
			L-H	Inappropriate use of equipment	3	2	2	1

In addition, the aggregated likelihood compared to the current conventionally manned ship was calculated as the following formula; where, P_n means aggregated likelihood corresponding to each degree of autonomy of MASS (n=1 to 4); p_n means likelihood for each human factors corresponding to each degree of autonomy of MASS (n=1 to 4).

$$P_n = \sum \frac{p_n}{3}$$

Since p_n set as 3 if the likelihood of each human factor is the same as conventionally manned ship, P_n is 1 if each likelihood is the same as conventionally manned ship. The result of P_n is shown in Table 4-2.

Table 4-2.
Aggregated likelihood

D1	D2	D3	D4
0.954	0.770	0.661	0.500

In terms of likelihood, there is no significant difference for D1. However, for D4, the likelihood is reduced to half compared to conventionally manned ships.

5. Discussion

5.1. Accidents distribution

In this section, the findings from the analysis of accident investigation reports are discussed. The first finding is features of factors identified through the coding of accident investigation reports. In this study, the scope of collision accidents was set to the accidents involving a container ship. Therefore, it was expected that some factors, which seemed to be related to the container ship or its operation, would be identified through the coding of the accident investigation reports. For example, one of the features of liner shipping is the high demand for the punctuality of the operation (Ma, 2021) and this can lead to factors such as time pressure and inappropriate voyage planning. Another example is the design features of the ship, which are related to stability and involve hull form, draft, and length, and directly affect ship motion. Ship motion might cause motion-induced sickness and motion-induced interruption of tasks and these negative effects are relatively common in container ships compared to other ship types such as tankers (Endrina et al., 2019). However, a few factors, which seem related to the container ship or its operation, were identified through the coding of investigation reports. For example, time pressure and design issues of equipment are categorized as formal process and technological environment in HFACS Coll classification (Chauvin et al., 2013); six of formal process factors and 16 of technological environment factors were observed respectively among 532 factors totally. These factors are considered as "latent" factors which might lead to unsafe acts such as decision or skill-based errors.

The second finding is the distribution of the identified factors in the categories of HFACS. In particular, a relatively low number of factors categorized for outside factors, organisational influences, and unsafe leadership were observed. This the relatively low observations of factors at outside factors, organisational influences, and unsafe supervision levels are also common in other studies which adopted HFACS, and this might be led by data source, i.e., accident investigation reports, rather than the features of accident causation (Hulme et al., 2019). In addition, these relatively low observations of latent failure are also contrary to the HFACS philosophy that emphasises to look into the latent failure of unsafe acts (Hulme et al., 2019). This might be related to the above finding that there were few observations of container ship related factors. The ideal principles of accident investigation are 'What-You-Look-For-Is-What-You-Find' followed by 'What-You-Find-Is-What-You-Fix', which means the purpose of accident investigation is to find the method to prevent feature re-occurrence of similar accidents and found causes of the accident through the investigation are to be fixed during follow-up (Lundberg et al., 2009). However, a limitation was highlighted in that the investigation was stopped at the level of causes which would be currently practically fixable, and this prevented the investigation from understanding the overall picture of the accident as a basis for measures to prevent re-occurrence (Lundberg et al., 2010). However, available data might be limited to conventionally manned ships since MASS is not widely operated but only a few at the trial phase at present, so more depth and wider scoped investigation would help not only future re-occurrence of the accident but basis for improving the safety of MASS.

5.2. Implications for maritime industries

This section discusses the challenges of collision avoidance of MASS highlighted in chapter 3. Several key issues were highlighted such as sensors, communication, cyber security and validation. Firstly, sensors are essential for the decision-making of MASS not only for collision avoidance but for overall operations. Therefore, measures to ensure the capability of sensors should be adopted. These include the adoption of highly reliable sensors and/or measures to ensure redundancy of sensors (Wróbel et al., 2018b). In addition, for the purpose of ease of modularized development of the MASS system, the common definition and format for the data set of obtained data from various sensors are also required (Burmeister et al., 2020). Furthermore, in relation to the other factors such as communication and human factors, the optimization of data from sensors is also necessary for the purpose of corresponding to the issues such as limited communication capacity, information overload, and conflicting information from different sensors (Burmeister et al., 2014).

Communication is also one of the essential elements for the safe operation of MASS. Although ensuring stable satellite communication with wider bandwidth is important (Felski & Zwolak, 2020), ensuring the communication between MASS and the conventionally manned ship is also important (Dreyer & Oltedal, 2019). Several measures have been considered but mainly communication from MASS to other ships utilizing for example lights and reserved AIS channels (Porathe, 2019). However, the means to ensure communication from conventionally manned ships to MASS and bidirectional communications also need to be developed.

Cyber security is another important element for MASS but also for the overall maritime sector since digitalisation has increased. The IMO issued guidelines, which provide high-level recommendations on maritime cyber risk management (IMO, 2017d), and later adopted the resolution to encourage administrations to ensure addressing the cyber risks properly in existing company's SMS (IMO, 2017b). However, these are the starting point for ensuring effective cyber security measures. Since MASS interact in the surrounding environment, including human beings, effective and comprehensive cyber security measures are necessary for the safe operation of MASS (Ghaderi, 2019; Katsikas, 2017).

The validation is also important for ensuring the overall safety of the MASS system. Although the majority of studies on collision avoidance of MASS adopted the special simulation environment (Burmeister & Constapel, 2021), a field test is preferable in terms of validation against uncertainties in the actual operating environment. In fact, several field tests have been conducted with large vessels and not small purpose vessels such as a coastal ferry (Rolls-Royce, 2018), a coastal going container ship (The Nippon Foundation, 2022) and an ocean-going LNG carrier (Hyundai Heavy Industries Group, 2022). These works are helpful not only for the development of technologies adopted for these projects but can also be used as a basis for the development of internationally accepted test methods for future development of the MASS system.

5.3. Future research

Finally, this section considers a future research direction on collision avoidance of MASS. Although MASS is expected to improve the safety and efficiency of shipping in general, the effects of the introduction of MASS on accident occurrence seem a complex issue. For example, Wróbel et al. (2017) reviewed 100 accident investigation reports and assessed the impact of MASS on maritime accidents under the condition that only known issues were addressed, and excluded security issues. They concluded that navigational accidents such as grounding and collisions are expected to decrease, while, non-navigational accidents such as fire, are expected to be more severe since there is no seafarer on board. Taking into account the high dependency of MASS on ICT, the potential impacts of cyber threats (Tusher et al., 2022) should be taken into account during future research. Furthermore, the mixed navigational environment, which involves MASS and conventionally manned ships (Chang et al., 2021; Kim et al., 2022), will be realized in the near future and might become the key issue for collision avoidance of MASS. However, this topic might be challenging in terms of uncertainties and available data sources since currently only a limited number of trials of MASS operation have been conducted, further research on this mixed navigational environment seems necessary.

6. Conclusion

It is well believed that human factors contribute to about 80% of maritime accidents. Therefore, the importance of human factors in maritime accidents has been recognised for several decades and it has also been addressed in the area of accident investigation. On the other hand, the rapid development of technologies brings MASS to maritime sectors. MASS is expected to overcome issues of human errors and improve the safety and efficiency of shipping. The motivation of this study was to answer the following question: How does MASS affect maritime accidents? To estimate the effects of the introduction of MASS on maritime accidents, collision accidents were adopted as a scope of accident types. In addition, the scope of collision accidents was set to accidents involving a container ship since it is expected that MASS will be actively introduced to container ships. This study consisted of mainly three parts. The first part was the analysis of accident investigation reports of 98 collision accidents utilising HFACS Coll and the SHEL model to understand the characteristics of current collision accidents. The second part was a literature review to understand the characteristics of MASS in collision accidents. The third part was the assessment of the effects of different degrees of autonomy of MASS on identified human factors utilising a Likert scale likelihood based on the result of analysis of accident investigation reports and literature review. The results are as follows. For the first part, from HFACS results, decision errors, perceptual errors, skill-based errors, adverse mental states, and SRM were major observed categories. On the other hand, from the SHEL results, L, L-E and L-L categories were major observed categories. For the second part, three measure categories of collision-related challenges of MASS were identified. In particular, hardware, which involves sensors and communication; software, which involves decision making and cyber security; and human factor, which involves issues on the interaction between MASS and conventionally manned ships were three major categories. For the third part, the likelihood of each human factor generally decreased with the increased degree of autonomy of MASS. From these results, although there were some limitations, this study could conclude that the introduction of MASS decreases collision accidents to some extent.

The limitation of this research and the possible future research are the following: Firstly, the scope of accidents was limited to accidents involving container ships and the majority of data sources relied on accidents investigated by JTSB. Secondly, this study adopted HFACS Coll and SHEL model to analyse human factors. These methods have an advantage in classification; however, these do not provide much information about the interaction of each human factor. Thirdly, although the likelihood assessment result on MASS effects on collision accidents was validated by the experts of WMU, there were uncertainties, such as those coming from potential cyber threats and the mixed navigational environment. In addition, the number of experts was limited and the affiliation of experts was limited to WMU. Finally, it is important to estimate not only the likelihood but also the consequences for assessing safety. Future research which corresponds to the above, for example, expanding the scope of accidents, adopting further analysis methods such as the Bayesian Network, and improving validation methods such as adopting the workshop, would be useful for assessing a wider picture of the effects of the introduction of MASS on maritime accidents.

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Appendices

Appendix 1 The list of analysed reports

Number	ID	Occurrence date	Title	Country
1	MO-2018-002	2018/1/23	Collision between the container ship Beijing Bridge and fishing vessel Saxon Onward, Tasman Sea, about 3 NM south-east of Gabo Island, Victoria, on 23 January 2018	Australia
2	MAB-13-04	2011/12/5	Collision between M/V Maersk Wisconsin and Tug and Barge Unit	US
3	2012005988	2012/6/5	SPRING GLORY and JOSEPHINE MAERSK - Collision on 5 June 2012	Denmark
4	7/2020	2018/8/4	Collision between container vessel ANL Wyong and gas carrier King Arthur	UK
5	Investigation Report 417/13	2013/5/7	Collision between the CMV CONMAR AVENUE and CMV MAERSK KALMAR on 7 May 2013 on the Outer Weser.	Germany
6	28/2015	2015/2/11	Collision between container vessel Ever Smart and oil tanker Alexandra 1	UK
7	MAR-20-02	2017/7/17	Collision between US Navy Destroyer Fitzgerald and Philippine-Flag Container Ship ACX Crystal	US
8	Investigation Report 36/14	2014/1/16	Collision between the WES JANINE and STENBERG on the Nordwest-Reede anchorage off Brunsbüttel on 16 January 2014	Germany
9	Investigation Report 53/13	2013/3/2	Collision in the Brunsbüttel siding between the CMV HERM KIEPE and CMV EMPIRE on 2 March 2013.	Germany
10	Investigation Report 15/13	2013/1/31	Collision between the MV CORAL ACE and the MV LISA SCHULTE at the Neue Weser Nord-roadstead on 31 January 2013.	Germany
11	Investigation Report 507/11	2011/11/22	Collision between the MOL EFFICIENCY and the SPLITTNES on 22 November 2011 at 2013 on the Weser.	Germany

Number	ID	Occurrence date	Title	Country
12	Investigation Report 250/11	2011/6/21	Collision between the CMV CCNI RIMAC and CMV CSAV PETORCA on 21 June 2011 in the area of the approach to the port of Yangshan.	Germany
13	15/2013	2011/12/11	Collision between container vessels Hyundai Discovery and ACX Hibiscus	UK
14	Investigation Report 117/11	2011/4/14	Collision between the TYUMEN-2 and OOCL FINLAND on 14 April 2011 in the Kiel Canal.	Germany
15	Investigation Report 211/19	2019/6/8	Collision between traditional vessel No 5 ELBE and container vessel ASTROSPRINTER on the River Elbe on 8 June 2019	Germany
16	11/2014	2013/3/19	Collision between container vessel CMA CGM Florida and bulk carrier Chou Shan	UK
17	27/2011	2011/3/6	Collision between container vessel Cosco Hongkong and fish transportation vessel Zhe Ling Yu Yun 135 with loss of 11 lives	UK
18	20/2011	2011/4/9	Collision between container vessel Philipp and scallop dredger Lynn Marie	UK
19	17/2011	2011/2/11	Collision between container vessel Boxford and twin beam trawler Admiral Blake	UK
20	MAB-20-19	2019/3/21	Collision between Containerships Marcliff and APL Guam	US
21	MAB-16-10	2015/2/22	Collision between St. Louis Express & Hammersmith Bridge	US
22	2020tk0011	2019/10/15	Collision between container vessel APL PUSAN and cargo ship Shoutoku Maru	Japan
23	2018tk0004	2018/5/4	Collision between container vessel NYK Venus and container vessel SITC Osaka	Japan
24	2016tk0008	2016/6/7	Collision between Container Ship ESTELLE MAERSK and Container Ship JJ SKY	Japan
25	2016tk0002	2016/2/19	Collision between container ship SINOKOR INCHEON and fishing vessel TOSHIMARU	Japan

Number	ID	Occurrence date	Title	Country
26	2014tk0009	2014/3/18	Collision between Cargo ship BEAGLE III and Container ship PEGASUS PRIME	Japan
27	2013tk0004	2013/2/25	Collision between Container ship, WAN HAI 162, fishing vessel SEINAN MARU No.7 and fishing vessel SEINAN MARU No.8	Japan
28	2013tk0002	2013/1/23	Collision between container ship BAI CHAY BRIDGE and Fishing vessel SEIHOU MARU No. 18	Japan
29	2012tk033	2012/7/3	Collision between Container ship TIAN FU and Chemical tanker SENTAIMARU	Japan
30	2012tk0023	2012/8/15	Collision between Container ship YONG CAI and Fishing vessel SHINYOMARU No.2	Japan
31	2012tk0003	2012/2/7	Collision between Container ship KOTA DUTA and Cargo ship TANYA KARPINSKAYA	Japan
32	2020yh0128	2020/9/4	Collision between container ship PANCON GLORY and fishing vessels Nisshou Maru No.1 and No.12	Japan
33	2020yh0065	2020/6/18	Collision between container ship POS YOKOHAMA and cargo ship Kinei Maru No.22	Japan
34	2020yh0045	2020/4/25	Collision between container ship JEJU ISLAND and cargo ship MADOKAMIYA	Japan
35	2020yh0022	2020/1/10	Collision between container ship Kouryu Maru and fishing vessel Shinei Maru	Japan
36	2019tk0024	2019/10/24	Collision between container ships SITC BANGKOK and RESURGENCE	Japan
37	2019kb0178	2019/10/23	Collision between container ship STAR PLANET and fishing vessel Seisho Maru No.11	Japan
38	2019kb0174	2019/9/26	Collision between container ship ONE BLUE JAY and oil tanker GUNECE	Japan
39	2019hs0132	2019/9/20	Collision between container ship MARVEL and cargo ship ZENITH VEGA	Japan
40	2019kb0104	2019/8/8	Collision between container ship MOL EXPLORER and cargo ship Kyowa Maru No.3	Japan

Number	ID	Occurrence date	Title	Country
41	2019yh0104	2019/8/2	Collision between container ship PACIFIC BEIJING and fishing vessels Shichifuku Maru and Taihei Maru	Japan
42	2019kb0157	2019/7/26	Collision between container ships Akashi and Tamon	Japan
43	2019hs0099	2019/7/12	Collision between container ship MUSE and fishing vessel Nao Maru	Japan
44	2019yh0084	2019/6/28	Collision between container ship GLORY TIANJIN andtug boat Fugaku Maru	Japan
45	2019hs0049	2019/4/20	Collision between container ship TRIUMPH and oil tanker Kaisei Maru	Japan
46	2019yh0023	2019/2/27	Collision between container ships TRIUMPH and HEUNG-A JAKARTA	Japan
47	2019kb0024	2019/2/21	Collision between container ship PACIFIC BEIJING and fishing vessel Nikko Maru No.2	Japan
48	2019yh0017	2019/1/31	Collision between container ship Futaba and cargo ship Seisho Maru	Japan
49	2018yh0105	2018/7/14	Collision between container ship NYK CONSTELLATION and fishing vessel Takuyo Maru	Japan
50	2018yh0060	2018/5/31	Collision between container ship CAPE NABIL and tug boat Tenjo Maru No.8	Japan
51	2018mj002	2018/2/15	Collision between container ship EF ELENA and cargo ship EVER PROSPERITY	Japan
52	2017mj0122	2017/11/24	Collision between container ship CRYSTAL ARROW and pleasure boat Nada Maru	Japan
53	2016kb0135	2016/10/14	Collision between container ship PEGASUS PACER and fishing vessel Wajima Maru No.16	Japan
54	2016hs0097	2016/9/22	Collision between container ship MARVEL and fishing vessel Kasuga Maru	Japan
55	2016hs0038	2016/4/12	Collision between container ship JI HONG and fishing vessel Eishin Maru	Japan

Number	ID	Occurrence date	Title	Country
56	2016kb0015	2016/1/27	Collision between container ship MAGNA and fishing vessel Takaryo Maru	Japan
57	2016mj0016	2015/12/27	Collision between container ship GOLDEN SHOWER ACE and fishing vessel Mitsu Maru	Japan
58	2015kb0123	2015/11/10	Collision between container ships CAPE FORBY and JRS CARINA	Japan
59	2015mj0109	2015/11/3	Collision between container ship UNI-POPULAR and chemical tanker PRETTY HANA	Japan
60	2015mj0071	2015/7/12	Collision between container ship PEGASUS PACER and tug and burge Spineer III(3)	Japan
61	2015kb0048	2015/6/5	Collision between container ship VENUS C and container ship J.PIONEER	Japan
62	2015kb0050	2015/6/5	Collisino between container ship VENUS C and container ships Maya and Koyo	Japan
63	2015hs0060	2015/5/14	Collision between container ship CHATTANOOGA and chemical tanker STO IRIS	Japan
64	2015hs0041	2015/4/1	Collision between cotainer ship Tosei and tug and burge unit Emerald (1)	Japan
65	2015kb0013	2015/1/28	Collision between container ship MAERSK ERVING and working vessel Goryu	Japan
66	2015kb0011	2015/1/14	Collision between container ship WAN HAI 261 and cargo ship Tomisu Maru	Japan
67	2015mj0007	2014/12/27	Collision between container ship MARVEL and fishing vessel Tadahiro Maru	Japan
68	2014mj0121	2014/11/18	Collision between container ship YI SHENG and fishing carrer No. 2010 Bosung	Japan
69	2014mj0105	2014/9/24	Collision between container ship SUNNY MARPLE and fishing vessel Kichi Maru	Japan
70	2014mj0092	2014/8/22	Collision between container ship Shosho Maru and fishing vessel Naho Maru No.1	Japan
71	2014yh0113	2014/8/12	Collision between container ship SINOKOR YOKOHAMA and cargo ship STARLINK HOPE	Japan

Number	ID	Occurrence date	Title	Country
72	2014mj0081	2014/7/24	Collision between container ship BOHAI STAR and fishing vessel Kaiho Maru No.18	Japan
73	2014kb0075	2014/7/3	Collision between container ship VENUS C and container ship J.PIONEER	Japan
74	2014sd0039	2014/6/26	Collision between container ship SINOKOR TOKYO and fishing vessel Fukusyo Maru	Japan
75	2014mj0001	2014/1/6	Collision between container ship HELMUTH RAMBOW and tug boat Shintou 1 and burge Shinei 2	Japan
76	2013mj0171	2013/12/9	Collision between container ships SITC YOKOHAMA and BO HAI	Japan
77	2014kb0020	2013/11/29	Collision between cargo ship ASIAN JOY and container ship Koyo	Japan
78	2013kb0170	2013/11/28	Collision between container ship OSG BEAUTEC and car carrier OCEAN PRIDE	Japan
79	2013yh0164	2013/11/13	Collision between container ship IKARIA and fishing vessel Tsukasa Maru No.26	Japan
80	2013mj0147	2013/11/6	Collision between container ship SITC BUSAN and fishing vessel Koyoshi Maru	Japan
81	2013kb0148	2013/10/2	Collision between container ship SAFMARINE MAKUTU and cargo ship PICES	Japan
82	2013yh0136	2013/9/5	Collision between coantainer ship STX TOKYO and cargo ship Nikko Maru	Japan
83	2013hs0068	2013/4/13	Collision between container ship HAPPY STAR and tug boat Sumiriki Maru No. 22 and burge S-23	Japan
84	2013hs0075	2013/3/6	Collision berween container ship Tenma and cargo ship Swanishi Maru No.3	Japan
85	2013mj0024	2013/3/5	Collision between container ship QIU JIN and fishing vessel Kahou Maru No.3	Japan
86	2012hs0204	2012/9/25	Collision between container ship HAI MEN and cargo ship Sanmanyoshi 5	Japan
87	2012kb0111	2012/8/23	Collision between container ship Hiyodori and bulk carrier Koyo Maru	Japan

Number	ID	Occurrence date	Title	Country
88	2012yh0090	2012/6/20	Collision between container ships WAN HAI 306 and UNI-PROMOTE	Japan
89	2012yh0089	2012/6/19	Collision between container ship SUN ROAD and liquid bulk carrier Koho Maru No.18	Japan
90	2011mj0188	2011/12/18	Collision between container ship X-PRESS ANNUAPURNA and fishing vessel Hakuho Maru No.8	Japan
91	2011yh0212	2011/11/26	Collision between container ship COSCO Y0KOHAMA and fishing vessel Yujin Maru No.7	Japan
92	2011kb0190	2011/11/16	Collision between container ship CHASTINE MAERSK and liquid chemical bulk carrier Kaiyu 21	Japan
93	2011yh0156	2011/8/26	Collision between container ship QIU JIN and work vessel Taiho Maru No.5	Japan
94	2011nh0037	2011/8/11	Collision between container ship MELL SEMAKAU and fishing vessel Kaiho Maru	Japan
95	2011hs0154	2011/6/21	Collision between cargo ship PHOENIX ISLAND II and container ship PROVIDENCE	Japan
96	2011ns0018	2011/3/9	Collision between container ship UNI-POPULAR and fishing vessel Ebisu Maru No.8	Japan
97	2011yh0041	2011/3/2	Collision between container ship CLL NINGBO and cargo ship Kiyotake Maru	Japan
98	2011sd0021	2011/2/1	Collision between container ship KOTA DAHLIA and container ship Olion	Japan