人間工学とルール形成戦略からの自動運航船に関する国際規則と技術革新の同時構築

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Doctoral Dissertation

DEVELOPMENT OF INTERNATIONAL REGULATION AND TECHNOLOGICAL INNOVATION ON MARITIME AUTONOMOUS SURFACE SHIPS FROM ERGONOMIC AND RULE-MAKING STRATEGIC VIEWPOINTS

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Keywords

Competence; Goal-based gap analysis; IMO; Identification system; International legal engineering; International maritime transport; Maritime autonomous surface ship (MASS); Mental workload; Remote control; Remote operator; Ship sense; Situation awareness; STCW; Safety regulation; Taxonomy classification; Technical standards; Technology strategy;

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Chapter 1: Introduction

The creation of “new technologies” by innovation has contributed to building safe and reliable societies, such as safety enhancement and environmental protection. On the other hand, “regulations” have been penetrated in societies as one of the most effective tools to maintain safety and environmental sustainability. These factors have a strong co-relationship. Regulations sometimes restrict technologies and hinder their improvement [1]. Conversely, regulations promote technological innovation for dealing with severer restrictions related to safety, environment and labour[2]. Thus, appropriate collaboration between technological innovation and technical standards (regulations) are indispensable for the sustainable development. In this regard, the question is raised: what is necessary to strengthen the collaboration and enhance the bridge between them. This thesis take MASS as an example.

The recent remarkable innovation in Information and Communication Technology (ICT) has had a large effect on the maritime domain. Shipping companies have introduced a number of automated and communication systems in their commercial vessels to improve cost-effective operation as well as to reduce the crew’s workload and stress. The movement has already come to an ‘autonomous’ and ‘unmanned’ level, which is defined as Maritime Autonomous Surface Ship (MASS) at International Maritime Organization (IMO). Finferries and Rolls-Royce (currently Kongsberg) conducted a demonstration project on the autonomous ship in 2018 [3]. Yara International plans to operate a totally unmanned commercial ship in Norway, although the plan has been suspended [4]. Nippon Foundation started a new demonstration project to promote unmanned commercial ships in 2020 to operate them in 2025 [5]. In addition, NYK successfully demonstrated the manned autonomous system as the first international autonomous shipping project in the world that complies with the International Maritime Organization (IMO)’s interim guidelines for MASS trial [6].

When it comes to international regulations, IMO has carried out Regulatory Scoping Exercise (RSE) to assess the potential gap in existing IMO conventions and codes and ‘analyse and select the most appropriate way of addressing MASS operations [7]' for the MASS. Maritime Safety Committee (MSC) in IMO has played a key role in this activity and agreed to include the agenda for RSE in 2017. MSC has completed the work of RSE at MSC 103 in May, 2021. RSE is the holistic approach and just a starting point for detailed development in the future. Industrial guidelines have been also developed. Some examples are the guidelines by DNVGL [8] and Maritime UK [9].

One of the most critical points when considering the requirements is the human-centred and ergonomic approach. The existence of ship crews cannot be ignored taking into account that the future where all operating vessels are totally unmanned has not come in decades. MASS would be operated in the sea with a lot of non-MASS and be navigated by crews or remote operators. In addition, the developed technologies for the MASS are not meaningful if they would not be smoothly practiced in the market by regulatory restriction. The balance between safety and technological innovation is indispensable. Moreover, the regulations regarding the new technologies lead to the industrial competitiveness. In this sense, a strategic approach for the development of the regulations is sought from smooth implementation and competitive viewpoints.

Based on the above background, this research aims to Construct the basic scheme underlying development of international safety regulations and technological innovation on MASS from ergonomic and rule-making strategic viewpoints. In order to achieve the aim, this research focuses on three facets that have not been studied in the past research; (1) Involvement of the ergonomic viewpoint (i.e., situation awareness and mental workload) into the IMO regulation, and (2) Identification of strategic process on the development of international safety requirements. Regarding (1), this research further focuses on situation awareness regarding the competence requirements of navigators in the STCW Convention((1)-1), and identification of factors that would affect mental workload and lead to a possible revision of current IMO instruments ((1)-2). In addition, with regard to (2), this research focuses on the stage of submission of new work programme in the IMO and tries generalization in order to enable to utilise the results into other domains. (See Fig. 1).

The remaining chapters are organised as follows: Chapter 2 discusses the possible development of the STCW Convention based on the constructed unique model according to situation awareness. Chapter 3 consults mental workload of MASS navigators based on another proposed scheme. Chapter 4 discusses the trend of new work programmes at MSC in IMO and apply that to MASS. Chapter 5 concludes the whole discussions.

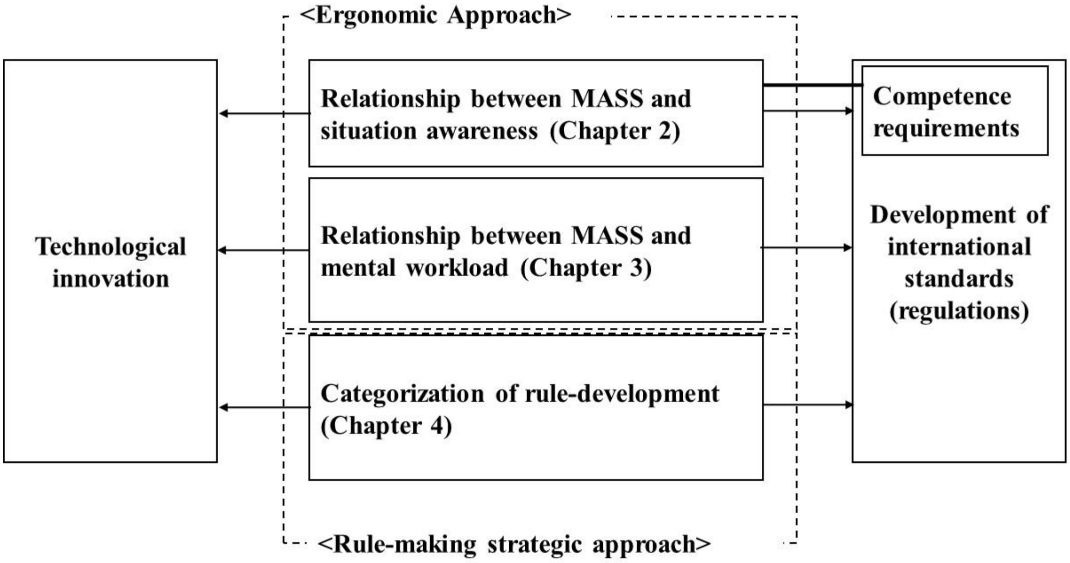


Figure 1-1. Image of the research in the thesis

Chapter 2: Relationship between MASS and Situation awareness

2.1 INTRODUCTION

As described in Chapter 1, Maritime Autonomous Surface Ship (MASS) have been rapidly developed over the world. Since the autonomous level of MASS is wide, many parties and organisations categorise them in their ways, such as Lloyds Register [10], Maritime UK [9] and IMO [7]. Although they set the fully autonomous situation, which decides a ship's action independently without supervision by a human, this extreme situation will not happen shortly considering the safety and security. Most MASS system will keep operators as a back-up function onboard ships as well as at another centre on land [11]. The operator takes the final role to maintain safety in case of the failure of the MASS system [12]. In this sense, the Remote Control Centre (RCC) will play a key role in the MASS system.

Remote Operator (RO) is the core of the RCC. Although the role of RO is different according to the autonomous stage of MASS, the main task is to monitor and supervise the MASS operation and make a final decision of her action. In some cases, RO should immediately take over the operation control from the onboard autonomy computer system to correct its failure. The safety of unmanned remote control ships highly depends on the qualification of RO [13]. In fact, RO's competence and training are one of the most important elements to avoid accidents pertinent to human errors. Acquiring the competence on the appropriate watch for navigation is especially inevitable. It can be probed considering that the main common factors in collisions are 'bad decision-making and poor lookout during the duty on a watch [14]. ROs face the risk of making human error since they make the wrong recognition of the situation [11].

A regulatory flame is important not only to improve MASS but also to secure safety. A wide range of issues has been raised in previous research and discussion. Since the definitions of ship or vessel' are different among conventions, Allen [15] suggests that Convention's and Treaty's interpretation rules should be thought about whether MASS is qualified as a vessel. All maritime-related international regulations in the IMO, such as the International Regulations for Preventing Collisions at Sea 1972 (COLREG) and the International Convention for the Safety of Life at Sea (SOLAS), have supposed that the master and crew are onboard. Zhou et al. [16] highlight that the ‘proper lookout’ rule of COLREG should be amended to allow only the computer to have a vision alone. IMO also started Regulatory Scoping Exercise (RSE) to assess the potential gap in existing IMO conventions and codes and ‘analyse and select the most appropriate way of addressing MASS operations [7]’. When it comes to RO, seafarers’ requirements on competence for navigation are regulated in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). However, the STCW Convention has regulatory problems to be applied to MASS and RO, just like the other regulatory instruments. Article 3 of the Convention states that it applies to ‘seafarers serving onboard seagoing ships’. There is currently no clear understanding in the STCW Convention about whether RO is regarded as a master or a crew onboard. This situation would make it difficult for each state to implement requirements in Article 94 of the UNCLOS from the point of training the shore-based ‘crew’ [17]. Although IMO has carried out the consultation on the regulatory framework described above, the detailed discussion on RO’s competence has not been internationally commenced.

Given the above background, this paper aims to show the direction to establish the appropriate regulatory requirements on competence for shore-based RO, focusing on watchkeeping based on provisions of the STCW Convention, taking characteristics and conditions of remote operation into account. The following two research questions are analysed to achieve the objectives:

RQ1: What difficulties does RO have during operation for watchkeeping at RCC?

RQ2: What competence should be included (or removed) for the requirements of RO taking regulations in the STCW Convention into account?

The remaining parts are organised as follows: Section 2 identifies the human behaviour model on the bridge based on situation awareness and ship sense. Utilising the model, Section 3 proposes a model to identify the competence of RO for watchkeeping on MASS. Then this paper demonstrates the model by a case study in Section 4 and 5, which utilises the data of projects on the remote control by Tokyo

University of Marine Science and Technology, including a demonstration project. Section 6 discusses the results, and Section 7 concludes the paper.

2.2 HUMAN BEHAVIOUR MODEL ON THE BRIDGE

Cognitive skill is essential for completing the task by operators for safety navigation [12]. Endsley [18] compares the cognitive procedure for a human to take action with other articles to measure the impact of the autonomy interface. Although there are some differences in taxonomy between them, he states that the process is categorised in ‘situation awareness’, ‘decision-making’ and ‘action’. Smidts et al. [19] identify the model on the behaviour for the staff of new clear power plants as ‘IDA (Information diagnosis, Decision and Action)’. IDA model is utilised to express the human-autonomous interaction in an autonomous ship such as Ramos et al. [20]. However, this model is similar to Endsley’s categorisation [18]. This research adopts the categorisation of Endsley [18] and extends the model. The extended model is the loop of environment inside/outside the bridge, information resources, required information for SA and SA, decision-making and action. The information required for SA of OOWs is extracted from the environment inside (e.g., pitching of a ship) and outside a ship (e.g., weather, sea condition, target ship) through two information resources, bridge navigation items (e.g., gyro compass and ECDIS) and ship sense (e.g., visibility and sound) (see Figure 2- 1). OOWs are aware of the situation based on the required information and make decisions (e.g., Steering a ship with manoeuvring order). Action taken by OOWs’ or ROs’ decision-making is feedbacked and reflected in the environment at the next moment. The next sections explain each element of Figure 2-1.

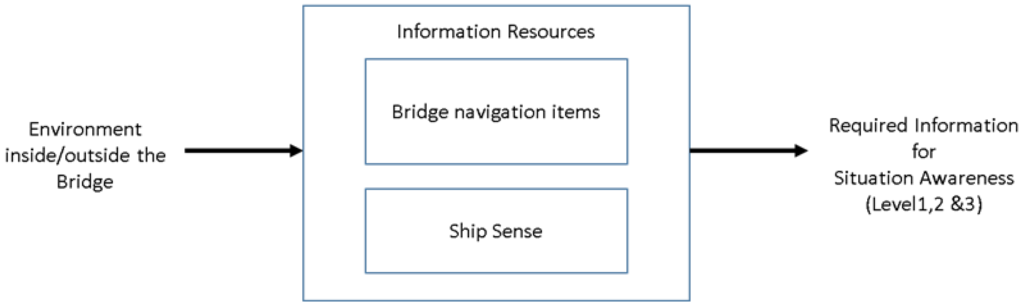


Figure 2-1. Flow from environment inside/outside bridge to required information.

2.2.1 Situation Awareness and Required Information

Endsley [21] suggests that situation awareness (SA) plays an essential role in making a decision for safety. He defines SA as ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future’. This definition has been often used in past research in many areas, including the maritime domain, with three levels of SA: perception (Level 1), comprehension (Level 2) and projection (Level 3). Chauvin et al. [22] analyse young trainees’ decision-making processes to avoid collisions at sea by using three SA categories and showed the difference from the veteran crew. Chauvin et al. [23] also enumerate information that to be gathered from Automatic Radar Plotting Aid (ARPA) for collision avoidance when ships are crossing according to the three AS levels (e.g., speed, course, distance for Level 1 SA, overtaking situation, ship type of target for Level 2 SA and bow or rear crossing range for Level 2 SA). Sharma et al. [24] list detailed information (around 80 items) required for navigators on each Level SA during pilotage between the pilot port and berth (e.g., ship status, equipment status, route plan for Level 1SA, a deviation between the current position and planned position for Level 2SA, the projected position of own ship and projected visibility for Level 3 SA). Porathe et al. [25] pick up 165 items of information for RO and categorise them into nine groups, such as voyage, sailing and observations.

2.2.2 Information Resources

The integration of two information resources provides the required information for SA. The first one is the objective knowledge from the items equipped on the navigation bridge. The required items are different depending on ship type, ship size, navigation area, etc. International Chamber of Shipping (ICS) [26] shows the list of bridge equipment for masters and Officers on Watch (OOWs) of commercial ships to be familiar with.

Another vital resource is ship sense. Ship sense is defined by Prison [27] as perceived knowledge of bridge navigator for safe manoeuvring. This knowledge is gained by using the navigator’s sense, such as the feeling of ship movement (e.g., heaving), visibility from the outside environment and hearing other than the information from bridge equipment [25]. Ship sense is essential for considering ‘whether the absence of ship sense in the shore control centre will inhibit the ability to acquire SA to assist the vessel in achieving harmony with the environmental factors acting on the ship [28]'.

2.3 COMPETENCE IDENTIFICATION MODEL FOR RO

Information resources (ship sense, and bridge navigation items), required information and SA, which are defined in the last Section, are the key tools to identify the competence for ROs from cognition's viewpoint. This research constructs the identification model that combines goal-based analysis and gap analysis.

2.3.1 Goal-Based Analysis

The goal-based approach has played a significant role for long years in the evaluation [29], and can be utilised in various methods, including goal-based analysis. Many terminologies and analysis methods are applied depending on the objectives of projects. Sharma et al. [24] adopt 'goal-directed task analysis (GDTA)' methodology, which is introduced by Endsley [30] to decide situation awareness requirement information from the goals.

2.3.2 Gap Analysis

Gap analysis is a useful tool to analyse the gap in the skill of trainees. People can recognise what skill they should develop to make their careers better [31]. This method also identifies what competence persons have a shortage of depending on their job level, such as first-level manager and higher-ranked one [32]. This means that the gap can be recognised in each different level of the situation. Conversely, the difference in perception of persons in the same performance and environment can also be assessed through the gap analysis [33].

2.3.3 Goal-Based Gap Analysis (GBGA)

Goal-based gap analysis (GBGA), constructed in the present research, integrates the goal-based method and gap analysis (see Figure 2-2).

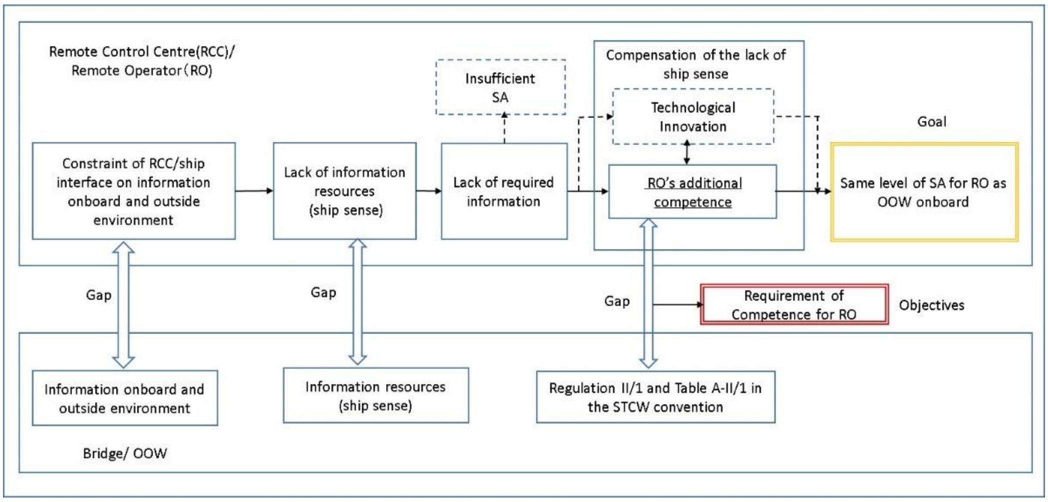


Figure 2-2. Scheme of goal-based gap analysis.

The first step of GBGA is to set a goal that is clear and easy to understand. Theoretically, a high level of autonomous ships might enable to decrease the workload of RO since the autonomous system, such as autopilot, can replace some of the navigation tasks. If the automation system has some decision-making ability on its own with higher and sufficient reliability in the future, RO can trust the system and decide with low SA [18]. Nevertheless, it is expected that RO will be sought to retain the high level of SA for deciding with confidence, e.g., in case of sudden overtakes of the task from the autonomous system. In fact, Sætrevik and Hystad [34] suggest that navigators who retain better quality SA tend to decrease the chance to face accidents because they are aware of and control the critical condition more comfortably. Their study also points out that the poor SA is 'a sharp end causal factor' for human error. Ahvenjärvi [35] stresses that SA should be maintained during remote control. DNVGL further suggests that RO should retain the same or better level of SA despite the lack of 'human sense' [8]. Taking these into account, it is appropriate to set the goal as to 'keep the same quality of SA for RO as OOW onboard a ship.

The second step is to identify the goal constraint, which is almost the same as the goal obstacle, which Anton [36] defines as 'behaviours or other goals that prevent or block the achievement of a given goal'. The beginning of goal constraint in Figure 2- 2 is the restriction on the interface of the information between RCC and the environment inside/outside the bridge of a ship because of, for example, the limit of data communication capacity. This restriction leads to the lack of information resources, especially ship sense, i.e., RO will have limited ship sense [37]. The lack of information resources connects the lack of required information for each SA. High level of lack emerges as the difficulty of ROs for being engaged in the navigational watch (RQ1 in Section 1) arises.

Once the goal constraints are identified, the next step is to set measures to overcome the limitation and keep the provided goal. There are mainly two ways to deal with the issue: technological innovation and the addition of RO’s competence. Since the present research focuses on the competence of RO, it adopts the acquisition of additional competence as a solution to supplement the lack of ship sense.

Finally, regulatory requirements on competence for RO will be identified by utilising the provisions of the STCW Convention. These additional competence and regulatory requirements, especially regulatory requirements, are the answers of RQ2 in Section 1.

Through all stages, gap analysis is used. Maritime UK [9] recommends HAZard and OPerability studies (HAZOP) to develop training materials for MASS operators, including ROs. The gap analysis of workshop-type is used to compare the current training level with further training requirements. Mindykowski [38] utilises related accidents that happened in the past to analyse the relationship between the cause of the accidents and the lack of competence on a power plant in a ship. Sharma et al. [39] use a questionnaire survey to OOW of commercial vessels. The method by Rosenberg et al. [40] is to measure the gaps in paediatric practice training through a focus group discussion. Although there are various methods for gap analysis, one of the key points is to involve experienced experts who have enough knowledge, in this case, on competence-based assessment and training described in the STCW Convention as participants of the discussion.

2.3.4 Competence-Based Assessment and Training in the STCW Convention

International requirements on qualification and training of seafarers are regulated in the STCW Convention. The STCW Convention was first adopted in 1978 and entered into force in 1984 (STCW78). STCW78 described the minimum knowledge required for certificating officers and ratings but did not include detailed criteria. After some tremendous shipping accidents, IMO started reviewing the Convention [41]. Finally, the amended Convention was adopted in 1995 and entered into force in 1997 (STCW95). The revised one primarily modified the requirements, especially about minimum knowledge. It introduced a competence-based assessment and training scheme, which is also named ‘outcome-based’, ‘performance-based’ and ‘criterion-referenced/validated’ [41]. The minimum required knowledge regulated in STCW78 was detailed and updated under the Knowledge, Understanding and Proficiency (KUP) column. Moreover, two columns, Methods for Demonstrating Competence and Criteria for Evaluating Competence, are newly added in STCW95. Then IMO has further amended and added some parts in the latest STCW Convention (STCW2010).

One of the most important points on the introduction of competence-based training (CBT) in STCW95 is that candidates’ training became ‘outcome-based’. They should ‘demonstrate their ability’ to achieve the tasks that are required for the certification [41]. In other words, seafarers certified according to CBT are proved to take appropriate actions that are sought in their responsibilities onboard ship. Another point is that, in CBT system, training should be designed based on ‘measurable standards of performance’, assessment should be placed as an ‘essential part’ and the training and assessment should be carried out with high level of quality assessment [42]. That means that CBT allows some flexibility on the design of the training course by maritime education institutes under explicit competence, and requires the quality assessment of the training scheme as an indispensable matter.

Although there are some critics in the current competence requirements of STCW2010 that they have many concerns, including unclear and vague assessment criteria in the competence table [43], this system has recognised as a standard competence assessment and training tool in the world. Baldauf et al. [44] suggest that current provision of regulations in the STCW Convention could be the starting point for discussing minimum training standards for autonomous systems. In fact, RSE in the IMO [7] utilises the STCW Convention when considering the competence of RO and crews. Sharma et al. [24] also review the competence for OOW in MASS by utilising Table A-II/1 in the STCW Convention.

CBT in the STCW Convention requires the experience of seagoing service or onboard training for acquiring competence to be OOWs, chief mates and masters. For example, a cadet to be OOW on a seagoing ship of 500GT or more shall receive an approved onboard training program of not less than 12 months or an approved seagoing service of not less than 36 months.

2.4 METHOD OF CASE STUDY

A case study was carried out to verify GBGA in section 3.3 and recognise the trend on competence requirements for RO about a typical scenario. The remaining sections explain each process.

2.4.1 Goal-Setting

Based on GBGA in section 3.3, the following six goals were provided for the case study. Goal 3 (G3) and Goal 4 (G4) are related to the answer of RQ1, and Goal 5 (G5) and Goal 6 (G6), especially G6, are related to the answer of RQ2.

- Goal 1 (G1): Lists the bridge navigation items necessary for acquiring the required information for Level 1 SA.
- Goal 2 (G2): Lists ship sense that is necessary for acquiring required information for SA
- Goal 3 (G3): Rates the lack of ship sense by limiting data communication for visibility of the screen and sound at RCC.
- Goal 4 (G4): Rates the lack of required information for each SA.
- Goal 5 (G5): Lists the items on possible additional competence to compensate for the lack of ship sense.
- Goal 6 (G6): Lists the items of competence requirements that should be added or removed from Regulation II-1 and Table A-II/1 in the STCW Convention.

2.4.2 Assumption-Setting

The following assumptions were provided for the study.

Size of Ship

The level of information required for SA is different depending on the ship size. For example, a small boat does not need long-range visibility than a sizeable oceangoing ship such as a container ship and an oil tanker. This study set the ship size of around 3000 gross tonnages (GT) since this size is the largest in the thresholds that the STCW Convention defines to qualify OOWs, masters and first mates.

2.3.2.2 Navigation Area, Bridge Manning and Autonomy Level

The STCW Convention requires proper arrangement for watchkeeping personnel following the situation considering the limitation of individuals' qualifications or fitness (A-VIII/2 Part3). Based on that, the bridge manning level is provided in the Safety Management System (SMS) developed by the shipping company individually in accordance with Chapter IX of the SOLAS Convention and the ISM Code. The level decides the arrangement for watchkeeping, depending on, for instance, the navigational condition and navigation area. The style and contents have not been unified and standardised; some companies use three categorised colours, red, yellow and green. Other companies use four categorised number style [45]. As an international guide, ICS [26] shows an example of a bridge manning matrix. The matrix categorises the manning level by three factors, navigation area (port(entering and leaving), restricted water, coastal water, ocean water and anchorage), visibility (clear and restricted) and daylight (daylight, darkness and night). This study utilised ICS's manning matrix and excluded the port area (entering and leaving) and restricted water since these areas require complicated navigation, including frequent communication with vessel traffic service (VTS) centre and other vessels and pilots. It finally chose a coastal area with clear visibility and daytime based on the project's information described in section 4.2. According to the matrix, the manning of this case study is the team of OOW (i.e., RO) and Lookout. Both of them were assumed to be on duty at RCC to simplify the situation.

Emergencies such as search and rescue (S&R), a fire onboard and a cyberattack were excluded from this study to avoid complex factors of watchkeeping.

It was also assumed that this case study's autonomy level was the same as the current common ships to minimise the variables to be considered. That means that RO navigates the ship with no autonomy at RCC.

Constraint of Information Transmission between RCC and Bridge

The following two projects were referenced to set assumptions regarding the constraint of information transmission. Regarding visibility, this case study utilised the information on the remote control system that has been installed between the training ship (425GT) of Tokyo University of Marine Science and Technology and RCC, and on a demonstration project that was carried out using the same ship in 2019. For the condition of audio information, another project carried out in the Japanese coastal area was referred to [46]. The outline of the visual condition on the screen at RCC and sound condition that RO can hear at RCC are shown in Table 2-1. It was assumed that the data of electronic navigation equipment on the bridge were simultaneously transmitted to the same type of equipment at RCC and indicated the information without any delay and trouble.

Table 2-1. Visual condition on the screen at Remote Control Centre (RCC) and sound condition that Remote Operator (RO) can hear at RCC.

Factor	Condition
Viewing angle of screen	360°
Screen resolution	1500 × 300 (pixel)
Visual Intermittency of screen	5~10 s/h (Completely recover in 30 s)
Visibility of screen	Clear (Clear weather)
Delay of video on the screen between Bridge and RCC	< 0.1 sec
Range of identifiable objects on the screen	✓A small boat one (1) nautical mile ahead ✓A large vessel (length of 150 m) four (4) nautical miles ahead
Data communication system	3G system and LTE system
Audio quality at RCC on sound at Bridge	Clear
Audio delay between Bridge and RCC	< 0.8 sec

Competence Table and Officer's Level

As described in section 3.4, the STCW Convention includes mandatory competence tables that OOWs should satisfy. The tables are divided depending on crew's qualifications; OOWs onboard a ship more than 500GT (Table A-II/1), chief mates and masters onboard a ship of 500GT and more and ones onboard a ship of 3,000GT and more (Table A-II/2). This study utilised the table for OOW (Table A-II/1), taking into account that it focused on watchkeeping except for ports and restricted water without emergency conditions. This study also defined the level of OOW and RO as 'a novice (inexperienced) officer who is qualified as an STCW II/1 officer and can have a duty for watchkeeping of a ship described in section 4.2 (e.g., officers who have graduated Maritime Education and Training Institute within two years)'.

2.4.3 Methodology

The present study adopted the qualitative method, in detail, the focus group discussion for securing the validity of listing and rating through the discussion [47]. The 'Mini focus group' discussion, which is formed in case of a small potential number of participants [48] between 2 and 5 [49] with outstanding expertise, was made to achieve each goal in section 4.1 considering a few numbers of experts. The interview by the written Q & A and one-to-one oral interview was also done before the discussion for preparing the material for the group discussion. The mini focus group unanimously agreed on the rating and listed items as results of the case study at the final stage. Different listed items and rating by the experts in the interview were open to the group and 'resolved through the mutual discussion' by the experts, which was a process similar to the past study [50]. Comments in the interviews were recorded, and all summarised comments and answer sheets were provided at the group discussion for all experts. Comments during the discussion were also recorded. The comments at the interview and the group discussion were utilised for analysing the background of the results and limitation of the study.

2.4.4 Participants of Case Study

Taking into account the complexity of the case study that combines the consideration of the possible international regulation changes as well as ship sense and SA in MASS, experts were chosen according to the following five criteria to acquire sufficient results:

- Experts who have experience of being involved in the consultation on regulations of the STCW Convention, such as the international discussion including IMO's meeting (e.g., Sub-Committee on Human Element, Training and Watchkeeping (HTW)), since they should have profound knowledge including background and recent development on the IMO's regulations;
- Veteran trainers who have profound experience in a management position for onboard training in the training ships to teach cadets since they should objectively know various novice OOWs' general characteristics and level;
- Non-retired seafarers on active duty since their experience and knowledge should not be outdated;

- Experts who have knowledge of autonomous technologies since they should easily recognise the discussion on MASS;
- Qualified masters over 3000 GT in the STCW Convention (Regulation II/2) since they should have profound knowledge of navigation.

As a result, a total of three (3) experts who meet the above criteria participated in the case study. All of them have taught cadets for 15–22 years onboard various training ships, including more than 6000 GT, in Maritime Education and Training Institution (METI). They also have experience of being involved in the consultation process for developing the STCW Convention, including RSE of MASS at Maritime Safety Committee (MSC).

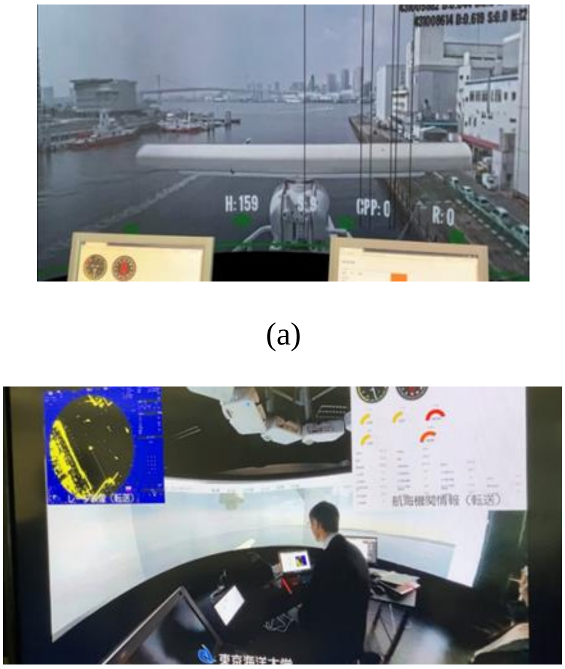
2.4.5 Process of Mini Focus Group Discussion and Interview

At first, the experts received the explanation on this case study, including its objective, human behaviour model and GBGA model, goal, methodology, assumption and questions, using online meeting schemes (e.g., Microsoft Teams and Zoom) or face-to-face.

Second, the experts visited the RCC in Tokyo University of Marine Science and Technology, and recognised the level of visibility of the screen for remote control by watching the actual screen that is connected with the bridge of the berthed training ship, and the recorded video of the demonstration project (see Figure 2- 3).

Third, the questionnaires (see Table 2-2 about questions to experts) based on the goal in section 4.1 were sent to the experts. After receiving the answer sheets, the interview was conducted face-to-face or using an online meeting scheme to mainly ask the background of the answers.

Fourth, the mini focus group discussion was carried out twice by using an online meeting scheme. As described in section 4.3, the answer sheets and the summarised comment papers were prepared for the discussion. The results of Q1 to Q5 were agreed upon in general after the discussion in the first round. Q6 to Q7 were also discussed. In the second round, the results of Q1 to Q5 were confirmed and agreed on. Then the group discussed Q6 to Q7 and agreed on the results. All results were confirmed by the corresponding base. All agreements were unanimous and based on consensus by all experts.



(a)

(b)

Figure 2-3. (a) Screen at RCC (scenery from berthed training ship); (b) RCC at the demonstration project.

Table 2-2. Questions to experts.

Question 1 (Q1)	✓What are bridge navigation items related to ship sense and required information for SA under the assumed condition in section 4.2? *(*) Participants were shown the draft list that the seafarer, who meets the five criteria in section 4.4 but did not participate in the interview and discussion due to his voyage, prepared based on ICS's Bridge Resource Procedure* [26], *then answered additional items.*
Question 2 (Q2) (related to G1 in section 4.1)	✓What bridge navigation items are necessary for acquiring the required information for Level 1 SA? Please answer the items that you actively use for acquiring each required information for perception (Level 1 SA) at that moment under the assumed condition in section 4.2. *(*) Participants were shown the draft list that the seafarer same as Q1 prepared, then answered additional items with their causes.*
Question 3 (Q3) (related to G2 in section 4.1)	✓What kinds of ship sense are necessary for acquiring required information for each SA? Please answer the ship sense that you actively use for acquiring each required information at that moment under the assumed condition in section 4.2.
Question 4 (Q4) (related to G3 in section 4.1)	✓To what extent does ship sense of RO have a shortage compared with OOW onboard a ship in case that there are constraints on the transmission of information between the bridge and RCC that are shown in section 4.2.3 (i.e., visual information on screen and sound inside/outside the bridge (e.g., alarm from other ship) are restricted.)? If possible, please rate the extent as your preferred way.
Question 5 (Q5) (related to G4 in section 4.1)	✓To what extent does the lack of ship sense affect the required information for each SA of RO? If possible, please rate the extent as your preferred way.

Question 6 (Q6) (related to G5 in section 4.1)	✓What is the additional competence necessary for RO to compensate the lack of ship sense and keep the quality of SA?
Question 7 (Q7) (related to G6 in section 4.1)	✓How should Regulation II/1 and Table A-II/1 in the STCW Convention be modified based on the additional competence in Q6?

2.5 RESULTS

The results of the case study are shown in the following sections.

2.5.1 Bridge Navigation Items Related to Required Information for SA (Q1 in Table 2-2)

Table 2-3 shows the results of the case study on the bridge navigation items that OOWs use for acquiring SA under the condition described in section 4.2. This table was simultaneously discussed with the matter in section 5.2 in the mini focus group. Since there was no additional comment on the provided draft during the interview, the experts confirmed the list two times in the group, before discussing G2 (section 5.3) and at the final stage of the study, and finally agreed on it.

Table 2-3. Bridge navigation items.

1	GPS	11	Engine Revolution Counter
2	ECDIS	12	Rudder angle Indicator
3	ARPA/Radar	13	Anemometer
4	Gyro Compass	14	Alarm of BNWAS
5	EM Log	15	Clinometer
6	AIS	16	Chart
7	Doppler Sonar	17	Magnetic Compass
8	VHF	18	Meteorological recording device
9	Echosounder	19	Passage Plan
10	NAVTEX		

2.5.2 Linkage Between Bridge Navigation Items and Required Information for Level 1 SA (G1 in Section 2.4.1. and Q2 in Table 2-2)

The required information utilised in this case study is partly rearranged from the study by Sharma et al. [24]. Based on the results of the interview, the experts discussed in the mini focus group how the bridge navigation items in Table 2-3 are utilised for acquiring each required information for Level 1 SA, provided the linkage sheet, and agreed on it . Table 2-4 sums up the results. The items were limited to the ones that

OOWs actively use for acquiring the required information for Level 1 SA (perception) ‘at this moment’ under the assumed condition in section 4.2. because the results would diverge depending on the time duration for perception and situation. ECDIS supplies a wide range of information resources (e.g., position, speed, target location). AIS information displayed in ECDIS and ARPA is also utilised to acquire many items of required information . On the other hand, there are a few types of bridge navigation items that supply specific information resources. For instance, a magnetic compass gives only magnetic compass course information. Some information resources consist of a combination of information from multiple pieces of items. For example, the information resource to precipitate the location of navigation hazards is gathered from seven items (ECDIS, ARPA, Gyro Compass, AIS/Radar, VHF, NAVTEX and Chart).

Table 2-5 extracts the required information to which two or more bridge navigation items are related from the agreed linkage sheet. This suggests that OOWs acquire required information in multiple ways utilising various bridge navigation items.

Table 2-4. Linkage between required information for Level 1SA and information resources (bridge navigation items).

No	**Required Information**	**Bridge navigation items (No. in Table 2- 3)**	**No**	**Required Information**	**Bridge navigation items (No. in Table 2- 3)**
1	Ship’s position	1, 2, 3, 4, 16	23	Speed of tidal current	1, 2, 5, 7
2	Speed through the water	2, 3,5, 7,11	24	Direction of tidal current	1, 2, 4, 7
3	Speed over the ground	1, 2,3, 7, 16	25	Direction of wave (wind, swell)	4, 18
4	Gyro compass course	2,3, 4	26	Height of wave (wind, swell)	18
5	Magnetic compass course	17	27	Target location	2, 3, 4, 6
6	Heel	15	28	Target speed	2, 3, 6
7	Rudder angle	12	29	Target distance	2, 3, 6
8	Rate of turn	4	30	Target course	2, 3, 6
9	Pitching	–	31	Target bearing	2, 3, 4, 6
10	Yawing	4	32	Number of targets	2, 3, 6
11	Rolling	–	33	TSS to be followed	2, 4, 8, 16
12	Swaying	–	34	VTS communication frequency	2, 8, 16,19
13	Surging	–	35	VTS standing instructions	8
14	Under keel clearance	2, 9, 16	36	Location of navigation hazards	2, 3, 4, 6, 8, 10, 16
15	Visibility	–	37	Anchorage areas	2, 3, 4, 8, 16

16	Temperature	18	38	Location of wreck, shoals, underwater rocks	2, 3, 4, 10, 16
17	Sea Temperature	18	39	Density of traffic	2, 3, 6
18	Moisture	18	40	Planned route	2, 16, 19
19	Amount of cloud	–	41	Distance to waypoints	2, 3, 4, 16
20	Sky condition	–	42	Planed speed for each leg	2, 16,19
21	Speed of wind (relative and absolute)	13	43	Air draft	2, 16, 19
22	Direction of wind (relative and absolute)	4, 13			

Table 2-5. Detailed explanation on the relationship between required information for Level 1 SA and information resources (bridge navigation items) (in case that two or more items are related).

No	Required Information	Relationship with Bridge Navigation Items
1	Ship's position	See the information obtained from GPS (1) as well as on the screen of ECDIS (2) and ARPA/Radar (3). Confirm the position through the distance between the parallel index and some objects (e.g., cape) by ARPA/Radar (3). Confirm the position obtained by comparing the ship bearing information using Gyro compass (4) with the information of location written in the Chart (16). Confirm the position by Chart (16) and ECDIS (2).
2	Speed through the water	See the information obtained by EMLog (5) and Doppler Sonar (7), respectively. Also see the information on the display of ECDIS (2) and ARPA/Radar (3). Confirm the speed approximately by Engine revolution counter (11) as well.
3	Speed over the ground	See the information obtained by GPS (1) as well as on the screen ECDIS (2) and ARPA/Radar (3). See the information obtained by Doppler Sonar (7). Confirm the speed by periodical position fixing by Chart (16).
4	Gyro compass course	See the information obtained by Gyro compass (4), ECDIS (2) and ARPA/Radar (3), respectively.
14	Under keel clearance	See the information obtained by Echosounder (9). Confirm the under keel clearance by comparing the water depth information from ECDIS (2) and Chart (16) with maximum water draft.
22	Direction of wind (relative and absolute)	See the information obtained by Anemometer (13). Confirm the direction by comparing the ship bearing information obtained by Gyro compass (4) with the relative wind direction by checking wave rippling.
23	Speed of tidal current	See the information obtained by Doppler Sonar (7). Compare the information of the speed through the water obtained by EMLog (5) with one through the ground from GPS (1) with ECDIS (2).
24	Direction of tidal current	See the information obtained by Doppler Sonar (7). Compare the ship bearing information obtained by Gyro compass (4) with geographical ship direction information obtained by GPS (1) with ECDIS (2). Compare the ship bearing information

		obtained by Gyro compass (4) with the information on the current direction obtained by the flow of form and marine waste.
25	Direction of wave (wind, swell)	See the information obtained by Meteorological recording device (18). Confirm the direction by comparing the ship bearing information obtained by Gyro compass (4) with the information on the relative wave direction obtained by wave rippling.
27	Target location	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3). Confirm the direction of the target from the ship bearing information obtained by Gyro compass (4).
28	Target speed	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3).
29	Target distance	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3).
30	Target course	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3).
31	Target bearing	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3). Confirm the target bearing by checking the ship bearing information obtained by Gyro compass (4).
32	Number of targets	See the information obtained by ARPA/Radar (3). Identify the target ships by AIS (6) on the screens of ECDIS (2), and ARPA/Radar (3).
33	TSS to be followed	Confirm the information obtained by ECDIS (2) and Chart (16), respectively. Confirm the announcement from VTS stations by using VHF (8). Confirm the distance to the point based on the ship's position obtained by comparing the ship bearing information using Gyro compass (4) with the information of location written in the Chart (16).
34	VTS communication frequency	Confirm the information by ECDIS (2) and Chart (16), respectively. Confirm the information by Passage Plan (19) obtained from Sailing Directions. Confirm the announcement from VTS stations by using VHF (8).
36	Location of navigation hazards	See the information obtained by ECDIS (2) and Chart (16), respectively. Confirm the distance from the ship based on the ship's position obtained by comparing the ship bearing information using by Gyro compass (4) with the information of location written in the Chart (16). Identify the hazards (e.g., virtual buoy) by AIS (6) on the screen of ECDIS (2) and ARPA/Radar (3). Confirm the information by the announcement of VHF (8) and NAVTEX (10).
37	Anchorage areas (Areas shown in the Chart and instructed by a	See the area information from ECDIS (2), Chart (16), respectively. Confirm other ships' information from ARPA/Radar (3). Confirm the distance from the ship based on the ship's position obtained by comparing the ship bearing information using by Gyro compass (4) with the information of

	local port authority)	location written in the Chart (16). Confirm the information by the announcement of VHF (8) from the port authority, etc.
38	Location of wreck, shoals, underwater rocks	See the area information obtained by ECDIS (2) and ARPA/Radar (3), respectively. Confirm the distance from the ship based on the ship's position obtained by comparing the ship bearing information using by Gyro compass (4) with the information of location written in the Chart (16). Confirm the current situation (e.g., water depth and wreck) by NAVTEX (10) information.
39	Density of traffic	See the information obtained by ECDIS (2) and ARPA/Radar (3), respectively. Identify the ships by AIS (6).
40	Planned route	Confirm the current planned route by checking ECDIS (2) and Chart (16), respectively. Compare the current planned route in the Passage plan (19).
41	Distance to waypoints	Confirm the information obtained by ECDIS (2) and Chart (16), respectively. Confirm the waypoints by using Electronic Bearing Line (EBL) and Variable Range Marker (VRM) of ARPA/Radar (3). Confirm the distance from the ship based on the ship's position obtained by comparing the ship bearing information using by Gyro compass (4) with the information of location written in the Chart (16).
42	Planned speed for each leg	Confirm the planned speed by checking ECDIS (2) and Chart (16) compared with Passage plan (19).
43	Air draft	See the height from the surface by ECDIS (2) and Chart (16), respectively. Confirm the information on the air draft in the Passage Plan (19).

(*) The functions of ARPA/Radar are assumed to the ones required in Resolution MSC.192(79).

2.5.3 Linkage Between Required Information for Level 1 SA and Ship Sense (G2 in Section 4.1. and Q3 in Table 2-2)

Table 2-6 shows the relationship between the required information for Level 1 SA and the ship sense. The experts discussed in the mini focus group whether the ship sense listed by each expert in the interview was reasonable and there was additional ship sense, and agreed on all items. All information required for Level 1 SA is linked to ship sense except VTS-related information; i.e., OOW needs ship sense to some extent to acquire almost required information for Level 1 SA. The necessity of ship sense decreases dramatically in Level 2 and Level 3 SA to nothing. They suggested that the information needed for these levels is made of Level 1 SA.

Table 2-6. Linkage between required information for Level 1 SA and ship sense.

Required Information (Level 1SA)		**Ship Sense (Visibility)**		**Ship Sense (Others)**
1	Ship's position	✓	* Landmark (e.g., lighthouse, chimney, summit of mountain) * Sight outside the bridge	

2	Speed through the water	✓	* Sight outside the bridge		
3	Speed over the ground	✓	* Motion of scenery * Movement of form and floating objects on a sea surface		
4	Gyro compass course	✓	* Landmark (e.g., lighthouse, chimney, summit of mountain) * Position of buoy * Celestial position * Direction to land		
5	Magnetic compass course	✓	* Celestial position * Direction to land		
6	Heel	✓	* Motion of scenery	✓	* Body balance (labouring of a ship)
7	Rudder angle	✓	* Motion of scenery	✓	* Body balance (centrifugal force)
8	Rate of turn	✓	* Motion of scenery	✓	* Body balance (centrifugal force)
9	Pitching	✓	* Motion of scenery	✓	* Body balance (Labouring of a ship)
10	Yawing	✓	* Motion of scenery	✓	* Body balance (Labouring of a ship)
11	Rolling	✓	* Motion of scenery	✓	* Body balance (Labouring of a ship)
12	Swaying	✓	* Motion of scenery	✓	* Body balance (Labouring of a ship)
13	Surging	✓	* Motion of scenery	✓	* Body balance (Labouring of a ship)
14	Under keel clearance	✓	* Colour of sea surface * Distance from land	✓	* Smell (Salty air)
15	Visibility	✓	* Scenery outside the bridge		
16	Temperature			✓	* Thermal sense
17	Sea Temperature	✓	* Water vapor on the sea		
18	Moisture			✓	* Thermal sense (Humidity)
19	Amount of cloud	✓	* Scenery outside the bridge		
20	Sky condition	✓	* Scenery outside the bridge	✓	* Thermal sense
21	Speed of wind (relative and absolute)	✓	* Wave motion	✓	* Body sense (wind) * Sound
22	Direction of wind (relative and absolute)	✓	* Wave motion	✓	* Body sense (wind)
23	Speed of tidal current	✓	* Sailing wave and sea wave		

			* Form on the sea surface and floating object * Lean of a buoy		
24	Direction of tidal current	✓	* Sailing wave and sea wave * Form on the sea surface and floating object * Lean of a buoy		
25	Direction of Wave (wind, swell)	✓	* Wave motion	✓	* Body balance (Labouring of a ship)
26	Height of Wave (wind, swell)	✓	* Wave motion	✓	* Body balance (Labouring of a ship)
27	Target location	✓	* Appearance of target ships	✓	* Sound (Whistle, Engine of target ships)
28	Target speed	✓	* Movement of target ships * Ship wave * Change of course of target ships		
29	Target distance	✓	* Appearance of target ships		
30	Target course	✓	* Appearance of target ships (e.g., bow direction)		
31	Target bearing	✓	* Change of course of target ships * Appearance of target ships		
32	Number of targets	✓	* Appearance of target ships		
33	TSS to be followed	✓	* Location of the object of land or sea		
34	VTS communication frequency				
35	VTS standing instructions				
36	Location of navigation hazards	✓	* Location of land object (confirmation of the distance between a ship and navigation hazards)	✓	* Smell (Salty air)
37	Anchorage areas	✓	* Location of land object (confirmation of the distance between a ship and anchorage areas)		
38	Location of wreck, shoals, underwater rocks	✓	* Location of land object (confirmation of the distance between a ship and these areas) * Colour of sea	✓	* Smell (Salty air)
39	Density of traffic	✓	* sight outside the bridge		
40	Planned route	✓	* Location of land object (confirmation of the position of a ship)		

41	Distance to waypoints	✓	* Location of land object (confirmation of the position of a ship)
42	Planed speed for each leg	✓	* Location of land object (confirmation of the position of a ship)
43	Air draft	✓	* sight outside the bridge

2.5.4 Lack of Ship Sense and Required Information for SA of RO (G3 and G4 in Section 4.1. and Q4 and Q5 in Table 2-2)

As described in 3.3, the required information for SA of RO has a shortage due to the constraint of transmission of the information on environment inside/outside the bridge of a ship to RCC. The experts discussed in the mini focus group how they rate each item of ship sense and required information based on the results of G1 and G2 and the interview, and agreed upon them. Table 2-7 is the matrix of lack of ship sense and lack of required information for Level 1 SA. Each lack was rated on a three-point scale (A-large, B-middle and C-low for ship sense, and 1-critical, 2-middle and 3-low for required information for Level 1 SA). The category of ‘lack of ship sense’ indicates the sensitivity of ship sense against the restriction of the data transfer. For example, if RO can easily feel ship sense even by rough visual screen, the lack is small. The results show that ship sense is failed at least at the middle level (B-middle); i.e., participants feel that the restriction of data transmission affects ship sense at a high level.

The lack of required information indicates the need of ship sense in the total information resources to acquire the required information. VTS-related information is removed from this matrix since these items do not connect ship sense (see Table 2-6). The need for ship sense is not high if the lack of required information is low even with a high level of the lack of ship sense. For example, RO has a shortage of ship sense on sea temperature (No. 17 in Table 2-7) since it cannot feel the temperature at RCC. However, information on the temperature required for Level 1 SA decreases very little since most information is gathered from the item on the bridge (thermometer) at RCC. Nevertheless, each item’s level of the required information is generally the same as or almost similar to one on information resources (e.g., Level A-Level 1, Level A- Level 2) and keeps a high level. The items regarding the target are incredibly high (Level A-Level 1).

Table 2-7. Relationship between lack of ship sense and lack of required information for Level 1 SA.

	<Level 1> Lack of Information Required for Level 1 SA is Critical, and RO is Difficult to be Aware of Situation	<Level 2> Lack of Information Required for Level 1 SA is High, but RO Can be Slightly Aware of Situation	<Level 3> Lack of Information Required for Level 1 SA is Low
<Level A> Lack of Ship Sense is Large	1 Ship’s position 3 Speed over the ground 4 Gyro compass course 5 Magnetic compass course 15 Visibility 21 Speed of wind (relative and absolute) 22 Direction of wind (relative and absolute) 23 Speed of tidal current 27 Target location 28 Target speed 29 Target distance 30 Target course 31 Target bearing 32 Number of targets	16 Temperature 18 Moisture 24 Direction of tidal current 25 Direction of wave (wind, swell) 26 Height of wave (wind, swell)	17 Sea Temperature
<Level B> Lack of Ship Sense is Middle		2 Speed through the water 6 Heel 7 Rudder angle 8 Rate of turn 9 Pitching 10 Yawing 11 Rolling 12 Swaying 13 Surging 14 Under keel clearance 19 Amount of cloud 20 Sky condition 33 TSS to be followed 36 Location of navigation hazards 37 Anchorage areas 38 Location of wreck, shoals, underwater rocks 39 Density of traffic 40 Planned route 41 Distance to waypoints 42 Planed speed for each leg 43 Air draft	
<Level C> Lack of Ship Sense is Low			

Table 2-8 shows the lack of required information for Level 2 SA. Experts suggested that RO would have a high shortage of required information, especially on items related to target ships. Level 3 SA has similar results to Level 2 SA (see Table

2-9). The items pertaining to target ships and congestion mark a high level of shortage of required information. Planned visibility is also at the highest level.

Table 2-8. Lack of required information for Level 2 SA.

<Level A> **Lack of Information Required for Level 2 SA is Critical, and RO is Difficult to be Aware of Situation**	**<Level B>** **Lack of Information Required for Level 2 SA is High, but RO Can be Slightly Aware of Situation**	**<Level C>** **Lack of Information Required for Level 2 SA is Low**
1 Deviation between current position and planned positions 2 Deviation between current heading and planned heading 8 Impact of traffic conditions 13 Current separation between own ship and other ship 14 Type of situation (overtaking, heads-on situation, cross situation) of target 15 Type of target (e.g., cargo ship, fishing vessel) 18 Present manoeuvre of target	3 Deviation between minimum Under Keel Clearance (UKC) and current UKC 4 Validity of position, speed, heading and other indicators 5 Risk level of system related emergencies 6 Deviation between current speed and planned speed 7 Deviation between planned course and course made good 9 Impact of ship manoeuvres 10 Impact of alternation of course 11 Impact of alternative speed 12 Impact of weather condition 16 Times to closest point to approach to target 17 Bow or rear crossing range of target	

Table 2-9. Lack of required information for Level 3 SA.

<Level A> **Lack of Information Required for Level 3 SA is Critical, and RO is Difficult to be Aware of Situation**	**<Level B>** **Lack of Information Required for Level 3 SA is High, but RO Can be Slightly Aware of Situation**	**<Level C>** **Lack of Information Required for Level 3 SA is Low**
1 Planned position of own ship 2 Planned movement of targets 3 Planned relative separation 4 Planned traffic congestion 7 Planned visibility	5 Estimated time of arrival to waypoints 6 Planned weather condition 8 Planned wind speed 9 Planned currents or tidal stream	

2.5.5 Additional Competence and Possible Change and Impact on Competence Requirements for RO (G5 and G6 in Section 4.1. and Q6 and Q7 in Table 2-2)

Additional competence that RO should have to compensate for the lack of required information described in the last section is listed in Table 2-10. The experts discussed whether the listed competence extracted during the interview is linked to the results in the last section and agreed on them with adding one more competence (Item

8 in Table 2-10). Regarding the linkage, they expressed the opinion that the additional competence listed in the table cannot be applied to a specific item of required information but rather to multiple or whole items.

Table 2-10. Proposed additional competence for RO.

Item	Additional Competence for RO
1	Ability to recognise necessary information from a display of equipment (e.g., ECDIS, ARPA) and other items at RCC (e.g., passage plan) under the restricted condition at RCC
2	Ability to confirm the accuracy of the information obtained from restricted ship sense, radar display and other items at RCC
3	Correct understanding of the effect of sea condition on the motion of a ship under the restricted condition at RCC
4	Ability to recognise the target ship and other objects that have the most significant risk for safety with traffic congestion under the restricted condition at RCC
5	Ability to take immediate actions through the accurate recognition of the alarm under the restricted condition at RCC
6	Ability to predict future situation based on restricted condition of perception and understanding at RCC
7	Ability to take appropriate back-up actions when the data transfer on moving image of the screen between bridge and RCC is interrupted
8	Ability to identify the source of the problem at RCC when the electronic navigation system of MASS is in trouble

The experts elaborated Table A-II/1 in the STCW Convention on whether the additional competence for RO affects the current competence requirements from three perspectives:

- ‘X’: Competence in Column 1 based on KUP in Column 2 in Table A-II/1 for RO cannot be acquired without competence in Table 2-10. That means that detailed competence requirements in Column 2 marked ‘X’ have the possibility to be increased.
- ‘V’: Competence in Table 2-10 cannot be acquired without competence in Column 1 based on KUP in Column 2 in Table A-II/1 for RO. That means that competence requirements in Column 2 marked ‘V’ increases their importance for RO to acquire additional competence.
- ‘Z’: Competence in Column 1 based on KUP in Column 2 cannot be performed for RO due to the lack of required information for SA at RCC. That means that detailed competence requirements in Column 2 marked ‘Z’ have the possibility to be removed.

The results are shown in Table 2-11. They made the following suggestion.

- A few items should possibly strengthen the requirements in KUP of Column 2 by adding detailed competence (items marked as 'X'). These can be categorised into three parts:
    - Navigation competence utilising electronic navigation equipment, 'Electronic systems of position fixing and navigation,' 'Radar navigation' and 'Navigation using ECDIS'.
    - Bridge resource management and leadership competence, 'Bridge resource management' and 'Application of leadership and teamworking skills' and
    - Other competence, 'Terrestrial and coastal navigation' and 'watchkeeping.'
- The inclusion of the above requirements should assess the inclusion of all additional competence in Table 2-10 except the followings:
    - 'Terrestrial and coastal navigation' and 'Electronic systems of position fixing and navigation' should assess the inclusion of the additional competence on Item 1 and 2 in Table 2-10, and
    - 'Radar navigation' should assess the inclusion of the additional competence on Item 1 to 7 in Table 2-10,
- Many competences in the current requirements are essential for acquiring the additional competence in Table 2-10 (items marked as 'V'), including:
    - Wide range of navigation competence (e.g., Terrestrial and coastal navigation, and Radar navigation) is necessary for acquiring additional competence on recognition of information, assessment of the accuracy of the information;
    - Competence on theoretical and fundamental knowledge on navigation and ship (e.g., meteorology, ship manoeuvring and handling and ship stability) is necessary for acquiring additional competence on recognition of the effect of sea circumstance on ship movement;
    - Competence on knowledge of regulatory framework including the COLREG is necessary for acquiring additional competence on risk identification of target ships and objects, and correct prediction of future circumstance;

- Competence on the practical ability to use electronic navigation equipment such as ECDIS and ARPA/Radar is necessary for acquiring additional competence of taking back-up action in case of data interruption on the screen at RCC;
- Competence on theoretical and fundamental knowledge on electronic navigation system on the bridge (e.g., ECDIS, ARPA/Radar and steering control system) is necessary for acquiring additional competence on identifying the cause of the trouble on electronic navigation system of MASS, and proper recognition of the alarm.

The experts also agreed that additional requirements are necessary for Item 7 and 8 in Table 2-10 since the current requirements do not cover data communication technology for remote control at RCC.

Regarding the relaxation of the competence requirements (items marked ‘Z’), the experts identified only the item on celestial navigation, especially position fixing skill by using a sextant.

The experts did not make an assessment on whether detailed requirements in KUP of Table A-II/1 should be added or not, although they suggested the possibility. According to them, it is because it depends on the interpretation of each requirement and has difficulty to lead a conclusion in this study.

The results of the discussion in the mini focus group on Regulation II/1 (experience of seagoing service) are shown in the last part in Table 2-11. The results suggest that all additional competence except competence of taking back-up action in case of data interruption of the screen at RCC needs more experience of watchkeeping onboard a ship for RO to acquire them (Items marked ‘E’). In addition, according to them, competence on data transformation in Item 7 of Table 2-10 cannot be covered by the experience of seagoing service of a conventional ship, and other training ways are necessary (items marked as ‘R’). In this regard, the experts suggested that the familiarisation at RCC for RO to be smoothly engaged in watchkeeping at RCC might be necessary about Item 1 to 6 and 8 in Table 2-10 (items marked as ‘r’).

Table 2-12 sums up Table 2-11.

Table 2-11. Relationship between additional competence for RO in Table 2-10 and Table A-II/1 and Regulation II/1 in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)

Table A-II/1 in the STCW Convention		**Additional Competence in Table 2-10 (Item)**							
Column 1: Competence	Column 2: Knowledge, understanding and proficiency	1	2	3	4	5	6	7	8
Plan and conduct a passage and determine position	*Celestial navigation*	V –	V Z	– –	– –	– –	V –	– –	– –
	Terrestrial and coastal navigation	X V	X V	– –	– –	– –	– V	– –	– –
	Electronic systems of position fixing and navigation	X V	X V	– –	– –	– –	– V	– V	– V
	Echo sounders	V	V	–	–	–	V	–	V
	Compass—magnetic and gyro	V	V	–	–	V	V	V	V
	Steering control systems	V	V	V	–	V	–	V	V
	Meteorology	V	V	V	V	V	V	–	–
Maintain a safe navigational watch	*Watchkeeping*	X V	X V	X V	X V	X V	X V	X –	X –
	Bridge resource management	X	X	X	X	X	X	X	X
Use of radar and ARPA to maintain safety of navigation	*Radar navigation*	X V	X V	X V	X V	X V	X V	X V	– V
Use of ECDIS to maintain the safety of navigation	*Navigation using ECDIS*	X V	X V	X –	X –	X V	X V	X V	X V
Respond to emergencies	*Emergency procedures*	–	–	–	–	–	–	–	–
Respond to a distress signal at sea	*Search and rescue*	–	–	–	–	–	–	–	–
Use the IMO Standard Marine Communication Phrases and use English in written and oral form	*English language*	–	–	–	–	–	–	–	–
Transmit and receive information by visual signalling	*Visual signalling*	–	–	–	–	–	–	–	–
Manoeuvre the ship	*Ship manoeuvring and handling*	– –	– –	– V	– V	– –	– V	– –	– –
Monitor the loading, stowage, securing, care during the voyage and the unloading of cargoes	*Cargo handling, stowage and securing*	–	–	–	–	–	–	–	–
Inspect and report defects and damage		–	–	–	–	–	–	–	–

to cargo spaces, hatch covers and ballast tanks									
Ensure compliance with pollution-prevention requirements	*Prevention of pollution of the marine environment and anti-pollution procedures*	–	–	–	–	–	–	–	–
Maintain seaworthiness of the ship	*Ship stability*	–	–	V	–	–	–	–	–
	Ship construction	–	–	V	–	–	–	–	–
Prevent, control and fight fires onboard	*Fire prevention and fire-fighting appliances*	–	–	–	–	–	–	–	–
Operate life-saving appliances	*Life-saving*	–	–	–	–	–	–	–	–
Apply medical first aid onboard ship	*Medical aid*	– –	– –	– –	– –	– –	– –	– –	– –
Monitor compliance with legislative requirements		V	V	–	V	V	V	–	–
Application of leadership and teamworking skills		X	X	X	X	X	X	X	X
Contribute to the safety of personnel and ship		–	–	–	–	–	–	–	–

Regulation II/1 in the STCW Convention	Additional competence in Table 2-10 (Item)							
	1	2	3	4	5	6	7	8
Regulation II/1 *Approved OBT for the period of not less than 12 months or approved seagoing service of not less than 36 months (watchkeeping duties for the period of not less than 6 months)*	Er	Er	Er	Er	Er	Er	R	Er

X: Competence in column 1 based on KUP in Column 2 for RO cannot be acquired without Competence in Table 2-10. V: Competence in Table 2-10 cannot be acquired without Competence in column 1 based on KUP in Column 2 for RO. Z: Competence in column 1 cannot be performed for RO due to lack of required information for SA at RCC. E: More experience of watchkeeping duties onboard ships is necessary. R: Other training ways than 'E' are necessary. r: Familiarisation might be necessary.

Table 2-12. Proposal on possible change on the STCW Convention (Summary).

Additional Requirements
Experience of seagoing service (Regulation II/1) Fail-safe to the intermittence of data communication (Regulation II/1 and/or Table A-II/1) Basic knowledge of wireless communication & data transfer (Table A-II/1)
Possible Strengthening of Current Requirements by Adding Detailed Competence
Bridge resource management (Table A-II/1) Application of leadership and teamwork skills (Table A-II/1) Terrestrial and coastal navigation (Table A-II/1) Electronic systems of position fixing and navigation (Table A-II/1)

Watchkeeping (Table A-II/1)
Radar navigation (Table A-II/1)
Navigation using ECDIS (Table A-II/1)
Increase of Importance of Competence Requirements for In Table A-II/1 For Acquiring Competence of RO
Navigation competence (e.g., Terrestrial and coastal navigation, Radar navigation)
Knowledge of regulatory framework (e.g., COLREG)
Theoretical and fundamental knowledge (e.g., Meteorology, Ship manoeuvring and handling, electronic navigation system)
Practical ability related to navigation equipment (e.g., ECDIS, ARPA/Radar, Steering control system)
Decrease of Competence Requirements
Celestial navigation (Position fixing skill by using sextant) (Table A-II/1)

2.6 DISCUSSION

The present research aims to develop the direction to establish the appropriate regulatory requirements on competence for the shore-based RO, focusing on watchkeeping based on the STCW Convention's regulations provision, taking characteristics and conditions of remote operation into account. Thus, it focused on RO at RCC and assessed the lack of ship sense and required information, then reviewed the additional competence and possible requirements to compensate for the shortage. The results of the case study in Section 5 through the proposed GBGA in Section 3 make some observations.

Concerning ship sense (G2), although the original element of ship sense is various, visibility outside the bridge is the most important key factor. Examples of the objects to get ship sense are landmarks such as lighthouse and buoy, forming and colour of the sea surface, cloud movement, motion of scenery and wave and encountering ships. As listed in Table 2-6, visibility relates to almost elements of ship sense. Although other ship sense is also necessary for getting the required information, the most part can be compensated by visibility. For instance, body balance is used for grasping the motion of a ship, such as pitching, yawing and rolling; nevertheless, these movements can also be recognised by visually capturing the change of scenery outside the bridge. It is difficult for ROs to feel body balance at RCC. Nevertheless, they can manage to be aware of the situation by utilising the remaining information resource (i.e., restricted visibility outside the bridge), as shown in Table 2-7. In this sense, the extent of the constraint of data transmission and consecutive visibility significantly affects SA and safe navigation. The visibility outside the bridge was relatively clear and less intermittent in the case study since the demonstration project adopts 3G or long-term evolution (LTE) (see. Table 2-1). However, it is likely to happen that the visibility would be less clear, and a ship could not send a moving image because of the restricted data communication capacity when the ship uses the satellite communication as a data transmission tool in the ocean. In this case, the lack of visibility would be more extensive, and RO would not be able to satisfactorily be aware of yawing and rolling.

The lack of ship sense widely affects the acquirement of required information for each Level SA, as described in Table 2-7 to 9 (G3 and G4, RQ1). The adverse effects of the lack of ship sense on the information of target ships and traffic density are comparably large through all Level SA (e.g., target speed, target location, target distance and target course for Level 1 SA, Impact of traffic condition, type of situation of the target for Level 2 SA, planned movement of the target and planned traffic congestion for Level 3 SA). This can lead to two implications. First, OOW and RO trust the information from ship sense regarding the targets and objects that might directly risk accidents. Experts indicated that they attach an exceptionally high value to ship sense and utilise the information from bridge navigation items such as ECDIS and ARPA only for confirming and supplementing ship sense. Thus, the shortage of ship sense immediately induces the failure of situation awareness. Another implication is the complexity of acquiring the target-related SA, especially in Level 2 and 3 SA. These items of SA are linked with various sources of lower Level SA although the process is not ‘linear’ but ‘dynamic’ [51]. For example, the information on the deviation between current speed and planned speed in Level 2 SA is linked mostly only with ship speed in Level 1 SA. On the other hand, an expert pointed out that OOWs and ROs need various kinds of Level 1 SA including own ship’s position and speed of the target to be aware of the situation on the impact of traffic condition. The intricate connection between different Level SA would induce uncertainty and lead to a high lack of the required information.

Regarding competence (G5 and G6, RQ2), all experts stressed that it is impossible for novice officers qualified as OOW of Regulation II/1 in the STCW Convention to have a duty of RO. The results can classify additional competence in three ways. The first additional point is the accurate recognition of the situation, including spatial awareness, appropriate prediction of future status by utilising the information from bridge navigation items and the remaining ship sense when required information is partly failed. An expert pointed out that this competence is opposite to what he has learned from instructors and taught to cadets. Crews have learned their competence for navigation in which they rely on ship sense even without electronic navigation equipment. Once acquiring this competence, they can handle the equipment well. Conversely, ROs should heavily rely on the MASS system's navigation items at RCC with limited ship sense in many cases. The expert suggested that ROs could handle this difficult situation only when they have seagoing experience and get the navigational expertise described above. Young professionals lack the skill to 'grasp relevant information from their environment' under uncertain situations [22]. Experience of seagoing is essential to appropriately review the condition of the autonomous ship [52]. Considering these, 'experience' is the crucial item to supplement the lack of ship sense and failure of the required information. In this regard, more experience of seagoing service after being engaged in watchkeeping should be added.

The second is the competence for fail-safe. Although the case study does not cover emergency situations such as fire, collision and grounding, sudden intermittent delay of visual data is likely to happen even if redundancy has been kept. In this case, visual sense will face unusual failure. Encountering ships might be close to the ship at the same time. According to an expert, even in this situation, RO should have the competence to appropriately specify the cause of the condition and predict the next event on the screen at RCC in bounded time without panic. Although professional crews can control a ship in the 'strategic' way even under complicated situations based on the experience of seagoing service [23], they do not have competence for the fail-safe due to the lack of the experience of 'visual intermittent'. Therefore, the seagoing service's ample expertise is not sufficient for handling these situations, and another requirement on the fail-safe should be newly added to the regulation. Moreover, the training methods to get this competence are also important. Since it is difficult to make these situations in non-MASS ships, the simulation and virtual reality (VR) training will be one of them.

The next is the fundamental and theoretical knowledge of a ship, including ship motion, bridge equipment, data communication and meteorology. The abilities that RO should hold are built on fundamental knowledge. For instance, the ship's motion changes depending on various natural elements such as speed and direction of a wind, ship condition such as ballast condition and a ship's character such as manoeuvring characteristics, including course changing and stopping ability and ship size. Being familiar with the fundamental nature and specification of bridge equipment is also essential since manoeuvre at RCC should highly rely on the human–machine interface with the limited visual sense. Moreover, basic knowledge of wireless data communication is necessary, bearing in mind that ships will seek a 'more comprehensive communication system' [53]. Although officers engaged in watchkeeping currently learn most of this fundamental knowledge, RO's competence level should be more profound.

The last is the bridge resource management (BRM), which is the regulatory requirements introduced in STCW2010 and includes 'teamwork and leadership' [54]. The necessity of this competence depends on the formation of bridge manning. An expert mentioned that this competence might be less critical if the RO were engaged in the watchkeeping of an unmanned ship alone at RCC. However, more profound knowledge is necessary for this study since RO and Look-out should navigate the ship as a team under restricted conditions. Moreover, the separation of the navigation crews between the bridge of a ship and RCC will make BRM much more difficult. The overlook of essential information for safety is caused by inappropriate manning [55], and BRM and leadership are indispensable competence to secure the operation of manning. Moreover, according to Kim and Mallam [37], a new leadership style, such as a non-hierarchical type connecting man and machine, might be expected. Considering these, the competence of BRM and leadership will be more critical except for a few special cases.

Although this study looks for the item that can be removed from the current requirements besides the additional requirements, the results are quite limited. This study suggests only celestial navigation, in detail position fixing skill by using sextant, since using this knowledge will not be likely to happen. However, an expert suggested that the basic concept of celestial navigation is necessary to understand.

2.7 CONCLUSION

This research improved the method to develop the regulatory frame on the competence of RO, focusing on watchkeeping on the navigation bridge under the recognition that remote control and RO are the critical elements for future MASS. It adopted the extended SA model and constructed GBGA model as a tool for developing the regulatory frame. The goal of GBGA model is set as ‘keep the same quality of SA for RO as OOW’. Then GBGA model was demonstrated by a case study in which experts were made mini focus group discussions with interviews. The results expressed the trend of ship sense on required information for each Level SA for watchkeeping, and the lack of ship sense and the failure of required information for RO, then additional competence and possible change of regulatory requirements compared to current provisions in the STCW Convention.

There are some limitations to this research. At first, this research applies one typical case on a remote control system based on the previously conducted projects. It could recognise the trend of the failure of ship sense and required information and additional requirements. Nevertheless, deferent or more detailed outputs can be found if GBGA could be applied to various MASS situations by changing assumptions, including autonomy level and operation area. Second, the case study was made by three experts. All of them are professional officers and veteran instructors, and sufficient and constructive output could be made based on the interview and active discussions. Notwithstanding, the participation of more experts will bring out additional useful comments and suggestions. Third, the measure to retain safety for MASS should take a comprehensive approach. An expert commented that the addition of competence is not enough, and it is necessary to consider the combination of RO’s competence and other factors such as bridge manning and technological innovation. He stressed, in particular, the style of watchkeeping might change according to future technology. Lastly, the competence for dealing with an emergency situation, including a fire, pirate, and cyber-attack, is also vital for safety and security. Future research should consider this matter.

Despite the above limitation, the output of this paper has useful implications. At first, the case study supports that the proposed GBGA method is a valuable tool to develop regulatory requirements for seafarers’ competence based on ship awareness. Thus, the method can be utilised as a tool not only for establishing international or national rules of RO in MASS but also for assessing whether regulatory requirements for RO are sufficient for newly introduced MASS. Second, the points that were suggested in the discussion show the whole trend of RO as described in the last paragraph. Therefore, future research on the requirements of RO can consider these points. Lastly, the results can be a basement for introducing the combination of competence requirements, the training for officials and innovative technology for MASS.

Future research on detailed consideration of competence requirements for RO under various cases is expected based on this research.

Chapter 3: Relationship between MASS and mental workload

3.1 INTRODUCTION

Shipping is an essential tool for maintaining the supply chain. World seaborne trade has become more than 60 trillion ton-miles internationally, by utilising over 50 thousand commercial vessels [56]. The stability and safety of shipping could not be achieved without skilled and experienced seafarers. They are currently more than 1.6 million, including 774 thousand officers [56]. The turmoil of shipping by the constraints of crew changes due to the restriction of international and domestic transport by the COVID-19 pandemic has reiterated these facts. The International Maritime Organization (IMO) stresses the necessity of seafarers and encourages governments to recognise them as “key workers” who conduct an “essential service [57].”

One of the critical issues for seafarers is human error that causes maritime accidents. According to Coraddu et al. [58], multiple studies indicate that over 80% of marine accidents are caused by human-related failures. One of the crucial factors that induce human error is mental workload (MWL). When MWL exceeds the upper limit, the level of performance decreases [28]. Then, the failure of decision-making and human error are induced [59], and safety may not be maintained [60]. Excessive MWL, similarly referred to as excessive “stress” [61], also causes fatigue [62] that has a significant influence on ship safety, while fatigue is caused by a wide range of elements, such as the lack and poor quality of sleep and rest [63]. The level of influence is enormous, especially for the officers responsible for ships’ safety and security. Crews are exposed to significant stress from work pressure compared to land-based work [64]; therefore, controlling MWL is vital for ship safety.

One useful solution to overcome the issue is ship automation, autonomy, and remoteness. The contemporary development of information and communication technology, including computation and artificial intelligence (AI), has enabled these ships’ emergence. IMO defines these ships as maritime autonomous surface ships (MASS). The broad level of autonomous ships has been demonstrated and developed technologically. Examples are international voyages using a navigation support system [6], a fully autonomous project demonstrated in coastal water [3], and an unmanned com-mercial ship planned in Norway [4].

On the other hand, automation and autonomy will not always decrease mental stress, but rather heighten the risk of human error in some cases. For example, a remote control system needs a higher level of cognition for operators [28] and might lead to higher mental stress. Remote operators' stress at the remote control centre (RCC) might sometimes increase due to information overload by receiving enormous amounts of visual data to compensate for the lack of the feeling of the environment inside or out-side a ship [65]. According to Endsley [18], the workload generally increases at the decision-making stage in automation despite decreasing the situation awareness at the implementation stage. This implies that seafarers' stress navigating MASS might be higher at the decision-making stage than traditional ships, depending on the automation level. Wróbel et al. [66] suggested a relationship between keeping psychological conditions and operating remotely controlled ships safely. Taking into account ship safety and the mental health of operators navigating MASS (from now on called "operators"), the MWL of operators should be retained at an appropriate level [28].

The activities to ensure the safety of MASS through international regulation have been carried out at the IMO. It adopted the interim guidelines for a trial in 2019 [67]. It has also conducted regulatory scoping exercises (RSE) of international regulations, including 13 conventions related to maritime safety [7], since 99 sessions of the Maritime Safety Committee (MSC). In the RSE discussions, the IMO [7] shows four regulatory ways to achieve safe operation of MASS, including "amending existing instruments" and "developing new instruments". Some industrial associations and classification societies have also prepared non-mandatory standards and guidance. For example, Mari-time U.K. has developed industrial guidance for MASS less than 24 m in length [9]. DNV GL, a classification society, also sets guidelines on technical rule and acceptance criteria, etc., based on a goal-based approach [8]. These guidelines suggest the necessity of the linkage between human elements including stress and technical requirements. While these activities are expected to accelerate, the inclusion of the detailed elements of MWL in the rules is indispensable for establishing an effective regulatory framework.

On the other hand, little research has focused on the relationship between MWL and MASS. Wulvik et al. [68] measured the MWL of engineering students on two scenarios by using bridge simulators to investigate the relationship between the subjective and physiological change of remote operators. Ramos et al. [69]21] suggested factors that have effects on shore control operators' decisions, such as boredom, by using human reliability analysis. Porathe et al. [70] discussed the human–machine interaction of operators from a human factors perspective. Nevertheless, no research comprehensively discusses a model for identifying the factors that influence operators' MWL in the MASS related systems.

Based on the above background, this paper aims to construct a scheme for identifying the relationship between MWL and MASS in the maritime domain. The scheme can be utilised for not only rulemaking, but also technology development, focusing on the navigation of a ship (Figure 3-1). It focuses on a normal navigational condition and excludes emergencies such as fire, collision, and search and rescue to simplify the assumption and eliminate complicated cases, considering that MWL is likely to drastically change in these cases.

The remaining parts are as follows. Section 3.2 explains the mental workload model that is adopted in this research. This section also builds the identification scheme of the relationship between MWL and MASS based on the adopted model. Sections 3.3 to 3.5 carry out the case study on the typical patterns and show the results. Section 3.6 discusses the results, including verification of the scheme. Section 3.7 concludes the research.

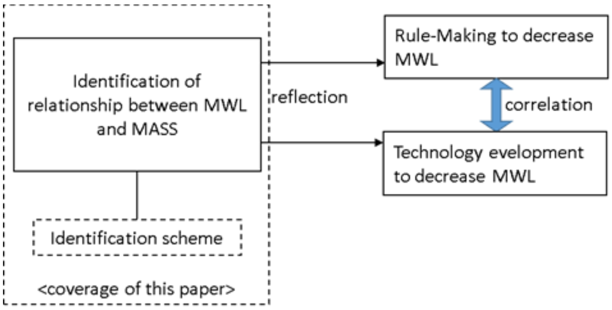


Figure 3-1. Image of this research.

3.2 MWL IDENTIFICATION SCHEME

This section provides the scheme that identifies the relationship between MWL and MASS, after explaining the concept of MWL.

3.2.1 Mental Workload and Safety

Hart and Staveland [71] defined the workload as not task-centred, but hu-man-centred. MWL is a widely utilised concept in ergonomics and is used in various ways, including analysis of the effects of additional tasks such as the new automated design [72]. MWL can also measure the effects on elements of the safety of transportation, such as drivers' reaction time [73]. The commonly used MWL concept comprises three domains: the input of load outside the human factor, the effects inside the human factor, and performance (data output) caused by a human operator [61]. Pickup et al. [72] developed Johannsen's model [61] by adding the concept of physical and cognitive demand, elements of goals and strategies to discuss the MWL of railway signalling operators. As a partly similar model, Wong and Hang [60] show a unique mental process on road safety, including the MWL model, to analyse contribution factors that influence MWL and discuss the optimal situation. According to them, "task activities" are generated from eternal conditions such as roadway conditions and traffic situations. Then, the task activities connect to "task demand" through situation awareness. "Motivated capability" originating from physical capacity and psychological condition also influences MWL. When it comes to shipping, there are some differences from land transport. For instance, ships do not have fixed routes except in some areas such as traffic separa-tion schemes, (TSSs), narrow channels, and in ports. Sudden crossing by small boats often happens even in fixed traffic areas. Moreover, some weather conditions (e.g., waves and wind) have effects on ships' manoeuvring. Nevertheless, the mental process is similar between ships and automobiles.

The MWL can measure the safety level. Jex [74] suggests that MWL is the "opera-tor's evaluation of the attentional load margin (between their motivated capacity and the current task demands) while achieving adequate task performance in a mission-relevant context". MWL would have a potential safety risk of navigation when task demand exceeds motivated capacity and the workload margin becomes negative [60]. In this case, MWL is too high. On the other hand, the too-much margin becomes the too-low MWL that also leads to a safety risk due to a careless attitude. They suggested that adjusting these two items was necessary to keep MWL at an optimal level and drive safely. This could apply to the navigation of a ship. The too-high MWL leads to excess task demand beyond motivated capacity (negative load margin). A potential safety risk of navigation emerges in this situation. Too-low MWL leads to far less task demand than motivated capacity (too much positive load margin), where a potential safety risk of navigation also emerges (Figure 3-2).

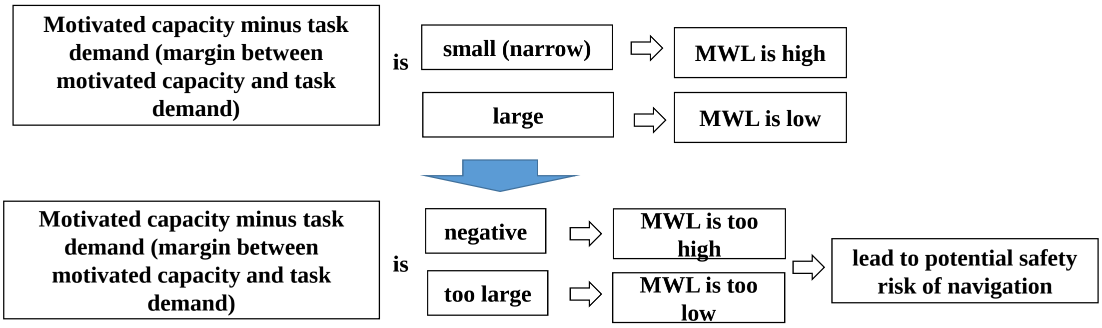


Figure 3-2. Image of relationship between MWL and navigation safety.

3.2.2 Scheme of identifying the relationship between MWL and MASS

Figure 3-3 shows the process for identifying the relationship between MWL and MASS. The scheme finally identifies factors that affect the MWL of operators in the MASS related systems, and sub-elements of MWL that significantly change (step 5 in Figure 3-3). The first step is to define the candidate factors and set options and levels of each factor (step 1 in Figure 3-3). Wong and Huang (2009) specify the factors related to driving task demand and drivers’ motivated capabilities in the MWL model. Figure 3-3 lists five key factors for this scheme based on their specification. In addition, it also specifies five factors that should be added, according to the introduction of MASS. A detailed explanation is shown in the next section. Once MWL is measured in each factor (step 2 in Figure 3-3), the next step is to confirm that the increase and radical decrease in MWL corresponds to the potential safety risks described in Section 3.2.1 (step 3 in Figure 3-3). Then, the gap of MWL among levels and options of each factor is measured (step 4 in Figure 3-3). Finally, factors and sub-elements are identified (step 5 in Figure 3-3).

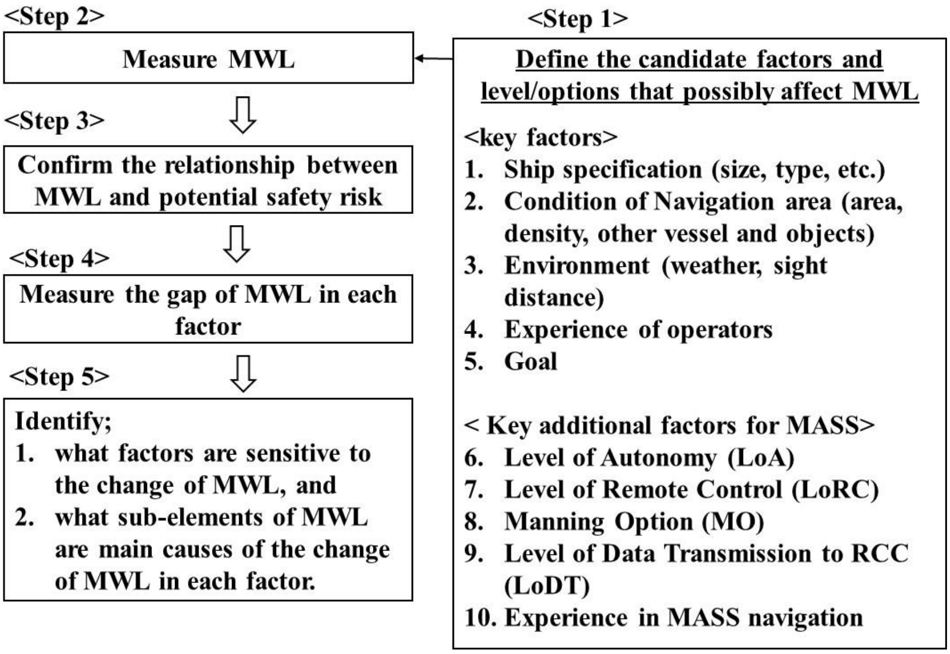


Figure 3-3. Outline of scheme of identifying the relationship between MWL and MASS

3.2.3 Key additional factors for MASS

One of the critical factors is the autonomy level of MASS. Various articles and documents define the level. Zhou et al. [16] separated the process for MASS development into four stages; “system decision support”, “shore-based remote control with seafarers onboard”, “shore-based remote control without seafarers onboard”, and “fully autonomous”. This stage is almost the same as the degree of MASS used in the IMO [7]. These stages can be categorised into two dimensions: level of autonomy (LoA) and level of remote control (LoRC). Maritime U.K. [9] provides six autonomous levels. These categories are defined depending on to what extent the human (operator) is involved in the navigation. DNV GL’s degree [8] is almost the same as Maritime U.K. Ringbom uses two key functions, LoA and manning level on board (MLoB) [75]. MLoB is classified into three levels: fully manned, periodically unmanned, and unmanned. The periodically unmanned level can apply to a wide range of situations, according to LoA. For instance, an unmanned situation onboard might be possible in the open sea and under low congestion, then a watch officer will rush to the bridge in the emergent situation by noticing a false alarm. The Norwegian Forum for Autonomous Ships (NFAS) adopts a similar approach [76]. It divides the level into two axes: “Operational autonomy level” and “Bridge manning level”. Combining four levels of the operational autonomy level and three bridge manning levels, it also defines the type of autonomy (e.g., automatic ship by the combination of automatic levels, and unmanned bridge with crew onboard).

From a human-centred point of view, some issues should be considered to define the autonomy level. Firstly, because multiple crews who are engaged in special duties are onboard a ship unless it is just a one-crew small boat, the manning formation and relationship should be carefully considered. From a fatigue perspective, effective management of the manning level contributes to its reduction [77]. Appropriate manning will be one of the factors to reduce stress and fatigue. “Appropriate” means not only the number of crews but also the tasks given to each crew.

Ships provide a bridge manning matrix that describes who will be on the bridge and what tasks they should do during navigational watch. Based on the matrix, they work together as the bridge team [26]. Bridge resource management is vital for safe navigation. For instance, double manning during navigation causes ambiguous command and enhances collision risk [78]. The responsibility of seafarers is also a critical point. For instance, while the captain has a final and ultimate responsibility for the ship’s safety, remote operators might be responsible for navigational watch on behalf of a captain and manage the bridge team [26]. These differences in the responsibility be-tween seafarers are reflected in the stress. According to Liu et al. [79], a captain shows the highest mental stress in the four levels of navigation staff (captain, officer on watch (OOW), steersman, and pilot), probably due to the difference in responsibility; the steersman’s stress is the lowest due to them having the most straightforward tasks. The MASS related systems drastically change the bridge management team’s formation including their tasks, and formation of the MASS navigation team should be elaborated. Who takes the ultimate responsibility and in which position the person is engaged in duty on the bridge or at the RCC are especially important.

The second key factor is the information that operators acquire. The appropriate information positively affects MWL [60] and contributes to keeping the MWL at an optimal level. Conversely, according to Svensson et al. [80], improper information such as a lack, complexity, and overload of information would deteriorate air pilots’ performance and face the risk. Seafarers are the same; the lack of information as well as in-formation overload induces the issue of MWL and ship navigation in many cases. The complexity of information also influences MWL. MASS operators should manage the information under different conditions from conventional ships. In particular, due to the possible limitation of data transmission between the bridge and RCC, the quality and quantity of the information that the operators at the RCC can receive would change a lot.

The final factor is the experience of navigating MASS as an operator. Wong and Huang [60] suggest that experiences affect motivated capacity in the mental model. This also applies to MASS.

To sum up, the key additional factors for the MASS related systems are: (i) level of autonomy (LoA); (ii) level of remote control (LoRC); (iii) manning option (MO), including formation and responsibility; (iv) level of data transmission to RCC (LoDT); and (v) experience of MASS navigation (EoM).

3.3 CASE STUDY (METHOD AND IDENTIFICATION OF FACTORS (STEP1 IN FIGURE 3-3))

The case study was carried out using the identification scheme described in Section 3.2 to confirm the scheme’s verification, find the trend in typical cases, and identify the limitation of the scheme.

3.3.1 Levels and Options of Candidate Factors That May Affect the MWL of Operators (Step 1 in Figure 3-3)

This case study sets the levels and options of factors in Table 3-1. There are many factors (variables); therefore, some of them had only one fixed option, to decrease the number of scenarios that interviewees should answer. At first, the ship type and size were set as a general type of vessel of 3000 gross tonnages (GT). This is because the highest rank in the competencies for seafarers that International Convention on Standards of Training, Certification and Watchkeeping of seafarers (STCW Convention) re-quires is a master (captain) and a chief mate of a ship of “3000 gross tonnages (GT) and more” (Regulation II/2). The goal to be achieved by operators was to navigate safely to the next port without a long delay. The study set only one option of operator’s experience (deck officer), considering the number of interviewees. Operators were assumed to have no experience of navigating MASS because all interviewees had not yet experienced it. Finally, it was assumed that operators at the RCC could acquire the same in-formation displayed on the bridge equipment (e.g., ECDIS and Radar/ARPA) without any delay. The next sections explain the detail of other factors.

Table 3-1. Outline of factors that may affect MWL of operators in this study.

Factor	Option/Level
Ship size	Approximately 3000 gross tonnages (GT)
Ship type	General type of ship (ocean-going ship)
Goal of operators	Navigate safely to the next port without a long delay
Weather	Clear, Rain, Heavy rain, and Fog (Section 3.3.2)
Navigation area	Open sea, Coastal water, and Channel (Section 3.3.2)
Traffic density	One vessel every four hours, Two vessels every one hour, and Five vessels every one hour. These vessels approached own ship at the same time (Section 3.3.2)
Visibility	Visibility of 1 mile, 3 miles and 7 miles ahead from own ship (Section 3.3.2)
Experience of operators	Deck officer
<Additional factors for MASS>	
Level of Autonomy (LoA)	No autonomy, Navigation support system, Autonomous navigation system with monitoring and Autonomous navigation system without monitoring (Section 3.3.3)
Level of Remote Control (LoRC)	No remote control, Support of navigation, and Navigation (Section 3.3.3)
Manning Option (MO)	Combination of responsible officer and support officer between the bridge of a ship and remote-control centre (RCC) (Section 3.3.3)
Level of Data Transmission to RCC (LoDT) (visibility on screen and sound at RCC)	Static image (one picture/10 sec), rough video and clear video (Section 3.3.3)
Level of Data Transmission to RCC (LoDT) (data of navigation equipment (e.g., ARPA/Radar and ECDIS))	Same between the bridge and RCC (i.e., operators can acquire the same data without delay and trouble)
Experience of MASS navigation (EoM)	No experience

3.3.2 Factors on General Matters (1–5 of Step 1 in Figure 3-3)

Navigational condition

Detailed navigational conditions used in this case study, including weather, navigation area, traffic density and visibility, are shown in Table 3-2. Each option in the table was set based on scenarios that happen in the actual navigation area. It excludes the port area because the operators' task in this area is complicated. They sometimes navigate the ship with the help and advice of a pilot [24] in the pilot area.

The main difference between Option 2 and 3 is visibility and average wave height, and the difference between Option 3 and 4 is the navigation area (density).

Table 3-2. Navigational condition in the case study.

Option	Navigation Area	Expected Area	Frequency of Approaching Ship(s)	Non-AIS-Equipped Ships	Visibility (Weather)	Average Wave Height
NC-1	Open Sea	Pacific Ocean	A vessel every 4 h	No	Visibility of 3 miles ahead (Rain)	3 m
NC-2	Coastal water	Coast of Boso Peninsula	Two vessels every one hour at the same time	Small fishing vessels Leisure crafts	Visibility of 7 miles ahead (Clear)	1 m
NC-3					Visibility of 1 mile ahead (Heavy rain)	3 m
NC-4	Channel	Uraga Channel	Five vessels every one hour at the same time		Visibility of 1 mile ahead (Fog)	1 m

AIS: Automatic Identification System.

3.3.3 Additional Factors for MASS (6–10 of Step 1 in Figure 3-3)

Level of Autonomy (LoA) and Level of Remote Control (LoRC)

LoA and LoRC were categorised into four and three levels, respectively, based on the function of autonomy and remote-control systems (see Table 3-3). LoA4 was elimi-nated in this case study because this level does not involve any operators. The autono-my functions of LoA-2 and LoA-3 are as follows:

- LoA-2: The system can identify non-AIS ships (e.g., small boats) and objects (e.g., driftwoods), make some warning on the existence of these objects, and advise on appropriate collision avoidance routes;
- LoA-3: The system can make autonomous collision avoidance in addition to LoA2. The system takes preventive action for collision avoidance before the target ships enter the obstacle zone by the target;
- Both systems are highly reliable, although there is a slight chance of failure.

Table 3-3. LoA and LoRC in the case study.

LoA	Detail	LoRC	Detail
LoA-1	No Autonomy	LoRC-1	No remote control

LoA-2	Navigation Support System (NSS) The system can identify non-AIS ships (e.g., small boats) and objects (e.g., driftwood), make a warning, and advise appropriate collision avoidance routes.	LoRC-2	Support of Navigation
LoA-3	Autonomous Navigation System (ANS) with monitoring The system can make autonomous collision avoidance in addition to LoA-2, and is monitored by responsible officers (ROs) defined in Section 3.3.3	LoRC-3	Navigation
LoA-4	Autonomous Navigation System (ANS) without monitoring This system is totally autonomous without any human monitoring (not applicable in the case study).		

Manning Option (MO)

Table 3-4 shows the manning options in this study. Navigational manning comprises a captain, OOW, remote operator, lookout, and a helmsperson. A helmsperson steers a ship by order of responsible officers on the bridge. This position might be omitted if the autonomy level is high, because responsible officers can easily steer a ship independently. The lookout has the task to “look out” around the ship on the bridge and reports every important sight and hearing signal to watchkeeping officers [26]. This study divides the manning into two groups:

- Group 1 (responsible officer: RO): remote operators, OOWs or captain and helmsperson (total of two persons) who have the responsibility for navigation;
- Group 2 (support operator: SO): lookout for supporting watchkeeping.

Five options are defined depending on the places (Bridge and RCC) where the groups are.

Table 3-4. Manning options in the case study.

Option	MO-1	MO-2	MO-3	MO-4	MO-5	MO-6
	LoRC-1	LoRC-2	LoRC-1	LoRC-3	LoRC-3	LoRC-3
Bridge of a ship	RO + SO	RO	RO	-	SO	-
Remote control centre (RCC)	-	SO	-	RO + SO	RO	RO

Level of Data Transmission to RCC (LoDT) (visibility on Screen and Sound at RCC)

The speed of network connection between a ship and shore directly affects the level of data transfer and information that operators can receive at the RCC. The current satellite system commonly used for ships is L-band, and its bandwidth is low (e.g., 432 Kbps of the Inmarsat Fleet Broadband Service [81]). In this case, it is not easy to continuously and simultaneously send large amounts of data such as video data to shore. On the other hand, recent IT development has led to improved commercial satellite systems [82]. For example, StarLink plans to service 1 Gbps per user by utilising low earth orbit satellites [83]. In some sea areas close to land, ships can connect to 3G or LTE, whose maximum bandwidths are, e.g., from 2–3 Mbp to 40–50 Mbp of upstream speed in Japan, from a base station on the land. Rødseth et al. [84] suggest that around 4 Mbps should be required for a sufficient remote control system.

Nevertheless, the necessary bandwidth depends on the required resolution and level of redundancy, etc. Taking these into account, this study defines three levels of information level between a bridge and RCC, shown in Table 3-5. Level 2 utilises a similar situation to the demonstration project on remote control navigation that was carried out by using “Shioji-maru” of the Tokyo University of Marine Science and Technology in 2018.

Table 3-5. Level of visibility on screen and sound at the RCC.

Visibility	**LoDT-1***:* Static image with one picture/10 s - Identify vessel of a length of 45 m in 1 mile under the clear weather condition in the daytime. **LoDT-2***:* (rough) Video - Identify vessel of a length of 45 m in 1 mile under the clear weather condition in the daytime. **LoDT-3***:* (clear) Video - Identify vessel of a length of 45 m in 6 miles under the clear weather condition in the daytime. - Recognise the mast of a vessel in 10 miles.
Time delay	<0.1 s

Failure of data transmission	Redundancy by another internet connection Recover in 1 min
Sound	Clear and no delay

3.4 METHOD OF THE STUDY

3.4.1 Participants

The study selected the participants based on the following criteria:

- They were active seafarers, because they should accurately grasp the real situation from recorded video during the interview;
- They were qualified officers in charge of a navigational watch, chief mates (officers) or masters (captains) in accordance with regulation II/1 and II/2 of the STCW Convention, because they answered questions as a responsible officer (RO);
- They had an experience of international ocean-going service on a ship of more than 3000 GT; scenarios in the case study included the option of navigating this size of ships in the ocean;
- Participants should have a variation of ranks and experiences to acquire balanced results.

As a result, a total of ten (10) seafarers participated in the study. Their average experience of sea-going service as an officer was 9.5 years, with a maximum of 20 years and a minimum of 3 years. Their experience of sea-going service included very large crude carriers (VLCCs) of over 150,000 GT, container ships, roll-on/roll-off ships (ferries) and ocean-going training ships of over 4000 GT. Their latest ranks in the ship are shown in Table 3-6.

Table 3-6. Participant’s latest rank in the ship.

Level	Rank	Number of Interviewees
Management level	Captain (Master)	2
	Chief officer (Chief mate)	3
Operational level	2nd officer	2
	3rd officer	3

3.4.2 Scenario Setting

Table 3-7 shows the number of scenarios that were used in the interview. The number was scrutinised to 25 (28 with duplication) for the participants to be able to concentrate on the interview. Thus, in addition to Table 3-1, the study fixed some variable factors in the scenarios to one option or level, as described in the note (assumption) of Table 3-7. At first, coastal navigation (NC-2) was used in factors 1, 2 and 4 of Table 3-7 as an assumption, considering that MASS have been developed for navigating coastal water. In addition, clear visibility (good weather) in NC-2 was adopted to avoid the complexity of analysis. LoDT-2 (rough movie on the screen of RCC) was also used in factors 1, 2, and 3 of Table 3-7 as an assumption, considering the current communication level. LoA-3 (autonomous navigation system) was used in factors 3 and 4 of Table 3-7 as an assumption of autonomy level to recognise the direct change of mental stress under the autonomous conditions. Finally, MO-4 (every navigational staff at RCC) was adopted in factor 4 of Table 3-7 as an assumption to exclude the effects of support operators onboard a ship on MWL.

Table 3-7. Number of scenarios.

Variable Factors in Section 3.3.2	**Number of Scenarios**	**Note (Assumption)**
1. Level of Autonomy (LoA)	**17 scenarios** Three LoAs in Table 3-3 and six MOs in Table 3-4 are combined. One scenario (LoA-1 (no autonomy) and MO-3 (only RO onboard ship without support)) is excluded from the study because this scenario just makes current manning more severe without technological development and would be unlikely to happen.	NC-2 (coastal water in clear visibility) and LoDT-2 (rough movie on the screen of RCC) are applied as an assumption.
2. Manning Option (MO)		
3. Navigational Condition (NC)	**8 scenarios (*)** Four NC options in Table 3-2 and two MOs (MO-1 and MO-4)) in Table 4 are combined. (*) Two scenarios are duplicated with the scenarios used in LoA and MO.	LoA-3 (autonomous navigation system) and LoDT-2 (rough movie on the screen of RCC) are applied as an assumption.
4. Level of Data Transmission to RCC (LoDT) (visibility of screen and sound at RCC)	**3 scenarios (*)** Three LoDTs in Table 3-5 are used. (*) One scenario is duplicated with the scenario used in LoA and MO.	LoA-3 (autonomous navigation system), MO-4 (every navigational staff at RCC) and NC-2 (coastal water in clear visibility) are applied as an assumption.
Total	**28 scenarios (25 scenarios without duplication)**	

3.4.3 Methodology

The study adopted an interview that utilised the NASA task load index (NASA-TLX) [71]. NASA-TLX is a commonly used subjective MWL measurement tool. It measures the weighted average of MWL based on six subscales: mental demands (MD); physical demands (PD); temporal demands (TD); frustration level (FR); effort (EF); and own performance (OP). These ratings can lead to many “theories that equate workload with the magnitude of the demands imposed on the operator, physical, mental, and emotional responses to those demands” [85]. This study also adopted the six subscales as the sub-elements of MWL in step 5 of Figure 3-3. In order to obtain the re-sults of step 3 in Figure 3-3, the following closed question was added in each answer sheet; “Is your MWL in the given scenario as high as you feel a potential safety risk?”

3.4.4 Process of the interview

Figure 3-4 shows the process of the interview. The interview was on a one-to-one basis through a social network service (SNS) or face-to-face. Prior to the interview, the interviewees received information on the research’s objective and outline and consented to take the interview. The interviewer explained the detail of each scenario before interviewees filled the answer in each of them. The interviewees answered the questions under the assumption that they navigated ships as responsible officers (ROs). The average length of each interview was 2.5 h.

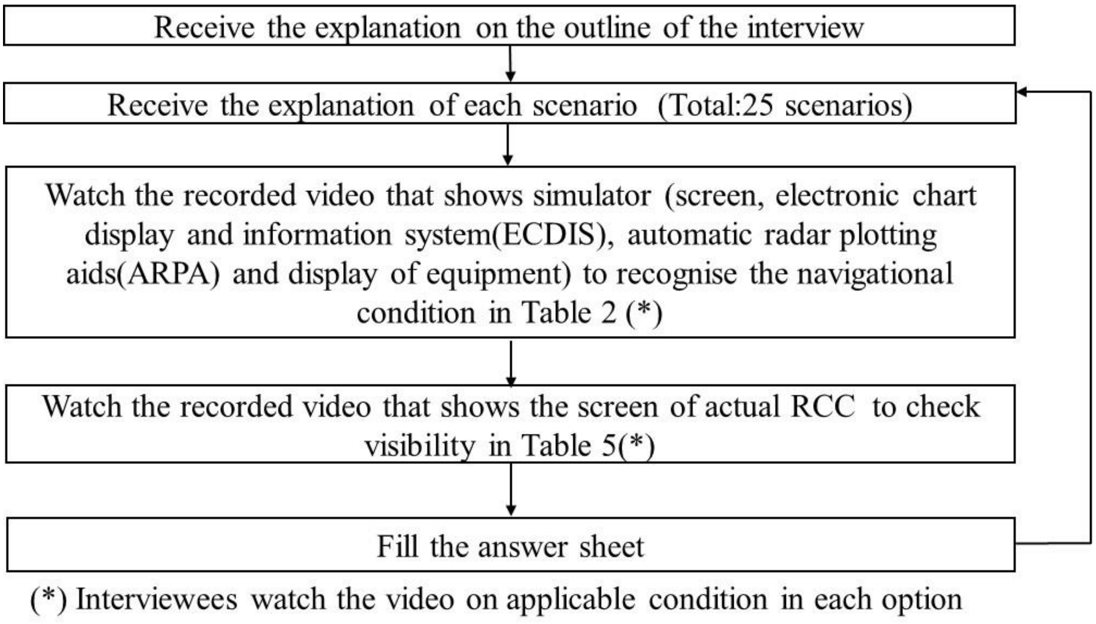


Figure 3-4. Process of the interview in this case study.

3.5 CASE STUDY (RESULTS (STEP2 TO 5 IN FIGURE 3-3))

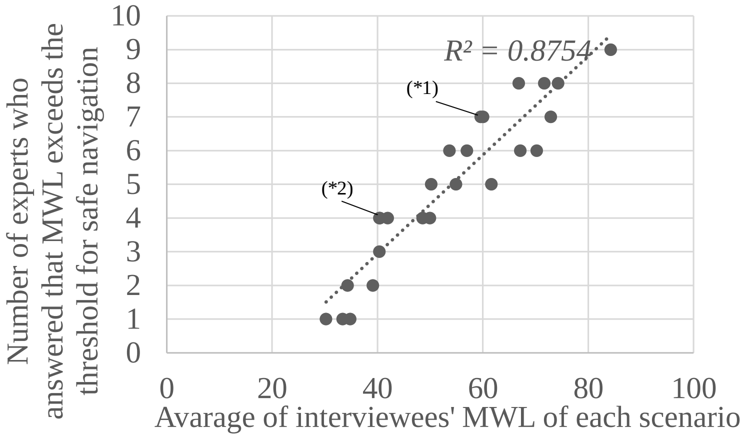
After measuring MWL by using the NASA-TLX (step 2 in Figure 3-3), steps 3 to 5 were analysed.

3.5.1 Relationship between MWL and potential safety risk (Step 3 in Figure 3-3)

Figure 3-5 shows the number of interviewees who answered that their MWL was so high as to feel a potential safety risk of navigation. The horizontal axis shows the aver-age MWL of interviewees in terms of each scenario. The number of interviewees in the vertical axis indicates the level of potential safety risk of navigation. The level of potential safety risk is higher when the number of interviewees in the vertical axis increases.

The results suggest a strong positive correlation between the two variables. The number of interviewees in the vertical axis increases approximately linearly with the increase in the average of interviewees' MWL in the horizontal axis. This means that the potential safety risk of navigation (vertical axis) increases when MWL (horizontal axis) increases. This can verify the theory on the relationship between the potential safety risk of navigation and MWL in Section 3.2.1 from one side. When MWL increases and becomes too high, a navigational safety risk emerges. Thus, this case study can identify the relationship between MWL and MASS in the context of minimising the navigational safety risk by decreasing the MWL.

On the other hand, Section 3.2.1 also indicates another theory on the relationship between navigation safety risk and MWL. The potential safety risk of navigation emerges when MWL is too low due to careless attitude, etc. If this theory could be verified, the number of experts in the vertical axis would increase when MWL in the horizontal axis was very small (negative correlation). However, the results do not show a negative correlation. Thus, the case study can neither justify the theory nor identify the relationship between MWL and MASS in the context of minimising the navigational safety risk by avoiding a too-low MWL.



(*1) Two points (MWL is 59.60 and 60.03) are overlapped
(*2) Two points (MWL is 40.33 and 40.43) are overlapped

Figure 3-5. Relationship between the average of weighted MWL and potential navigation risk.

3.5.2 Gap of MWL in each element (Step 4 in Figure 3-3)

Ship autonomy level

Table 3-8 shows the average weighted MWL of interviewees (n = 10) with the matrix of the navigation manning and level of autonomy. As described in Section 3.4.2, the op-tion of a combination of MO-3 and LoA-1 (grey-coloured cell in Table 3-8: a responsible operator (RO) onboard navigates the ship alone without any autonomous system and support by lookout) was not applied in this study. Rough video was displayed on the screen at RCC (LoDT-2 in Table 3-5). The ship was assumed to navigate the coastal water in clear visibility (NC-2 in Table 3-2). Figure 3-6 shows the scenarios considered to have a significant difference between the level of autonomy in the same manning options ($p < 0.05$ of t-test (two-trailed)). Cells (scenarios) at a start point and an endpoint of an arrow line in the figure are significantly different. Table 3-9 shows the difference of MWL in the scenarios extracted in Figure 3-6. Table 3-10 breaks down the differences into six sub-elements and describes the sub-elements considered to have a significant difference between them ($p < 0.05$ of t-test). These suggest the following findings:

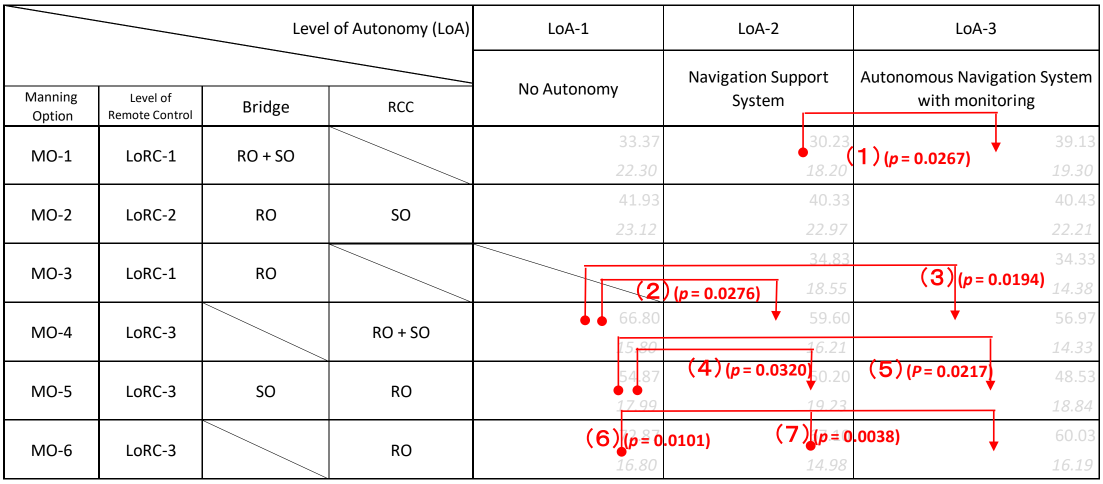
- Installation of navigation support systems (LoA-2) and autonomous navigation systems (LoA-3) do not show apparent positive effects on the MWL of responsible operators (ROs) when they are onboard a ship (MO-1, MO-2 and MO-3). The autonomous system rather negatively affected MWL in one case ((1) in Figure 3-6 and Table 3-9);

- Installation of navigation support systems (LoA-2) and autonomous navigation systems (LoA-3) show apparent positive effects on the MWL when ROs are at the RCC (MO-4, MO-5 and MO-6);
- MWL of ROs does not clearly change between navigation support (LoA-2) and autonomous navigation (LoA-3) when they are at RCC and lookouts support them (MO-4 and MO-5). Positive effects emerge when they navigate alone at the RCC (MO-6: (7) in Figure 3-6 and Table 3-9);
- Mental demands are the key sub-elements to decrease the MWL of ROs at RCC when autonomous navigation systems are installed in the case of (3), (5) and (6) in Figure 3-6 (Table 3-10). Mental demands were also the key sub-elements which increased the MWL of ROs on the bridge when autonomous navigation systems were installed in the case of (1) of Figure 3-6 (Table 3-10);
- Effort was the key sub-element to decrease the MWL of ROs at RCC when autonomous navigation systems were added to the navigation support systems in the case of (7) of Figure 3-6 (Table 3-10).

Table 3-8. Average rating of MWL (matrix of navigation manning and level of autonomy).

Manning Option and Level of Remote Control				**Level of Autonomy**		
Manning Option	**Level of Remote Control**	**Bridge**	**RCC**	**LoA-1**	**LoA-2**	**LoA-3**
				No Autonomy	**Navigation Support System**	**Autonomous Navigation System with Monitoring**
MO-1	LoRC-1	RO + SO	-	33.37(22.30)	30.23 (18.20)	39.13 (19.30)
MO-2	LoRC-2	RO	SO	41.93(23.12)	40.33 (22.97)	40.43 (22.21)
MO-3	LoRC-1	RO	-		34.83 (18.55)	34.33 (14.38)
MO-4	LoRC-3	-	RO + SO	66.80(15.80)	59.60 (16.21)	56.97 (14.33)
MO-5	LoRC-3	SO	RO	54.87(17.99)	50.20 (19.23)	48.53 (18.84)
MO-6	LoRC-3	-	RO	72.87(16.80)	67.10 (14.98)	60.03 (16.19)

Numbers in parentheses are standard deviations. RO, responsible operator; SO, support operator.



Manning Option	Level of Remote Control	Bridge	RCC	LoA-1 No Autonomy	LoA-2 Navigation Support System	LoA-3 Autonomous Navigation System with monitoring
MO-1	LoRC-1	RO + SO		33.37 22.30	30.23 18.20	39.13 19.30
MO-2	LoRC-2	RO	SO	41.93 23.12	40.33 22.97	40.43 22.21
MO-3	LoRC-1	RO			34.83 18.55	34.33 14.38
MO-4	LoRC-3		RO + SO	66.80 15.80	59.60 16.21	56.97 14.33
MO-5	LoRC-3	SO	RO	54.87 17.99	50.20 19.23	48.53 18.84
MO-6	LoRC-3		RO	72.87 16.80	67.10 14.98	60.03 16.19

Figure 3-6. Scenarios that have a significant difference between LoA in the same MO according to t-test (p < 0.05) (described by arrow lines).

Table 3-9. Difference of MWL in scenarios extracted in Figure 3-6.

In Manning Option	MWL of RO in LoA-Endpoint of Arrow Line in Figure 3-6	Increase or Decrease	Comparison to MWL of RO in LoA-Start Point of Arrow Lines in Figure 3-6 (Parentheses are numbers in Figure 3-6) [Square brackets are difference of MLW]
MO-1	LoA-3	increase	(1) LoA-2 [+8.9]
MO-4	LoA-2	decrease	(2) LoA-1 [−7.20]
	LoA-3	decrease	(3) LoA-1 [−9.83]
MO-5	LoA-2	decrease	(4) LoA-1 [−4.67]
	LoA-3	decrease	(5) LoA-1 [−6.34]
MO-6	LoA-3	decrease	(6) LoA-1 [−12.84], (7) LoA-2 [−7.07]

Table 3-10. Sub-elements of MWL that have a significant difference on each number in Figure 3-6 (p < 0.05 of t-test).

No	$p < 0.05$	No	$p < 0.05$	No	$p < 0.05$	No	$p < 0.05$	No	$p < 0.05$	No	$p < 0.05$	No	$p < 0.05$
(1)	MD	(2)	-	(3)	MD/TD	(4)	EF	(5)	MD	(6)	MD/FR	(7)	EF

MD, mental demands; TD, temporal demands; EF, effort; FR, frustration level.

Manning Option

Figure 3-7 shows the scenarios considered to have a significant difference between manning options in the same level of autonomy (p < 0.05 of t-test) in Table 3-8. Cells (scenarios) at the start point and endpoint of an arrow line in the figure have a signifi-cant difference. Table 3-11 shows the difference of MWL in the scenarios extracted in Fig-ure 7. Table 3-12 breaks down the difference into six sub-elements and describes the sub-elements considered to have a significant difference between them ($p < 0.05$ of t-test). These suggest the following findings:

- Formation changes between the onboard bridge and RCC (MO-1 and MO-2) and the decrease in lookouts (MO-3) generally do not have apparent effects on MWL of the responsible operators (ROs), regardless of the level of autonomy when they are onboard a ship;
- MWL of the ROs significantly worsens when they are at RCC (MO-4, MO-5, and MO-6) compared to when they are on the bridge of a ship (MO-1, MO-2, and MO-3). The effects especially emerge when ROs operate alone at RCC (MO-6: (1), (2), (9)–(10), (11), (21) –(23) in Figure 3-7 and Table 3-11). Negative effects on MWL are much smaller when an autonomous navigation system has been installed (LoA-3) compared to no autonomy (LoA-1) and navigation support (LoA-2). In other words, an autonomous navigation system works well to alleviate the mental stress of ROs at RCC (Figure 3-7);
- MWL of ROs at RCC decrease when a lookout onboard a ship supports them (MO-5), compared to the other cases (MO-4 and MO-6) when they are at RCC ((3), (6), (13), (16) and (24) in Figure 3-7 and Table 3-11);
- The set of mental demands and frustration are the overwhelming sub-elements that show the clear effects according to the change of navigation manning ((1), (2), (4), (7)–(11), (14), (15), (17)–(26) of Table 3-12);
- Time pressure, effort, and own performance emerged in two cases as significant sub-elements that increase MWL. Both cases are related to the situation where the lookout supports RO navigating at RCC ((6) and (13) in Table 3-12).

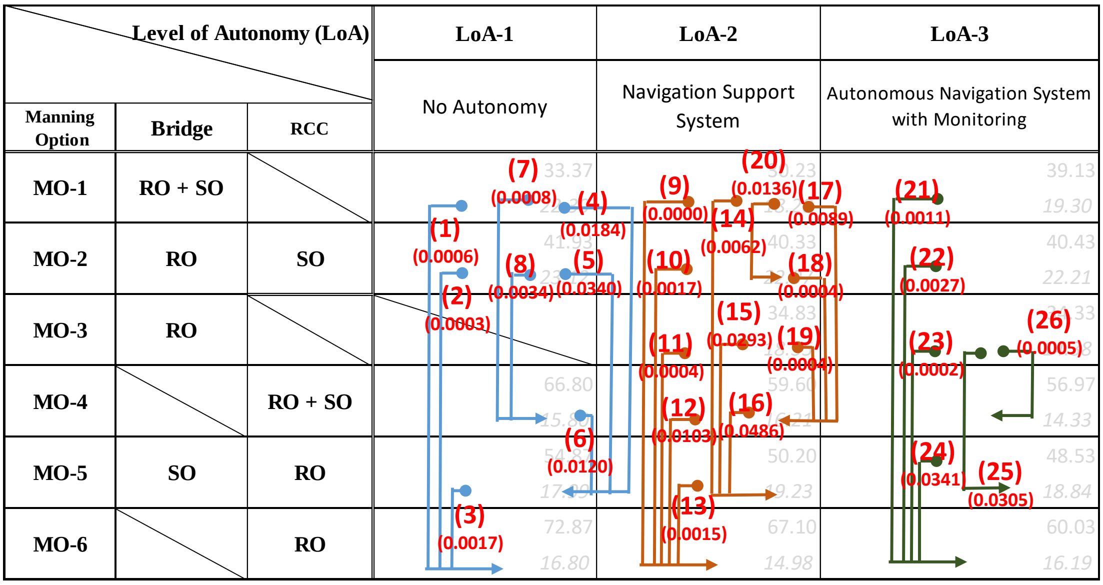


Figure 3-7. Scenarios that have a significant difference between MO in the same LoA according to t-test (p < 0.05) (de-scribed by arrow lines). Numbers in parentheses are p-values of the t-tests.

Table 3-11. Difference of MWL in scenarios extracted in Figure 3-7.

In LoA	MWL of RO in MO-Endpoint of Arrow Line in Figure 3-7	Increase or Decrease	Comparison to MWL of RO in MO-Start Point of Arrow Lines in Figure 3-7 (Parentheses are Numbers in Figure 3-7) [Square Brackets are Difference of MLW]
LoA-1	MO-6	increase	(1) MO-1 [+39.5], (2) MO-2 [+30.94], (3) MO-5 [+18.00]
	MO-5	increase	(4) MO-1 [+21.5], (5) MO-2 [+12.94]
		decrease	(7) MO-4 [−11.93]
	MO-4	increase	(7) MO-1 [+33.43], (8) MO-2 [+24.87]
LoA-2	MO-6	increase	(9) MO-1 [+36.87], (10) MO-2 [+26.77], (11) MO-3 [+32.27], (12) MO-4 [+7.5], (13) MO-5 [+16.90]
	MO-5	increase	(14) MO-1 [+19.97], (15) MO-3 [+15.37]
		decrease	(16) MO-4 [−9.40]
	MO-4	increase	(17) MO-1 [+29.37], (18) MO-2 [+19.27], (19) MO-3 [+24.77]
	MO-2	increase	(20) MO-1 [+10.1]
LoA-3	MO-6	increase	(21) MO-1 [+20.90], (22) MO-2 [+19.60], (23) MO-3 [+25.70], (24) MO-5 [+11.50]
	MO-5	increase	(25) MO-3 [+14.20]
	MO-4	increase	(26) MO-3 [+22.64]

Table 3-12. Sub-elements of MWL that have a significant difference on each number in Figure 3-7 ($p < 0.05$ of t-test).

No.	$p < 0.05$	No.	$p < 0.05$	No.	$p < 0.05$	No.	$p < 0.05$
(1)	MD/FR	(2)	MD/FR	(3)	MD	(4)	MD/FR
(5)	FR	(6)	MD/TD	(7)	MD/FR	(8)	MD/FR
(9)	MD/FR	(10)	MD/FR	(11)	MD/FR	(12)	-
(13)	OP/EF/FR	(14)	MD/FR	(15)	MD/FR	(16)	-
(17)	MD/FR	(18)	MD/FR	(19)	MD/FR	(20)	MD/FR
(21)	MD/FR	(22)	MD/FR	(23)	MD/FR	(24)	MD/FR

(25)	MD/FR	(26)	MD/FR

MD, mental demands; TD, temporal demands; EF, effort; FR, frustration level; OP, own performance.

Navigational Condition

Table 3-13 shows the average weighted MWL of interviewees (n = 10) depending on navigational condition. As described in Section 3.4.2, two typical manning cases are applied; every navigation staff is on board a ship (MO-1) and at RCC (MO-4). Rough video is displayed on the screen at RCC (LoDT-2 in Table 3-5). The ship is assumed to have an autonomous navigation system (LoA-3). Figure 3-8 shows the scenarios considered to have a significant difference between navigational conditions in the same manning option ($p < 0.05$ of t-test). Cells (Scenarios) at a start point and an endpoint of an arrow line in the figure have a significant difference. Table 3-14 shows the difference of MWL in the scenarios extracted in Figure 3-8. Table 3-15 breaks down the difference into six sub-elements and describes the sub-elements considered to have a significant difference between them ($p < 0.05$ of t-test). These suggest the following findings:

- MWL significantly increases when the visibility is restricted due to weather conditions (NC-3 and NC-4) compared to the clear visibility (NC-1 and NC-2), even if the ships have an autonomous navigation system (LoA-3) ((1) to (6), (8) and (9) in Figure 3-8 and Table 3-14).
- MWL is quite high when traffic condition is severest in the channel in bad weather (NC-4). The responsible operators (ROs) especially feel the highest mental stress in all 25 scenarios of the study when they are at RCC (Table 3-13).
- Responsible operators feel more time pressure in the congested channel (NC-4) than navigating in the other areas when they are at RCC (MO-4) ((5)–(7) in Table 3-15). Notwithstanding, mental demands and frustration are also the primary sources of a significant increase in MWL in general (Table 3-15).

Table 3-13. Average rating of MWL (navigational area).

Manning Option and Level of Remote Control			Navigational Condition			
	Bridge	RCC	NC-1	NC-2	NC-3	NC-4

Manning Option	Level of Remote Control			Ocean: relatively clear visibility	Coastal: clear visibility	Coastal: restricted visibility	Channel: restricted visibility
MO-1	LoRC-1	RO + SO	-	40.37(20.37)	39.13(19.30)	61.60(18.55)	70.23(19.77)
MO-4	LoRC-3	-	RO + SO	53.67(14.87)	56.97(14.38)	71.67(20.95)	84.27(14.45)

Numbers in parentheses are Standard Deviation. RO: Responsible operator, SO: Support operator.

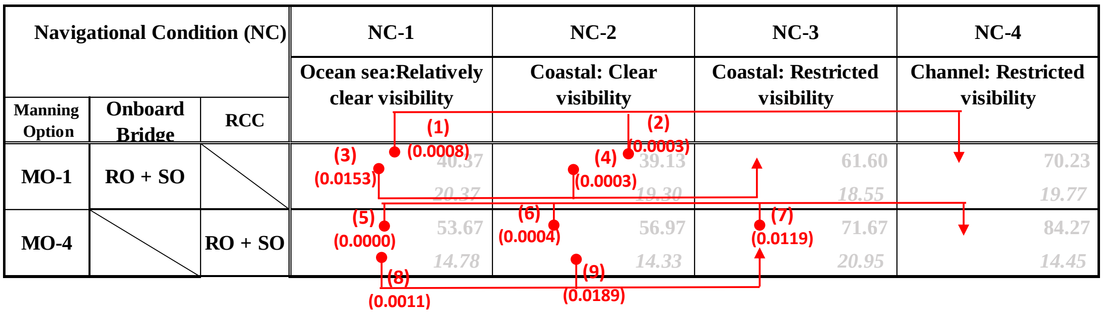


Figure 3-8. Scenarios that have a significant difference between navigational conditions in the same MO according to t-test (p < 0.05) (described by arrow line) (Number in parentheses is p-value of t-test).

Table 3-14. Difference of MWL in scenarios extracted in Figure 3-8.

In Manning Option	MWL of RO in NC-Endpoint of Arrow Line in Figure 3-8	Increase or Decrease	Comparison to MWL of RO in NC-Start Point of Arrow Lines in Figure 3-8 (Parentheses are Numbers in Figure 3-8) [Square Brackets are Difference of MLW]
MO-1	NC-4	increase	(1) NC-1 [+29.86], (2) NC-2 [+31.1]
	NC-3	increase	(3) NC-1 [+21.23], (4) NC-2 [+22.47]
MO-4	NC-4	increase	(5) NC-1 [+30.6], (6) NC-2 [+27.30], (7) NC-3 [+12.6]
	NC-3	increase	(8) NC-1[+18.00], (9) NC-2 [+14.70]

Table 3-15. Sub-elements of MWL that have a significant difference on each number in Figure 3-8 (p < 0.05 of t-test).

No.	$p < 0.05$	No.	$p < 0.05$	No.	$p < 0.05$	No.	$p < 0.05$
(1)	MD/FR	(2)	MD/FR	(3)	MD/FR	(4)	MD/FR
(5)	MD/TD/FR	(6)	MD/TD	(7)	TD	(8)	MD/FR
(9)	-						

Level of Data Transmission to RCC (LoDT) (Visibility on the Screen)

Table 3-12 shows the difference of MWL of interviewees (n=10) depending on the screen's visibility. Every operator is at RCC (MO-4) in the coastal area with comparably clear weather (NC-2). The ship is assumed to have an autonomous navigation system (LoA-3). Figure 3-9 shows the items considered to have a significant difference between them (p<0.05 of t-test). Table 3-13 breaks down the difference into six subscales and describes the scale considered to have a significant difference between them (p<0.05 of t-test). These suggest the following findings:

- Table 3-16 shows the average weighted MWL of interviewees (n = 10) depending on the screen's visibility. Every operator was at RCC (MO-4) in the coastal water in clear visibility (NC-2). The ship was assumed to have an autonomous navigation system (LoA-3). Figure 3-9 shows the scenarios considered to have a significant difference between data transmission levels ($p < 0.05$ of t-test). Cells (scenarios) at a start point and at an endpoint of an arrow line in the figure have a significant difference. Table 3-17 shows the difference of MWL in the scenarios extracted in Figure 3-9. Table 3-18 breaks down the difference into six sub-elements and describes the sub-elements considered to have a significant difference between them ($p < 0.05$ of t-test). These suggest the following findings:
- MWL significantly increased when the responsible officers (ROs) could see only a static image on the screen at RCC (LoDT-1: (1) and (2) in Figure 3-9 and Table 3-17). On the other hand, a significant difference between rough video (LoDT-2) and clear video (LoDT-3) was not found;
- Time pressure and frustration were the main critical sub-elements in a significant change (Table 3-18).

Table 3-16. Average rating of MWL (visibility on the screen).

Manning Option and Level of Remote Control				**Level of Data Transmission to RCC**		
Manning Option	Level of Remote Control	Bridge	RCC	LoDT-1	LoDT-2	LoA-3 LoDT-3
				Static image: 1 picture/10 s	Rough video	Clear video
MO-4	LoRC-3	-	RO + SO	74.27 (12.29)	56.97 (14.33)	49.93 (13.86)

Numbers in parentheses are standard Deviations. RO, responsible operator; SO, support operator.

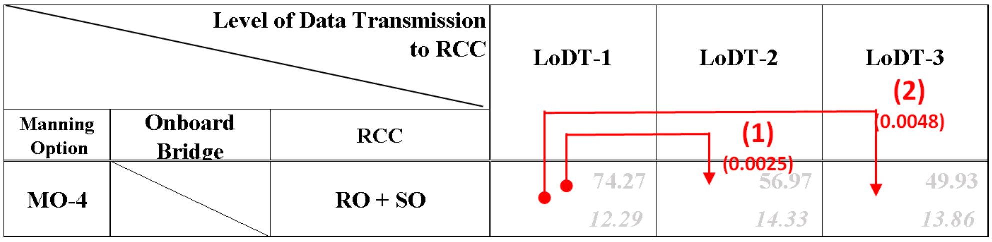


Figure 3-9. Scenarios that have a significant difference between level of data transmission to RCC according to t-test (p < 0.05) (described by arrow lines). Numbers in parentheses are p-values of t-tests.

Table 3-17. Difference of MWL in scenarios extracted in Figure 3-9.

In Manning Option	MWL of RO in LoDT-Endpoint of Arrow Line in Figure 3-9	Increase or Decrease	Comparison to MWL of RO in LoDT-Start Point of Arrow Lines in Figure 3-9 (Parentheses Are Numbers in Figure 3-9) [Square Brackets are Difference of MLW]
MO-4	LoDT-2	decrease	(1) LoDT-1 [−17.30]
	LoDT-3	decrease	(2) LoDT-1 [−24.34]

Table 3-18. Sub-elements of MWL that have a significant difference on each number in Figure 3-9 (p < 0.05 of t-test).

No.	*p* < 0.05	No.	*p* < 0.05
(1)	TD/FR	(2)	MD/TD/EF/FR

MD, mental demands; TD, temporal demands; EF, effort; FR, frustration level.

3.5.3 Summary of the Results

Table 3-19 sums up key points of the results in Section 3.5.2. The table also suggests the main linkages between the factors and the findings described in Section 3.6.1.

Table 3-19. Summary of the results in Section 3.5.2.

Factor	Key Sub-Elements of MWL That Mainly Cause MWL Change	Note (Effects on MWL)	Main Linkage with Findings in Section 3.6.1 (Section Number)
Level of Autonomy (LoA)	MD EF	**RO is on the bridge** - No significant effect (negative effects in one case) **RO is at RCC**	- Reliability of the autonomous system (6.1.4) - Mechanical-style movement of the system (6.1.5)

		- Positive effects by installing autonomous systems - No significant effect between NSS and ANS (except when RO is alone)	
Manning Option (MO)	MD FR	**RO is on the bridge** - No significant effect by manning change **RO is at RCC** - Significant negative effects compared when RO is on the bridge - Decrease in MWL when lookout is on the bridge	- Reliability of the autonomous system (6.1.4) - Conflicted situation (6.1.1) - Physical restriction (6.1.2) - Human–human and human–machine interface (6.1.3)
Navigational Condition (NC) (area, traffic density, weather, visibility)	TD MD FR	- Negative effects under high traffic density -Significant negative effects in restricted visibility in bad weather	- Conflicted situation (6.1.1) - Visibility constraint (6.1.6)
Level of Data Transmission to RCC (LoDT) (visibility on the screen)	TD FR	- Significant negative effects by using a static image - No significant effect between rough and clear movie	- Visibility constraint (6.1.6)

MD, mental demands; TD, temporal demands; EF, effort; FR, frustration level; NSS, navigation support system; ANS, autonomous navigation system.

3.6 DISCUSSION

3.6.1 Imprecation of Results

The results in the last chapter and discussions with interviewees imply some findings on factors that affect the MWL of ROs.

Conflicted situation

The first is the conflicted feeling between the safety and effectiveness of navigation. Crews navigate ships utilising personal capabilities including “spatial awareness” [27]. However, ROs navigate the ship at the RCC under restricted conditions, including limited information. In this situation, they express a desire to largely deviate from the planned route to secure safety. Nevertheless, they also face the pressure to maintain a “cost-effective” route to ensure that the ship arrives at the next destination on time. This situation induces severe ROs mental pressure. Congested situations and the existence of other appearing ships also challenge them to deviate routes for keeping safe. These conditions cause an increase in mental demands and frustration.

Physical restriction

Physical restriction leads to the increment of frustration. An interviewee expressed self-confidence that he could deal with various situations and make decisions with his responsibility even if the condition is harsh when navigating a ship on the bridge. Ac-cording to Hanton and Connaughton [86], self-confidence is closely related to anxiety and performance. When the RO could navigate a ship at a physically different and restricted place, such as the RCC, these situations influence self-confidence. This leads to anxiety about the performance and impatience.

Human-human and human-machine communication

Support of ROs at the RCC by lookouts at the bridge of a ship decreased MWL compared to the other options provided to ROs at the RCC. Interviewees stated that they communicate with lookouts onboard, suggesting that they gather the necessary information. In other words, they utilise the lookouts as part of their “eyes.” They pointed out that human–human communication is mentally more comfortable than using autonomous support and navigation system in this situation. These comments coincide with the suggestion by Guzman and Lewis [87]. According to them, the communication theory between humans and AI, which would be mainly used in the autonomous system, is different from traditional human-based communication. On the contrary, the support from a lookout at the RCC to RO at the bridge did not work well for decreasing the MWL of RO. Interviewees were sceptical of the information which the lookout acquired from the limited visibility of the screen at the RCC. Conflict of in-formation between the lookout and the autonomous system was also a point of concern from an interviewee. The mistake of support by lookouts based on the autonomous system’s wrong information is also a high risk for ROs.

Reliability of the autonomous system

Navigation support and autonomous navigation systems alleviate the high MWL to some extent if ROs remotely operate ships at an RCC. The addition of the ways to support ROs helps them make decisions under limited information, which corresponds to the decrease in mental demands. Nevertheless, these autonomy systems far from completely address the difficult situation, even in comparably clear weather. Innovative technologies should be to “overcome perceptions of risk and uncertainty” by users to improve their reliability [88]. The maritime autonomous system is also the same. Interviewees stressed that they could not wholly rely on the systems even if they were highly reliable and autonomous. An interviewee exemplified that autonomous navigation might misdirect based on the mismeasured information from a defective gyro-compass. Another interviewee pointed out that the stress would be kept high unless ROs could completely confirm that the system makes correct decisions based on appropriate information.

Mechanical-Style Movement of the System

Systematic and impersonal movement of the system would increase the stress. An interviewee suggested the complicated intention of ROs. For instance, ROs sometimes oversteer greatly, then ease to the appropriate position to encourage other ships to be aware of their ship. On the other hand, because human behaviour is quite complicated, the current situation far from completely understands human actions in the technological domain [89]. Therefore, the autonomous navigation system tends to take “mechanical-style” action. When it conducts such unexpected and “mechanical-style” navigations and supports, ROs should consider their meanings. This type of stress emerges even when ROs are at the ship’s bridge.

Visibility constraints

Visibility constraints owing to bad weather such as heavy rain and fog make the MWL much higher than good weather conditions, especially in high-congested areas. Visibility is the main tool for recognising the situation outside the bridge [25]. Multiple interviewees confessed that the limited visibility within one mile with many crossing ships feels so severe as to affect safe navigation in many cases, even when the RO and lookout are onboard. The prompt decision-making in a very short time is inevitable under these situations; thus, the time pressure of ROs rises significantly in addition to mental demands and frustration. All interviewees expressed that they could not imagine remote navigation without the crew’s support onboard with maintaining safety and stable mental conditions, even if highly reliable autonomous navigation systems were installed. An interviewee suggested that he could not judge whether the information from autonomous systems was accurate under the limited data transform condition, because the situation outside a ship changes rapidly. Another interviewee commented that he would turn off the autonomous navigation system under these situations if he was onboard. The most reliable tool is his “eye”, and unexpected intervention by autonomous systems would induce confusion. According to him, this feeling does not change as far as the RO has final responsibility for navigation.

The interruption of visual information that ROs acquire during remote navigation significantly increases the stress. This trend is outstanding in the congested area. ROs should manage a ship by the information of only navigation equipment during the interruption that changes the situation around a ship a lot. For instance, ROs cannot con-firm the movement of small fishing boats that do not have AIS on the screen during the interruption, even though the delay of decision-making for a few seconds would directly lead to an accident. According to interviewees, autonomous systems will not be alternated with visibility information, even if they are highly reliable. The case study used visual data that supplied static images every 10 s. All interviewees were surprised at the time length and stressed the irritated feeling and time pressure due to the lack of visual information while waiting for the next visual image. One unique comment was that 10 s of interruption under non-congested (e.g., ocean) and clear weather conditions would not lead to a significant rise of MWL because ROs can easily predict future situations.

3.6.2 Validity of the Identification Scheme and Limitation of the Case Study

Through the case study, the identification scheme can be verified as a useful tool to specify the factors that affect MWL and sub-elements of MWL that cause the main dif-ference of MWL. These results could largely contribute to the consultation of the devel-opment of regulations and technological development from a mental health perspective of ROs.

On the other hand, the case study also suggests the matters to be addressed for further studies utilising this scheme. Firstly, this case study scrutinises scenarios for the interview on each sub-element due to the time constraint. The result can indicate some trend of change in MWL. Nevertheless, the results would change according to the change of the assumption, such as the experience of operators and MASS navigation. The second is the number of interviewees. As described in Section 3.4.1, participants were carefully selected based on the criteria. In addition, the deck officer with enough competence in accordance with appropriate requirements could uniformly represent same ranked officers different from other normal cases. In fact, the case study worked well to verify the scheme and suggest the trend to some extent. Nevertheless, expanding the set of participants for future work would contribute to acquiring more stable results. Thirdly, the study used a recorded video for interviewees to recognise each option because they were to consider many scenarios. They could identify well and did not claim any restraint to filling in the answers. Notwithstanding, a study based on actual navigation using a simulator or actual MASS could produce more reliable data. The fourth issue is how to define the autonomy level. There are various types and levels of autonomy, and they change according to technological development. Even focusing on collision avoidance, many methods have been studied and developed [90]. The case study relatively defined the autonomy level including the system's reliability in Section 3.3.1., in order for each participant to be able to grasp the image according to their experiences. This approach worked well to some extent without any significant problem. However, a detailed and more objective definition should be considered in future micro-level studies. The last thing is the relationship between MWL and the navigational safety risk (step 3 of Figure 3-3). As described in Section 3.5.1, the case study could not discuss the relationship between MWL and MASS in the context of minimising the navigation safety risk by avoiding a too-low MWL. The main reason is that MWL of the interviewees did not decrease until they became careless in the given scenarios. Future studies are expected to deal with this issue by increasing the factors and options.

3.7 CONCLUSION

Shipping is an essential tool for keeping the supply chain, and sustainable shipping is maintained by skilled and experienced seafarers. Ship autonomy is expected as a useful solution to reduce the stress of the seafarers and marine accidents owing to human error. Despite the recent technological development of autonomous ships, the autonomous systems should also be carefully considered because they might increase MWL. This research firstly explained the relationship between motivated capacity and task demand in the MWL model. Secondly, it defined the factors that possibly affect the MWL of seafarers engaged in the duty of watching MASS navigation, developed a scheme that identifies the sensitive factors to the change of MWL, and detailed MWL sub-elements mainly causing the change of MWL. Then, a case study with a typical scenario focusing on watchkeeping duty in a normal situation was carried out. The case study was performed through the interview of ten (10) officers with various sea-going experiences. MWL was measured using NASA-TLX methods.

The results implied that operators’ MWL is considerably affected due to the conflicted situation, physical situation, the lack of human–machine communication, impersonal movement, and visibility constraints. The study can also confirm the validity of the scheme. At the same time, this study has some limitations, such as the inter-view’s limited scenarios and the use of recorded video because of the physical constraints. Nevertheless, the identification scheme (Figure 3-3) and the additional key factors for MASS (step 1 in Figure 3-3) are beneficial to the maritime sector.

It is expected that this research will be the trigger for further considerations of the development of international and national regulations and technological innovation from seafarers’ mental and health perspectives.

Chapter 4: Analysis on development of international maritime safety regulation

4.1 INTRODUCTION

As described in Chapter 1, technological innovation and technical standard and regulations have a close relationship. Regulations sometimes restrict technologies and hinder their improvement [1]. Conversely, regulations promote technological innovation for dealing with severer restrictions related to safety, environment and labour [2].

Considering these relationships from the view of industrial policy, “technological competition” should be considered as an additional factor. It is vital for each company to quickly respond to the severer regulation by utilising new technologies and be a “first mover,” in order to enhance the competitiveness in the market [91].

There are three patterns as the timeline between regulations and technological innovation; (a) emergence of technological innovation according to the change (enhancement) of regulations, (b) the change (enhancement) of regulations according to the emergence of technological innovation, and (c) simultaneous emergence of both phenomenon. From a “technological competition” perspective, to be a “first mover” taking into account these patterns is important.

The strategy to be a “first mover” is comparably simple if regulation is closed in the loop of each country. Companies can develop and spread new technologies considering the government's policy as the rule maker and the market trend. However, regulations have globalised recently in many sectors. For instance, the WTO/TBT agreement requires each country to establish national technical standards in accordance with international standards. The safety and environmental regulations have also globalized mainly in the transport sectors. Especially in the international shipping domain, almost all technical requirements have been established by international regulations, and each country adopts these mandatory requirements (non-mandatory ones in some cases) in their national rules.

The strategy for international regulations is not the same as the domestic ones. The most significant difference is the number of stakeholders. Various stakeholders, including member states and NGOs, are commonly involved in the consultation for establishing the international rules. That means that Japan is only one of the stakeholders. In such fields, the “national level” activities by collaborating government and industries are essential. It is also the key to take the initiative during the international discussion, at an early stage in particular, and develop the regulation as they expect. Taking into account that the development of new technologies implies a high uncertainty of realization in the market. In this sense, taking the initiative of the rulemaking process is also justified for reducing the risk.

Now the question is raised; how should we take the initiative in international rulemaking? One solution is to identify the characteristics of developed regulations. We can recognise the “positioning” of the innovative technologies in the regulations as the characteristics are identified. The recognition enables effective building of the rulemaking strategy. It can also become a useful tool to propose the new regulations that the innovators have an advantage.

Based on the above background, this chapter aims to define the trend of the rulemaking of the international regulations, which assumes to build the international rulemaking strategy linking technological innovation. In order to achieve the aim, this study focuses on the safety regulations in international shipping in the IMO and constructs the taxonomy on rulemaking based on defined categories.

With regard to domestic safety regulations, many studies analyse the background of their amendments. The examples are the amendment of the Building Standards Act on the back of architectural forgery [92], the relationship between Building Standards Act and Urban Planning Act pertinent to requirements of absolute height [93], and enforcement order of these acts [94]. In addition, the historical and theoretical background of Labor Safety and Health Regulations related to requirements of the height and gradient of the excavation surface [95] and validity of amendments of the Act on the Evaluation of Chemical Substances and Regulation of Their Manufacture, etc., including issues to be discussed in the future, [96] were analysed in the previous research.

When it comes to the international shipping sector, many papers study international requirements in the International Maritime Organization (IMO). For example, Schröder-Hinrichs et al. [50] analyse the trend of discussion in the IMO, focusing on human factors based on literature and documents in Maritime Safety Committee(MSC) of IMO. Knudsen and Hassler [97] extract the cause of that IMO regulations do not always contribute to the decrease of marine accidents and deficiencies, according to the results of Port State Control (PSC) in the Baltic Sea. Størkersen et al.[98] verify the validity of Safety Management Systems (SMS) based on the results of interviews with experts, focusing on the International Safety Management (ISM) Code. Moreover, a study analyses the priority and importance of safety based on interviews with seafarers [99]. However, the past studies have not linked the innovation strategy with the trend of developing technological regulations in international shipping sectors, including the background of rulemaking, which is comprehensively analysed and categorized.

The remaining sections are as follows. The next section organizes the outline of the safety requirements in the international shipping sector. Section 4.3 and 4.4 explain the target of analysis, and extracted items and the method for categorization, respectively. Section 4.6 discusses the results that are shown in Section 4.5. Section 4.7 concludes this chapter.

4.2 SAFETY REQUIREMENTS IN THE INTERNATIONAL SHIPPING SECTOR

4.2.1 Convention related to safety requirements in the international shipping sector

International regulations in the international shipping sector have been developed and established in the IMO, a specialized organization of United Nations (UN). Inter−Governmental Maritime Consultative Organization (IMCO), the previous body of IMO, was established by the adoption of IMCO Convention in 1948. IMO aims to enhance maritime safety, environmental protection and preservation, deal with regulatory issues, etc. The following safety-related conventions have been adopted in the IMO. These conventions consist of Articles and Annex in which technical requirements are included. The next sections apply to these conventions.

- International Convention for the Safety of Life at Sea, 1974 (SOLAS Convention): The Convention requires the technological requirements on ship safety. This Convention was adopted in 1974, and the latest version was adopted in 1974 (Entry into force in May 1980). One hundred sixty-six member states have ratified the Convention.

- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention): The Convention requires the competence of seafarers and watchkeeping, etc. This Convention was adopted in 1978 and entered into force in1984. One hundred sixty-five member states have ratified the Convention.
- Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREG): The Convention requires traffic rules in the sea to prevent ship collisions. The current Convention was adopted in IMCO after the first adoption in 1889 (Entry into force in 1977). One hundred sixty member states have ratified the Convention.

4.2.2 The ways to develop safety requirements in the IMO

The safety requirements are developed mainly in the following two ways. This section regards both mandatory and non-mandatory instruments as safety requirements.

Mandatory requirements (Convention (Annex), Protocol, Mandatory code)

With regard to the SOLAS Convention (Article and Annex I (General)) and the STCW Convention (Article), Maritime Safety Committee (MSC) adopts amendments of the conventions, then member states of two-thirds and more should accept the amendments (Explicit scheme). On the other hand, regarding Annexes stating safety requirements, amendments automatically enter into force unless either Contracting Governments that have gross tonnage of ships not less than 50% of world merchant ships or more than one-third of Contracting Governments notify the objection (Tacit Scheme). COLREG also applies a similar tacit scheme for the amendments; they automatically enter into force unless Contracting governments of more than one-third notify the objection by the date decided by the Assembly after its adoption. Thus, the process for the amendments of mandatory requirements is simplified to reduce the time. It is also noted that the mandatory codes and standards are often established to supplement the regulation in the Convention (e.g., International Code for Application of Fire Test Procedures (FTP Code)). These codes include non-mandatory requirements in some cases.

Non-mandatory requirements (e.g., guidelines, guidance)

IMO has established non-mandatory requirements such as guidelines, guidance and interpretation to supplement mandatory requirements in the Conventions, deal with the difficult issues to implement by the Conventions, shorten the term for developing mandatory requirements, acquire uniformed interpretation, etc. Contracting countries do not need to comply with these non-mandatory requirements. On the other hand, countries voluntarily incorporate the guidelines into national laws in many cases. Class societies and shipping industries also incorporate them into their standard. Therefore, these non-mandatory requirements are regarded as important instruments.

4.2.3 Process of rulemaking of safety requirements

Addition of a new work programme

The Assembly decides the work programme to be discussed in the IMO regarding maritime safety after the consideration by Council based on a proposal prepared in the MSC. The new work programme should be included in the agenda of MSC or sub-committees in the IMO. MSC discussed the new work programme proposed by member states (sometimes sub-committees) and decides whether it includes the programme as an agenda as well as items to be provided in the output of the agenda. The discussion in MSC is critical considering that the Council and Assembly basically confirm the results of MSC except for special cases. The next section explains in detail the proposal for the new work programme and the process of the discussion.

Discussion of safety requirements

Sub-committees make technical discussions on the new agenda in accordance with Terms of References (ToR) agreed in MSC. MSC sometimes discuss it by itself without suggesting to sub-committees. Seven (7) sub-committees have been carried out in the IMO. Safety requirements are discussed mainly by Sub-Committee on Human Element, Training and Watchkeeping (HTW), Navigation, Communications and Search and Rescue (NCSR), Carriage of Cargoes and Containers (CCC) and Ship Systems and Equipment (SSE). Intersessional Working Group (ISWG) and Corresponding Group (CG) discuss technical matters on some important agenda between the meetings in accordance with ToR of discussed MSC or sub-committees. One to three times of sub-committees are set by MSC for discussing the agenda;

however, it often happens that the term is extended, for example, while the discussion needs more time and comments from other sub-committees.

Adoption of safety requirements

Draft safety requirements approved in the sub-committees are sent to MSC. Mandatory requirements such as conventions and mandatory code related to the SOLAS Convention and the STCW Convention are communicated (sent) to all Parties after approved by MSC. After six months and more of communication, the MSC meeting adopts the draft requirements by a two-thirds majority. These conventions have another option by a diplomatic conference, although this chapter does not explain it in detail. They enter into force after 18 months of the adoption at the earliest case by the tacit scheme. With regard to the SOLAS Convention, almost draft mandatory requirements adopted after 2016 enter into force every four years (The next date of entering into force is on January 1st of 2024 about the draft amendments adopted by July 1st of 2022.). Regarding COLREG, the amendments enter into force on the date decided in the Assembly by the tacit scheme after its adoption by two-third majority according to MSC’s adoption and more than six months of circulation term after that. The non-mandatory requirements process is simpler. They are sent to MSC after the approval by sub-committee(s) and adopted by a simple majority. They can be implemented in the short term since there is no process for entry into force.

4.3 OBJECTS FOR ANALYSIS

4.3.1 New Work Programme

As described in the last section, safety requirements are developed in order of proposal of new work prgoramme, discussion of the contents, and adoption. Contents of requirements and the choice of mandatory or non-mandatory, etc., are decided through detailed discussion in the sub-committees or MSC. On the other hand, the outline and expected output of the requirements have been decided at the timing of the new work programme's consideration. The coverage of discussion of contents is basically limited in the established output. In addition, the clarification of background and necessity should be included in the proposal. Thus, analysis of the new work programme is appropriate to recognise the background and direction of the requirements. The next section shows the outline of the proposal for the new work programme.

4.3.2 Process of the proposal for the new work programme

IMO develops the strategic plan and high-level action plan for every six years (currently 2018-2023) and two years periods, respectively. Both plans are adopted in the Assembly. Every agenda item is included in the planned output of the high-level action plan and adopted in the Assembly. The Council can decide the revised output during the period of the high-level action plan in the MSC subject to the endorsement. A new work programme is generally proposed to MSC as an unplanned output and considered in the committee. The proposal should have a strong relationship with the strategic plan and high-level action plan. MSC discusses whether the proposal can be included in the output based on the preliminary assessment by MSC Chair, taking the following criteria [100] into account. MSC can also consider the results of the Formal Safety Assessment (FSA) based on the FSA guidelines (MSC-MEPC.2/Circ.12/Rev.2), provided that it accepts the results.

- “1. Is the subject addressed by the proposal considered to be within the scope of the mission of IMO?
- .2 Does the proposal involve the exercise of functions conferred upon a Committee by or under any international convention or related instrument?
- .3 Has a need for the output been justified and documented?
- .4 Has an analysis been provided that justifies and documents the practicality, feasibility and proportionality of the proposed output?
- .5 Has the analysis of the issue sufficiently addressed both the cost to the maritime industry and the relevant legislative and administrative burdens?
- .6 Are the benefits that are expected to be derived from the inclusion of the proposed output clearly stated?
- .7 Do adequate industry standards exist or are they being developed?
- .8 Has the proposed output been properly specified in SMART terms (specific, measurable, achievable, realistic, time-bound)?
- .9 Does the completed checklist for considering human element issues by IMO bodies, as set out in MSC-MEPC.7/Circ.1, demonstrate that the human element has been sufficiently addressed?

- .10 If inclusion of the output in the current biennium is proposed, is this action properly justified?
- .11 Would a decision to reject or postpone the commencement of the work in relation to the proposal pose an unreasonable risk to the Organization's overall mission? [100]”

4.4 EXTRACTED ITEMS AND CATEGORIZATION

4.4.1 Extracted items

This research adopts the proposal documents on the new work programme submitted to MSC as the research data that objectively show the background and necessity of rulemaking on maritime safety. It uses the documents submitted to MSC from member states for 14 years from 2006 to 2019 (MSC 81 to 101) and excludes the documents that were decided not to be included as a new agenda.

Required items in the documents are as follows, although they are different between submitted years; a) Introduction (e.g., Background), b) Need, c) Analysis of the issue, d) Analysis of implications, d) Benefits, e) Industry standards, f)Output, g) Human element, and h) Urgency and Target term.

On the other hand, each document has a difference in the level of description and contents in many cases. Moreover, some documents are not suitable for analysis since the description is stereotyped. Therefore, this paper extracts the following factors from the documents to objectively and sufficiently acquire the contents that follow this research's objective. Figure 4-1 shows the image of the extracted factors.

- Background and motivation for the development of the requirements (social viewpoint) - The background and motivation that lead to the establishment and amendments of the requirements are important indicators for assessing the imperious needs. Rational reason in line with the objective of the IMO of enhancing the safety requirements to the practical level [101] is necessary to start the development of the requirements.
- Safety requirements (technological viewpoint) - It is necessary to identify correctly what parts of safety the innovative technologies seek to enhance when consulting the strategy. Therefore, this research extracts the safety requirements that the proposal expects to develop.

- Regulatory issues (legal viewpoint) - The assumption of the development of requirements is to have a gap between expected rules and existing regulations. There would be no need if any issues were not be found in the existing provisions. Conversely, if any, the issues show explicitly or implicitly the solution to tackle the problem. Thus, this paper extracts regulatory issues of existing requirements from the proposal.

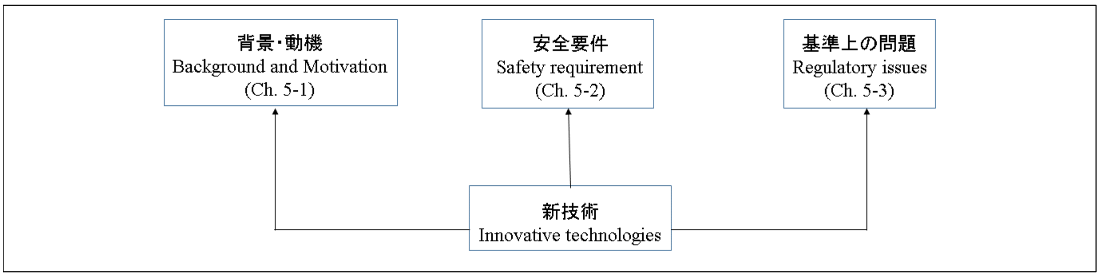


Figure 4-1. Overview of taxonomy on the establishment of safety requirements.

4.4.2 Categorisation

Each factor extracted in accordance with the last section is analysed and categorized based on past studies and literature. The taxonomy is generalised to the possible extent (e.g., IoT and new technology). Each proposal can be categorized with multiple items considering its complexity.

4.4.3 Level of taxonomy

Categorised items are divided by hierarchical taxonomy. This study adopts the bottom-up method; Large categories are provided based on subcategories after the smallest subcategories are decided as described in the last section. The co-relationship between different hierarchies is confirmed through feedback from larger categories to smaller ones.

4.5 RESULTS

4.5.1 Taxonomy on background and motives for the establishment of safety requirements

Table 4-1 shows the outline of the results on the analysis of background and motivation for developing safety requirements. The next sections explain it in detail.

Table 4-1. Overview about the taxonomy on background and motives for establishment of safety requirements.

Level 1	Level 2	Level 3

Accidents/Inspections	Specific accidents	Large scale marine accidents
		Middle or small scale accidents
	Increase or frequency of accidents	
	Inspections	e.g., Port State Control (PSC)
Change in environment	Change in maritime needs	
	Practice and dissemination of new technologies	Internet of Things (IoT)
		Other innovative technologies (e.g., materials)
	Other environmental changes	Future social risk (e.g., seafarers, security)
Recognition of other issues	Implementation of recently established or amended requirements	
	Requirements established a long time ago	
	Others	

Accident and Inspection

Specific marine accidents

Marine accidents are the main cause for enhancing the safety regulations. Tremendous accidents and disasters generally lead to appropriate and necessary action [102]. IMO has also established and amended the conventions according to large accidents. Examples are the sinking of the Titanic that became the trigger of the establishment of SOLAS, 1974, and the sinking of MS Estonia in 1994 that lead to the amendment of the SOLAS Convention. Moreover, the accident of MS Herald of Free Enterprise in 1987 started the active discussion on the human element in the 1990s [50]. A recent example is the disaster of a large cruise ship MS Costa Concordia that ran aground and capsized in 2012. This accident led to the proposal for amendments to the safety regulations on evacuation procedures and instructions. In addition, the explosion and sinking of the drilling rig, Deepwater Horizon, which happened in the Gulf of Mexico in 2010, led to the proposal for amending safety requirements on fire prevention and dynamic positioning system.

Not only large and tragic accidents but also comparably medium and small-sized accidents are the trigger of the amendments in many cases. One of the reasons is that political pressure tends to focus on strengthening safety regulation once marine accidents happen near the coast of each country [97]. The results of the accident investigation are another reason. These accidents are not limited to typical marine accidents such as fire, flooding and sinking. For example, safety requirements for construction and installation of onboard lifting apparatus were proposed based on the accident due to a cargo handling crane's failure. In addition, requirements for design and prototype testing of free-fall lifeboats were proposed due to the accident by the boat's unintentional release.

The results of studies on recent multiple accidents and similar types of accidents as well as a rapid increase in these accidents also become the motivation for the proposal. For instance, the increase of accidents during tender operations utilising lifeboats in cruise ships introduced the proposal on safety requirements for these boats. Revision of requirements on the accommodation ladder was proposed based on the increase of accidents by pilots being onboard ships. Incident reports related to Cargo Transport Units (CTU) connect the proposal for enhancing the inspection programme.

Inspection

The primary inspection on the ship safety is the Port State Control (PSC) in addition to the statutory regular survey (e.g., renewal and periodical surveys) required by the conventions such as the SOLAS Convention. In PSC, officers in national states inspect foreign ships to verify that these ships appropriately comply with the requirements of each convention. According to the deficiency level, the port states take appropriate actions to the ships regarded as substandard ones, including detention. Around 30,000 deficiencies and 983 detentions are reported in Asian and Pacific area in 2019 [103]. The level of risk of future accidents and the number of deficiencies in PSC have strong co-relationship, especially on significant disasters [104]. Based on these backgrounds, the safety issues are sometimes extracted from PSC results and lead to the IMO requirements proposal. For example, standardisation of the emergency drill is proposed owing to the deficiencies by PSC. Inspection campaigns by regional port states in cooperation with regional PSC organizations also result in the proposal. Another unique cause for the proposal to standardise the requirements is the fact and implied risk that PSC officers' suggestions are different between the port states (e.g., mechanism of davit of a lifeboat).

Environmental change

Change in maritime needs

Maritime needs change according to the change in external environments, such as increased ship transport and global warming countermeasures. The shipping trend definitely expresses the situation of global production and is largely affected by the change of the whole society, such as geopolitics and value chain [105]. The change in the shipping demand also affects ships themselves. The increase of container ships' size is an example [106]. Containerisation of shipping cargo in the 1980s led to increased ship transport and sizable container ships. The ships carrying more than 12,000 TEU containers are currently operated. The necessity to deal with these changes connects to the proposal of new requirements. For example, the appearance of specialized and larger sized ships has increased the ship damage by the parametric roll and pure loss of stability, etc. To tackle the issues, the development of 2nd phase intact stability requirements started [107]. The proposal documents also include the comprehensive review of requirements based on the increment of large passenger ships with the increased demand of cruise tours worldwide, and the development of emergency procedures, including assistance to passengers, to deal with diversified passengers (e.g., infant and disabled persons). In addition, the increased size of a container ship and a cargo container leads to the proposal of fire protection on deck and visibility from the bridge during watchkeeping. Moreover, some documents are related to the change of social needs in the environment sector. For example, offshore wind energy facilities have increased with heightening worldwide interest in global warming. Based on this trend, amendments of General Provisions on Ships' Routening (GPSR) was proposed.

Practice and dissemination of new technologies

Pettit et al.[105] define five innovation phases since the 1700s in the maritime sector as same as the other sectors, based on the study by Rodrigue and Notteboom [108]. The latest phase is the fifth one since the 1990s, including IT-related innovations such as digital networks and software and the increased ship size. The technological innovation closely links with the change of social and maritime needs described in the last section. One example is the development of LNG-fueled ships to cope with environmental regulation pertinent to NOx, SOx and global warming in the International Convention for the Prevention of Pollution from Ships (MARPOL) [109]. On the other hand, especially regarding the IT sector, some shipping companies actively incorporate innovative technologies in other sectors into the international shipping domain to take a competitive advantage in the maritime industry [110]. MSC has received the proposal based on the practical application and spread of the IT-related new technologies. Examples are the amendments and establishment of the requirements to involve new satellite systems in Worldwide Radionavigation System (WWRNS) and Automatic Identification System (AIS) in Global Maritime Distress and Safety System (GMDSS). Besides IT, standards on pipe and CTU for adapting new material were proposed.

Other environmental changes

Some proposals are not covered in the above types. This section shows two typical cases.

The first case is regarding future social risk. The maritime sector concerns human resources, the future lack of seafarers in particular, in addition to security. One proposal is to ensure the quality of the crew and give an opportunity of education where is raised based on the forecast by ICS and BIMCO [111] of the deficit of 150 thousand crew in 2025.

Another background is the amendments of related regulations, including in other sectors. In some cases, the proposal tries to apply the severer safety requirements in other sectors to the maritime sectors. One example is the application of the prohibition of fire-fighting forms containing perfluorooctane sulfonic acid (PFOS) regulated in the Montreal Protocol on Substances that Deplete the Ozone Layer to the maritime sector.

Recognition of other issues

Implementation of recently established or amended requirements

After the detailed and technical consideration by delegates of each member state and NGOs, MSC adopts the safety requirements. However, issues are sometimes recognised at the implementation stage. This issue is likely to happen when IMO establishes the new safety system. The past research analyses the effects of the regulation on safe return to port and suggests that the requirements have adverse effects on implementation, test and maintenance because of the requirements' complexity despite their positive impact [112]. MSC also receives various proposals related to these issues. Some examples are the unified interpretation of amended SOAL Convention pertinent to a safe return to port, evaluation criteria of thermal performance of immersion suits related to amended International Life-Saving Appliance (LSA) Code, post-rescue support and repatriation pertinent to amended International Convention on Maritime Search and Rescue (SAR), and guidance related to mandatory requirements on ECDIS.

Requirements established a long time ago

Requirements are sometimes left for a long time without the issues revealing, such as the regulation on infrastructure [113]. Even if the issues become apparent, they have not been improved in many cases because of less interest. Nevertheless, it is also the case that these issues may be recognised. While European countries recognise that safety requirements for fishing vessels are outdated [114], these issues are also recognised in the IMO, and some proposal has been made. Other examples are the alternative methods for the colour vision test on medical certificates of seafarers considering that previously required lantern tests were based on the standard more than ten years ago. Guidelines related to Vessel Traffic Service (VTS), the review on components of GMDSS whose requirements were developed more than 20 years ago, and fire extinguishment facilities in the engine room can be shown as examples.

Others

Besides the above factors, the issues are recognised while implementing the requirements and using the equipment and facilities. Examples are the guideline of unified specification for distress alert buttons and warning process due to the frequency of false emergency alerts and unified guideline to the link between VHF Digital Selective Calling (DSC) and Electronic Chart Display and Information Systems (ECDIS) based on the recognition of complex operation.

4.5.2 Taxonomy on safety requirements

This section classifies the safety requirements in the proposal. Previous research categorises the requirements according to the aim of the research. Pettit et al. [105] divide the measures to reduce greenhouse gas emissions into two ways, technology and operation to analyse the impact of innovative technologies. Heij and Knapp [104] categorise around 800 deficiencies of PSC into eight groups; “crew qualification, fatigue management, living condition, working condition, ship certificates, safety management, pollution prevention, and structural, machinery, equipment.” Jeon et al. [115] define three causes that affect marine accidents based on a literature review; “economic, ship-handling and management, and government budget allocation.” Mullai and Paulsson [116] categorise the causes of marine accidents from accidents data into eight factors for model analysis; “external factors, construction of the ship, technical faults in equipment, operation, management and design of equipment, cargo and safety, communication, organization and procedures, human factor, and unknown causes.” Schröder-Hinrichs et al. [50] categorise IMO documents from a human perspective into four main categories (Level 1: environmental context, organizational infrastructure, personnel sub-system, and technical system), ten subcategories (Level 2) and 24 sub-sub-categories (Level3) by utilising hierarchy method in FSA guidelines of IMO.

Since this research aims to propose the direction for providing the strategy of technological innovation, it is necessary to define taxonomy related to innovative technology and consider the taxonomy's utilization to other sectors. Thus, based on the above research and the analysis of the MSC documents, this research defines three main categories; Ship, facility, equipment and system, Ship operation, and Enforcement (inspection and audit). In addition, each main category has some subcategories. Table 4-2 shows the taxonomy with some example extracted by this research.

Table 4-2. Taxonomy on safety requirements proposed in new work program.

Level 1	Level 2	Example
Ship, facility, equipment and system	Design and construction	Inert gas system for fire safety, lifeboat davit
	Test and approval	Test of life jacket, Hydrostatic test of tanks
	Installment	Emergency escape breathing devices, Reversible inflatable liferaft, AIS Search and Rescue Transmitter (AIS-SART)
	Operation, maintenance and repair	Gearbox of accommodation ladder, Expiration date of life rafts
Ship operation	Human resources	Competency of crews carrying on ships operating polar water, Onboard drill
	Organization and operation control	Control of ships in emergency, Minimum manning
	Information	Display of AIS Aids to Navigation (A to N), International Meteorological & Hydrological information
	Cargo handling and fuel	Inspection of Cargo Transport Units (CTU), Handling of timber deck cargos, Diesel fuel
	Sea traffic and security	Traffic Separation Schemes (TSS)
Enforcement (inspection and audit)		IMO audit, Bottom survey

4.5.3 Taxonomy on regulatory issues

Regulatory issues are categorised into two types; the case where exact requirements do not exist and another case where applicable requirements have some issues. These categories (Level 1) are further divided into six subcategories (Level 2). Table 4-3 shows the outline of the taxonomy. The next sections explain the subcategory with some examples.

Table 4-3. Taxonomy on regulatory issues.

Level 1	Level2
No requirements	
Existing requirements have some problems	Inappropriate in the present circumstance
	Unclear
	Inconsistent between regulations
	Narrow scope of application
	Non-mandatory requirements
	Others (e.g., editorial error, non-effective Treaty)

No requirements

The most issues for developing safety requirements are to have no applicable requirements. These issues tend to appear when new movements arise, such as the practical realization of new technologies and the change of shipping demand. For instance, there is no performance standard of shipboard equipment applicable to the new satellite system such as Iridium. Another example is that there is no requirement on seafarers' competence who manages LNG cargo onboard ships under the situation that LNG carriers have been rapidly increasing.

Problem of current applicable requirements

The biggest issue in this category is that the existing requirements are not appropriate to the current situation. These issues are recognised especially in the requirements introduced a long time ago and newly developed requirements. For example, steering gear trial complying with the SOLAS regulations is impossible for some ship types such as large container ships and LNG carriers.

The second issue is that the application of requirements is different between countries due to the unclear description. An example is the means of escape from ro-ro space on cargo ships.

The third issue is an inconsistency between regulations. Inconsistence happens during the implementation of the regulations due to establishing various IMO regulations and duplication of requirements between these regulations [97]. Examples are the difference between the 1996 Stockholm Agreement and the SOLAS 2009 regulations on the calculation method of damage stability of roll-on/roll-off passenger ferry, and inconsistency between the International Maritime Dangerous Goods (IMDG) Code and the SOLAS regulations on fire safety provisions applying to cargo space carrying vehicles with fuel in their tanks.

The fourth issue is the narrow coverage of the type of ships applying the requirement. This issue happens mainly when the type of ship is not expected to introduce the requirements or was recognised as low risk when MSC considered before. For instance, as a proposal in MSC, ventilation systems such as fire damper were not applied to small passenger ships, and water level detectors are not applied to multi-hold cargo ships other than bulk carriers.

The fifth issue is that requirements are not mandated. As described in sector 4.2.2, non-mandatory requirements have effects to some extent; however, mandatory instruments are the most effective tool to force every member state to comply with them internationally. The issues have been presented in the proposal, especially when the application of non-mandatory instruments has not become outspread. Examples are the alcohol limits for watchkeeping officers and the instalment of ECDIS. Moreover, there are proposals to seek the strengthening of the criteria in addition to making them mandatory. An example is a noise inside a ship. This issue was suggested in the previous study [117], and the proposal was made to enhance the criteria of minimum noise level as well as develop mandatory requirements.

The last issue is the editorial error, non-effective Treaty, etc. An example of non-entry into force of the conventions is the Torremolinos International Convention for the Safety of Fishing Vessels,1977.

4.6 CASE STUDY

This section takes up Japan's proposal to MSC for safety standards for hydrogen carriers (MSC 94/18/3) as a case study to verify the categorisation in the previous section.

4.6.1 Outline of technology

Hydrogen has been attracting attention in recent years as clean energy that does not emit carbon dioxide. It becomes 1/800 of that of gas in volume at 1 atm and extremely low at -25 3 degree Celsius in temperature when liquefied. Considering explosive features in addition to the above-mentioned characteristic, sufficient measures are required for storage and handling [118]. Insulation technologies, which include vacuum structures, are essential for transporting liquid hydrogen by sea. The pilot ship built in the project by the Technology Research Association CO2-Free Hydrogen Supply Chain Promotion Organization (Hystra) as the business entity of the demonstration project of the New Energy and Industrial Technology Development Organization (NEDO) has a vacuum-insulated double structure. Moreover, a glass fibre reinforced plastic has been used as the support structure. This project is Japan's first hydrogen supply chain project in the world [119] .

4.6.2 Categorization of technology

Background and motivation

Hydrogen is attracting attention as a clean energy source as global warming countermeasures in the world. With the progress of hydrogen utilization, the shipping cargo transport of liquefied hydrogen is also expected to emerge. The shipping of liquefied hydrogen cargo is planned to start between Japan and Australia in 2017. There is a strong motivation for developing uniform standards aimed at improving the safety of transportation. Thus, this proposal is categorized as "changes in shipping needs due to changes in the social environment."

Safety requirements

The requirements are various. However, the main requirements are "design and equipment installation" and "testing." Specifically, it includes heat insulation, ventilation, piping (Piping), leak detection equipment, leak test, fire extinguishing device (carbon dioxide fire extinguishing), etc.

Regulatory issue

The relevant criteria relate to international regulations (IGC Code) on Ship Structure and Equipment for Bulk Transport of Liquefied Gas. Liquefied hydrogen corresponds to the applicable standard of the IGC Code, "liquefied gas having a vapour pressure exceeding 2.8 bar (absolute pressure) at a temperature of 37.8 degree

Celsius". On the other hand, hydrogen is not defined in the cargo list specified in Chapter 19 of the same code [120]. Therefore, it is in a state that "the corresponding standard does not exist".

4.6.3 Summary

Proposals for safety standards, including new technologies for transporting liquid hydrogen, have a strong motivation for establishing standards for improving safety, and the requirements and standards issues for safety standards are also clear. Therefore, as a result of verification, it is possible to propose the technology by including it in the safety standard to improve safety with a clear direction.

This matter was adopted as a new agenda item, and after that, Japan took the initiative through deliberation, and the provisional recommendation was adopted at MSC97 in 2016.

4.7 DISCUSSION

The last Section analyses the proposal documents on new work programmes submitted to MSC of IMO and categorises the direction of safety requirements from three factors. The results imply some findings.

Firstly, the trend on the development of safety requirements is not classified into only one categorisation but relates to multiple items. For example, the proposal for developing requirements on safe mooring operations has both background of marine accidents and practice of new technologies. The proposal for amending the code of safe practice for ships carrying timber deck cargoes has characteristics of technical design and cargo handling requirements. Therefore, all items of taxonomies should be elaborated when categorising innovative technologies utilising the taxonomy in this paper in future work. Cultivation of experts is also necessary, bearing mind that the deliberate approach with the expertise of the related sectors is inevitable for the categorisation analysis.

The second finding is regarding the categorisation of background and motivation. This research adopts the proposal documents for new work programmes and related IMO documents. The background that these documents do not state (e.g., the political situation of proposed countries) is out of this study's scope. The adopted documents are enough to achieve the goal of this research. Nevertheless, this kind of “out of document” background is necessary to consider the comprehensive strategy, including negotiation during the development of IMO requirements.

Finally, this chapter focuses on the safety requirements of the international shipping sector. However, the analysis methods and the taxonomy shown in the results are arranged as a general style and applied to other sectors. In particular, they can be applied to the international aviation sector that develops the wide range of requirements at International Civil Aviation Organization (ICAO) and the automobile sector that has recently improved the international requirements under UN/ECE/WP29.

4.8 CONCLUSION

This chapter analysed the trend on the development of international regulations that is the assumption for establishing international rulemaking strategy related to innovative technology, taking into account the recent accelerated globalization of regulation. This study focused on the international maritime sector's safety requirements that have been historically forced by national rules in accordance with international regulations. It analysed the process of rulemaking in the IMO and decided to consider the proposal on a new work programme in the IMO. Then MSC documents on the proposal for 14 years were adopted as data for the analysis. The study finally identified the hierarchical taxonomy on three factors; background and motivation, safety requirements and regulatory issues resulting from the analysis. The results found the implications; 1) many requirements cover multiple items of categorisation, and 2) potential background such as the political situation of proposed countries are not considered in the taxonomy. It was also suggested that the categorization in this paper could be easily generalized and applied to the other sectors, such as the international aviation and automobile sectors.

This study analysed the “introduction” part of the rulemaking strategy for international regulations taking technological innovation into mind. Comprehensive consideration, including discussion terms, technological development years, and incentive scheme, is necessary to provide the whole strategy. Although a few case study has been made in the previous research [121], future research in this matter is expected.

Lastly, it is essential to appropriately recognise the change of technology and society's recognition, positively revise the rules that connect society and technology, and build the new measures if necessary [122]. This is the basic policy of “legal engineering,” and it is also vital to involve the mind of legal engineering in the rulemaking.

Chapter 5: Conclusions

Information and autonomous technologies have drastically changed the maritime fields. Autonomous and automated ships have already been developed and demonstrated in many countries including Japan. Discussions on the safety requirements of MASS have also been carried out in the International Maritime Organization (IMO) and non-governmental organizations; however, this is just a start point. This research picks up three themes that contribute to acceleration of the rule-making and technological development.

The first two themes focus on the ergonomics in the MASS system. The first research in the second Chapter constructed the scheme to develop the competence requirements in the SCTW Convention for remote operator of the remote control centre by utilising the situation awareness model and ship sense. The scheme was verified by the case study. The semi-focus group discussion by selected three experts was done. The results shows the eight additional competences required for RO and possible additional provisions to the existing requirements in the STCW Convention, including the experience of seagoing service and Fail-safe to the intermittence of data communication. This research focused on the competence requirements of seafarers. However, the proposed model can apply to the other conventions. For example, new technologies can be developed to supplement the lack of ship sense. In this case, safety requirements for the technologies in the SOLAS Convention might be amended in some cases.

The second theme is regarding MWL. The research built the scheme to identify the relationship between MWL and MASS, in detail, the factors that are sensitive to the change of MWL and the elements of MWL that are the main cause of the change of MWL in each factor. The case study utilising the NASA/TLX method was made through the interviews to ten (10) experts. The results showed the clear effects of the Level of autonomy, Manning options level, Navigation condition, etc, on the MW of watchkeeping operators navigating MASS. It also verified the build identification scheme.

The final theme is regarding the way to develop the IMO regulations. Since the smooth development of the regulatory instruments are necessary to not only achieve the safe implementation of the innovative technologies such as MASS but also take the initiative in the rule-making and enhance industrial competitiveness in the market, this research identified the taxonomy on the trend of regulatory development of IMO safety requirements, focusing on the proposals of the new work programme. The constructed categorization can be generalised and applied to the other sectors such as international aviation and automobile sectors.

The results of each theme can be integrated to develop the whole strategy for the technological innovation and instalment of the international regulations of many autonomous sectors including MASS. Table 5-1 shows the image of the whole strategy. For example, not only competence requirements for RO but also safety requirements of other conventions such as the SOLAS Convention can be developed based on the identified lack of ship sense and required information of SA through the model in Chapter 2. Various countermeasures to offset the increase of MWL can be identified based on the identification scheme in Chapter 3. Categorisation of the trend for developing international safety regulation in Chapter 4 can utilised to smoothly and strategically submit the proposal for developing the related international regulation, and take the initiative of technological development in the market.

Further research should be made to development the whole strategy in the last paragraph since the coverage in this paper is limited. Nevertheless, this paper is believed to accelerate the development of MASS by showing the new viewpoints. In addition, this thesis is expected to be a trigger for the collaboration of multiple science fields including engineering, ergonomics and international law.

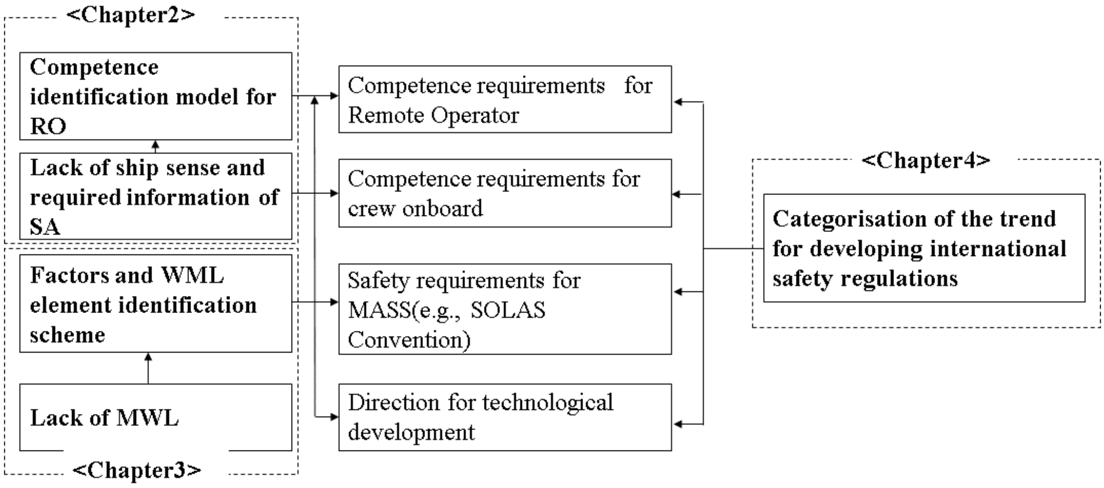


Figure 5-1. Image of whole strategy by utilising the methods in this research.

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List of Publications

Chapter 2

M. Yoshida, E. Shimizu, M. Sugomori, and A. Umeda, “Regulatory Requirements on the Competence of Remote Operator in Maritime Autonomous Surface Ship: Situation Awareness, Ship Sense and Goal-Based Gap Analysis,” Applied Sciences, vol. 10, no. 23, p. 8751, Dec. 2020. *For Chapter 2*

Chapter 3

M. Yoshida, E. Shimizu, M. Sugomori, and A. Umeda, “Identification of the Relationship Between Maritime Autonomous Surface Ships and the Operator’s Mental Workload,” Applied Sciences, vol. 11, no. 5, Art. no. 5, Jan. 2021.

Chapter 4

吉田 正則, 清水 悦郎, 梅田 綾子, 国際海事分野における安全基準の策定傾向の分析（イノベーション技術の社会実装のための国際基準戦略構築に向けて）, 日本機械学会論文集, vol. 87, no. 894, p. 20-00384, Feb, 2021.