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INVESTIGATING SEAFARER TRAINING NEEDS FOR OPERATING AUTONOMOUS SHIPS

By

Australian maritime College, University of Tasmania

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INVESTIGATING SEAFARER TRAINING NEEDS FOR OPERATING AUTONOMOUS SHIPS

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Executive summary

The fourth industrial revolution (called Industry 4.0) which started about a decade ago has and continue to transform all industrial sectors and society at large. Its impact on the shipping industry led to the emergence of the term Shipping 4.0, to reflect the technological changes that have radically transformed the industry. In this context of Shipping 4.0, recent years have witnessed an intensity of the automation debate, triggered by demand for high efficiency and pressures to decongest roads and reduce transport emissions. With few ship automation projects now completed and some still ongoing, it is envisaged that more and more automated systems will be installed on ships and in the near future shipping will witness unmanned ships controlled from shore-based stations.

Most of the emphasis has been on the technological developments that will mark this shift towards more automated and potentially unmanned ships. However, little emphasis has been on the training of seafarers that will operate these future ships. Nevertheless, empirical evidence from other literatures (e.g. aviation, nuclear energy generation, mining and broad human factor literature in general) have emphasised the need for proper training for automation technology users in order to avoid and mitigate the impacts of automation related accidents. It is thus critical to identify the new skills and competencies that seafarers of the future will need in order to operate highly automated ships either as crew members or from shore-based operation centres.

The purpose of this project was thus to investigate the future training needs of seafarers for operating autonomous ships in order to provide IAMU members and maritime industry's key stakeholders (IMO, regulators) with guidelines and a recommendatory framework for training future operators of autonomous ships. The project set out to answer the following four questions:

i. *What types of skills and competencies are required to perform shore-based operations of unmanned and autonomous ships?*
ii. *Are MET systems ready to provide those skills and competencies?*
iii. *What qualifications should future trainers possess?*
iv. *What are the regulatory gaps and statutory actions required to make sure that the workforce will be ready to meet the demand?*

A qualitative approach was adopted to answer the above questions involving the collection and analysis of interview data from representatives of the maritime industry across the globe. Among the interviewees were seafarers (both deck and engine), national and international maritime regulators, maritime businesses and maritime education and training providers (METPs). In line with the research questions and aim of this project, *constant comparative analysis* (CCA), one the most established qualitative data analysis techniques has been utilised for analysing the collected data. This technique consists of the following steps:

a) Reading through the entire set of data;
b) Organising chunks of data conveying the same idea into meaningful parts;
c) Coding each chunk of data; and
d) Allocating a code structure with the highest-level codes called themes.

Following these steps, that are not a one-off procedure but requires many readjustments until a logical coding structure which is a true reflection of the data is obtained, resulted in the emergence of two themes: *readiness gap* and *uncertainties about future training and skills needs*. In relation to the readiness gap respondents indicated that future developments in the maritime industry will be determined by the viability and safety of autonomous ship technology, the viability of the business model for shipping companies to invest in these types of ships and the elaboration of a regulatory framework that will enable autonomous ships to operate.

Concerning the training and skill uncertainties, in the absence of an established autonomous ship technology, regulatory framework and syllabus for training future seafarers, there are uncertainties about training administration, the preparations that maritime institutions should make and the future skills of operators of autonomous ships. With such uncertainties participants are of the opinion that the industry will witness an evolution from localised to generalised training. That is, training will first be administered by the technology providers or vendors. As different variants of the autonomous technology emerge, training might be administered through workshops and seminars. Once the technology has stabilised, course syllabuses will be developed by STCW convention and thereafter maritime colleges will be able to adopt and administer the training. Although, currently maritime colleges are aware that something need to change, their preparations are hindered by uncertainties in terms of types of infrastructures and the competences that they will need for training future seafarers. As a result, they can only speculate on the future skills that will be needed. This is based on the idea that only as the autonomous ship technology matures the exact skills will be known.

As per the four specific questions that this project attempted to answer, it emerged following analysis of respondents' answers on research question 1 that:

- Many of the current seafaring skills (both technical and non-technical) will still be needed in the era of autonomous shipping;
- The future adopted technologies will determine the new skills that will be needed to operate the autonomous and unmanned ships of the future; and
- Future operators of autonomous and unmanned ships must ideally first follow the traditional seafaring training before upskilling to be able to work in autonomous ships and shore-based stations.

From answers to question 2, it emerged that MET systems are not yet ready to provide all the skills and competencies that future seafarers will need while, the autonomous ships technology is still in an infancy stage. As a result, potential preparations in MET sector are hindered as there are uncertainties about future technological developments. Just as is the case for question 2, technological advancements will also determine the qualifications that trainers will need (question 3). As highlighted in the result section, future trainers should be trained to administer the adequate operational, cognitive, leadership, communication and decision-making skills to the seafarers of the future. Finally, regarding question 4, the complexity involved in achieving an international regulatory framework for autonomous and unmanned ships addressing the various autonomy levels acceptable by all IMO members was highlighted. Because the current regulations are all written on the base of having someone onboard ships, examples of regulatory gaps identified that should be addressed in current regulations included SOLAS Chapter 5, regulation 14 and 33, and COLREGs Part D – rule 37. In short, all regulations where the presence of human is indispensable for operations will have to be rewritten. A difficult task thus lies ahead for the IMO.

In summary, the skills required by seafarers for operating autonomous ships will be known progressively, as autonomous ship technology evolves and stabilises. With autonomous ship technology still at an infancy stage, the traditional seafaring training will continue for the foreseeable future. When autonomous shipping technology stabilises, the regulatory framework enabling their operations and the training syllabus will be developed, paving the way for their safe and efficient operation. Based on the finding of this project, a recommendary framework for training future seafarers has been proposed and is attached to this report. Also attached to this report is a separate document providing recommendations to the IMO regarding identified challenges of the STCW convention in addressing the training of future seafarers and a framework for future development.

1. Introduction

Over the years, technological advancements and breakthroughs have led to successive industrial revolutions. Although there is a lack of consensus in the literature on what exactly constitutes an industrial revolution, four are often distinguished from a technological evolution perspective (Culot et al. 2020; Oztemel & Gursev 2020; Xu, Xu & Li 2018). According to Tinmaz (2020) and Xu, Xu and Li (2018), the first, Industry 1.0 (the age of steam), started at the end of the 18th century in England and was marked by the mechanisation of production using hydro-electric and steam-powered equipment. The second, Industry 2.0 (the age of electricity), began in the USA in the early 20th century and was characterised by mass production using electric power. The third, Industry 3.0 (the information age) also began in the USA in the middle of the 20th century saw the advent computers and the automation of production using information communication technology (ICT). Finally, the current era, Industry 4.0 (the age of cyber physical systems (CPS)) which began in the early 21st century is mainly characterised by the convergence of CPS (basically autonomous systems) and the Internet of Things (IoT) technologies to produce intelligent (autonomous and unmanned) systems.

These systems are now applied in all industrial sectors and have become an integral part of our day to day life (e.g. driverless car/trains, delivery by drone, etc.) (Bai et al. 2020; Krupitzer et al. 2020; Turan et al. 2016; Vagia, Transeth & Fjerdingen 2016; Wahlström et al. 2015). They have also transformed the nature of work and the understanding of human-automation interactions at work is a field of study of his own (Benitez, Ayala & Frank 2020; Onnasch 2015; Parasuraman & Riley 1997). Although these advances in automations systems have provided many safety, environmental and economic benefits, they have also brought about many challenges (Gualtieri et al. 2020; Munim 2019). Indeed, because these systems are designed and operated by humans, they are not error free and occasionally fail (Bruder & Hasse 2020; Endsley 2016). Empirical evidence also demonstrates that depending on the level of autonomy, these systems can have negative consequences on human performance (Lee et al. 2020). Adequate training and education of personnel interacting with them has been identified as critical for mitigating automation failures as well as their negative consequences on human performance (Cárdenas, Shin & Kim 2020; de Visser, Pak & Shaw 2018; Emad 2010; Endsley 2016; Rondon & Fontes 2017).

From the perspective of the maritime industry, since 1964 when the first automated systems were installed on ships, technological advancements have led to more and more automations being introduced, and the current area the maritime industry has been referred to as shipping 4.0 (Bavassano, Ferrari & Tei 2020; Deling et al. 2020; Kavallieratos, Diamantopoulou & Katsikas 2020). Since the 2010s in particular, there has a resurgence of the topic of automation in the maritime industry, driven by environmental and land traffic congestion pressures. Various maritime industry projects around the globe have either been completed (e.g. MUNIN, AAWA and SVAN, sea hunter) or are currently being carried out (e.g. YARA Birkeland) with the purpose to decongest roads and provide more sustainable shipping (Deling et al. 2020; Munim 2019; Rødseth & Nordahl 2017).

With increased automations in the maritime industry, recent studies (Alop 2019; Deling et al. 2020; Edler & Infante 2019; Pazouki et al. 2018; Streng & Kuipers 2020) have also emphasised the importance of education and training as automation is increasingly adopted in this industry. Past and ongoing research projects on unmanned and autonomous ships suggest that they will play a key role in the future of maritime transportation as various technologies are being currently experimented (Bertram 2020; Munim 2019; Tanakitkorn 2019). Once these ships become operational, new forms of training will have to be incorporated into the training curriculum for seafarers. Understanding the perspectives of maritime industry stakeholders on potential skills that might be required by seafarers to operate these new ships is critical and will provide maritime industry governing bodies with insights on how to design future training program and regulations that will enable efficient and safety operation of these ships.

Therefore, the aim of this project was to provide IAMU members and maritime industry key stakeholders (IMO and national maritime regulators) with guidelines and a recommendatory framework for training future operators of autonomous ships. These guidelines will serve as a reference for ensuring the standardization of training in maritime institutions. The remainder of this report is structured as follows. Section 2 reviews the extant literature on autonomous shipping in the maritime industry while section 3 discusses the methodology. The results are presented in section 4 while section 5 concludes this report.

2. Literature review on autonomous ships

The first stage of the identification of this literature involved keyword searches in Scopus, Web of Science and Google Scholar. The words combinations used are summarised in Table 1 along with the number of hits. The abstracts and when necessary all the hit articles where read. The second stage consisted of looking at all issues published in two specialised maritime education inclined journals: Transnav and WMU Journal of Maritime Affairs. After correcting for articles found by the three search engines and in the journals, the 14 relevant papers relevant publications found are summarised in Table 2. These include 7 journal papers, a master thesis and 7 conference papers.

Table 1: First stage of the review process

Keyword searches	Scopus hits	Web of science	Google Scholar
Maritime education, seafarers, autonomous ships	4	2	44
Maritime education and training seafarers, autonomous ships	3	2	37
Maritime training and education, seafarers, unmanned ships	2	1	38
Training, unmanned ships, seafarers	4	3	166
Training, autonomous ships education,	3	5	152
Relevant papers	4	5	14

A variety of methodologies including case study, simulated based experiments, focus group and interviews are applied in the discussed papers. Most of the 13 papers are conference publications (summarised in Table 2). Of note, this literature is very scanty and education and training of seafarers in relation to autonomous ships is mainly treated as a secondary topic.

A close examination of this literature reveals that only two conference papers by Ahvenjärvi (2017) Emad, et al. (2020) and Vidan et al. (2019) specifically address the future MET in relation to autonomous ships. The other papers, though focusing on issues such human interaction with autonomous and unmanned ships, the operation of shore control centres, traffic scenario involving manned and unmanned ships and work organisation with the advent of autonomous and unmanned ships also sometimes refer to MET. The justification for this lack of interest in training can be justified by the below statement by one of the respondent in the study by Mallam, Nazir and Sharma (2019, p. 6): 'I think so far everyone is very occupied with the technology but not with how we train people in using these systems.'

The study by Man et al. (2015) which primarily focuses on human factor issues related to the operation of ships from shore control centres (SCCs) shows that future operators in SCCs will require training in terms of their cognitive skills in order to deal appropriately with all the information displayed on screens in SCCs. Man et al. (2015) fail to go a step further to propose any framework for the development of cognitive skills of future operators of ships from SCCs. The need for aligning seafarers training to technological developments in MASS is reiterated by the other papers in Table 2, yet without specifically mentioning the type of training that will be needed neither proposing a framework for developing the future skills of seafarers.

Table 2: Summary of the literature review

Authors and "*paper titles*"	**Objectives/ Research questions**	**Methodology**	**Findings in relation to training and automation**
Man et al. (2015) *"From desk to field - Human factor issues in remote monitoring and controlling of autonomous unmanned vessels"*	Identify the human factor issues in remote monitoring and controlling of autonomous unmanned vessels.	Scenario-based trials by four master mariners and a ship engineer operating the ship from the Shore Control Centre (SCC) located onshore.	Training seafarers in terms of cognitive is critical for carrying out their duties in SCCs. In addition, the design of SCC shall not mimic that of the bridge because it results in an inappropriately structured organisational hierarchy.
Ahvenjärvi (2017) *"Unmanned ships and the maritime education and training"*	What kind of new competences are needed for successful utilization of unmanned ships? How this will affect the education of seafarers? Are seafarers going to lose their jobs and how the profession of seafaring will maintain its attraction among youngsters?	- Satakunta University of Applied Science has decided to be involved in the development of training facilities for the future by planning a model-scale platform for training, demonstration and development of the unmanned ship. The ELSA platform is a cost-effective alternative for research, development and training purposes. ELSA will offer great opportunities for students of SAMK to get familiar with the technology and challenges of unmanned ships.	Maritime education and training must develop hand-in-hand with the technical development. New skills and competences are necessary for those who deal with design, operation and maintenance of unmanned ships.
Lokuketagoda et al. (2017) *"Moving the boundaries of MET with High Fidelity ERS Training"*	1) Explore the use of Engine Room Simulators (ERS) in future MET programmes to meet the requirements of the changing industry and technology. 2) Present options for expanding the boundaries, outreach and relevancy of MET through the planned increased use of simulators.	Case study	ERS has the potential to play a vital role in preparing the workforce for autonomous ships in the future.
Baldauf et al. (2018) *"E-Navigation, digitalization and unmanned ships: challenges for future maritime education and training"*	Investigate traffic scenarios including conventional manned and future unmanned ships.	Simulated experiment designed to address the following research questions: 1) What equipment set-up is more suitable for SCCs if the operators have a seafaring background? 2) What equipment set-up is more suitable for SCCs if the operators have a non-seafaring maritime background? 3) How can the navigational performance of seafarers and experienced non-seafaring maritime professionals be compared?	People with non-seafaring backgrounds can be trained along with seafarers to operate autonomous ships.

Pazouki et al. (2018) *"Investigation on the impact of human-automation interaction in maritime operations"*	Improve understanding of automation limitations, as well as identifying current maritime industry trends and ways to improve human automation partnership.	Pilot study monitoring the performance of 12 deck officer cadets using simulation video and endeavouring to understand the attitudes (e.g. level of trust in automation) of future seagoing deck officers towards shipboard automation.	Because designed methods associated with automation systems have remained unchanged, confusing automation logic results in a mental model (critical for recognising automation failures) that is inaccurate. Updating the manual skills of officers through regular practice and bridge simulator training is an effective method for reducing automation related errors.
Lušić et al. (2019) *"Seafarer Market - Challenges for the Future"*	Analyse today's seafaring market and provide forecast for the near future.	Different data sources used to analyse the seafarers' market.	Where will seafarers operating MASS come from and in what types of institutions will they be trained? Given the possible variants of future MASS, it will be a great challenge to design education programs covering the needs and requirements of the future MASS operators.
Lokuketagoda et al. (2018) *"Training engineers for remotely operated ships of the future"*	Identify and discuss from a Maritime Education and Training (MET) perspective the role of marine engineers in light of the gradual introduction MASS	-	Marine engineers could be trained using stimulator technology to operate future autonomous ships.
Alop (2019) *"The challenges of the digital technology era for Maritime Education and Training (MET)"*	How to be more flexible and responsive in the shipping 4.0 era? What is the new principle of education in the dynamically developing shipping industry and digital world where all information is available to everyone anytime? How to keep pace with the rapid and extensive changes in industries, including shipping?	-	Aligning training and education programmes to advancements in MASS in critical in the shipping 4.0 era. These include training for trainers as well as for future trainees.
Edler and Infante (2019) *"Maritime and other key transport issues for the future - education and training in the context of lifelong learning"*	Understand the changing and emerging job profiles triggered by shipping 4.0 and design appropriate training and education methods that will meet the special competencies, skills and abilities needed in the shipping industry.	Data collection through questionnaire	Ongoing digitalization requires the development of a trustful dialogue between educational and training institutions, in addition to the promotion of education and training. The development of qualified personnel will be the main task of the future.
Vidan et al. (2019) *"Autonomous systems & ships - training and education on maritime faculties"*	With the imminent advent of autonomous ships, what types of educational programmes shall maritime faculties develop for teachers and students?	-	The development of programmes in maritime faculties for trainers and trainees dealing with autonomous ships will require collaboration between governments and maritime colleges. However, these must be aligned to the guidelines set by the International Convention for Standards of Training, Certification and Watchkeeping for Seafarers (STCW).

Mallam, Nazir and Sharma (2019) *“The Human element in future maritime operations-perceived impact of autonomous shipping”*	Explore the impact and implications of autonomous technologies on shipping operations and the human element in the maritime domain.	Thematic analysis using interview data from ten Experts working within industry and academia	‘I think so far everyone is very occupied with the technology but not with how we train people in using these systems.’ The profile and skillset a future ship operator may need ranges from traditional seafaring education, certification and at-sea experience, to non-seafarers who have a computer science background with coding skills, to video game enthusiasts comfortable with command and control of virtual agents and virtual worlds.
Tran (2018) – Master’s thesis *“Integrating requirements of Industry 4.0 into maritime education and training: case study of Vietnam”*	1) Examine systematically Industry 4.0 and its implications in general 2) Understand implications of Industry 4.0 on maritime 3) Investigate experiences of countries , institutions around the world on dealing with MET towards industry 4.0’s requirements 4) Analyse current situation of Vietnam MET 5) Propose solutions for integrating requirements of Industry 4.0 into MET in Vietnam	Primarily literature review with secondary data from semi-structured, structured interviews and web search.	The design of new MET programmes for trainers and trainees should be an integral part of the Vietnamese government’s policy.
Praetorius, Hult and Sandberg (2020) *“Towards autonomous shipping - Exploring potential threats and opportunities in future maritime operations”*	Explore the future of shipping operations with a specific focus on issues related to human roles, responsibilities and the organization of work.	Focus group with 6 representatives from the Swedish shipping cluster and 2 representatives from academia.	The roles, responsibilities and a definition of potential operator competences need to be formulated to ensure a human-centred development for safer shipping.
Deling et al. (2020) *“Marine autonomous surface ship - a great challenge to maritime education and training”*	Analyse the competence requirements of seafarers on MASS in different development level and predict the impacts of MASS on MET.	-	The introduction of MASS will lead to two key structural changes in the maritime industry: the formation of high-level talent and the change in personnel allocation.

Maritime experts opinion gathered by Nguyen (2018) suggest that future training of seafarers will focus on:

- Simulator-based and computer-based training;
- The use of 3D simulation and gamification, which also allow seafarers to train and practice on board;
- Personalised training that is absolutely tailored to the individual needs;
- STEM competences (science, technology, engineering and math) provided for nearly all other technical industries;
- Advance knowledge in leadership and managing people, associated with management in the sector,
- Preparing the young seafarers for the life at sea;
- Educating personnel who will control future autonomous ships and their driving systems, whether from on board or remotely, whether as deck officers, marine engineers, or electro-technicians.

As per the profile of seafarers operating the ships of the future, Baldauf et al. (2018) and Mallam, Nazir and Sharma (2019) suggest that they might be coming from both seafaring and non-seafaring backgrounds. Simulators will play a key role in training seafarers of the future (Lokuketagoda et al. 2017). Not much is known about the exact types of facilities that will be needed for training the future operators of autonomous ships. According to Ahvenjärvi (2017), such a facility is being built at Satakunta University of Applied Science in Finland. As pointed out by Nguyen (2018), it is difficult at this stage to determine the exact facilities that will be needed as much of the technology is still in proof of concept stages.

3. Methodology

In this section, the methods used to collect and analyse data are discussed. In the data collection part, the ethical process followed and the procedures used to reach out to participants are discussed. Subsequently, justification is provided for the technique chosen to analyse data.

3.1 Data collection

Before contacting the participants, ethical clearance with reference number H0018512 was obtained from the university of Tasmania's Human Research Ethics Committee (HREC). Each of the potential participants was sent an invitation email along with the Consent Form and the Participant Information Sheet. Reminders were sent to those potential participants who did not respond in two, four and six weeks respectively after the initial invitation email was sent. Follow ups proceeded with the participants who accepted the invitation to participate to schedule an interview. Some interviews were conducted face to face while others by telephone.

The 37 participants interviewed were from the Asia Pacific region, Europe and South America and occupied different positions in maritime industry including:

- Maritime colleges;
- Nautical institutes;
- Classification societies;
- Imo committees;
- National maritime regulatory bodies; and
- Various maritime businesses.

The maritime businesses represented included:

- Maritime transport where seafarers (both deck and engines) were employed;
- Ship manufacturers;

- Port authorities;
- Maritime pilotage;
- Ferry operators; and
- Shipowners.

The diversity of participants both in terms of origin and areas of representation of the maritime industry ensured that different perspectives on this topic were obtained. Given the international nature of the maritime industry, this diversity was to ensure that the views of variety of stakeholders of maritime industry are considered in the research.

3.2 Data analysis technique

Being a qualitative study, an appropriate data analysis technique had to be chosen from the array of qualitative data analysis tools available. Following Miles and Huberman (1994), Leech and Onwuegbuzie (2007) and Leech and Onwuegbuzie (2011), the choice of the most appropriate technique was determined by the overall purpose of the project as well as the type of questions asked in this project. Accordingly, *constant comparative analysis* (CCA) was chosen. It is one of the most, if not the most established technique for analysing qualitative data collected during this project (Boeije 2002; Fram 2013; Leech & Onwuegbuzie 2007). The procedures involved in carrying out CCA involve:

1) Reading through the entire set of data;
2) Organising chunks of data conveying the same idea into meaningful parts;
3) Coding each chunk of data; and
4) Allocating a code structure with the highest-level codes called themes.

It is important to note that this is not a one-off procedure but requires many readjustments until a logical coding structure which is a true reflection of the data is obtained.

4.Results

Using the procedures described in section 3.2, two main themes emerged following a holistic analysis of the data: a) *readiness gap* and b) *training and skills uncertainties*.

a) The following major codes were categorised under the readiness gap theme:

- Technology;
- Regulatory framework;
- Business case; and
- Safety.

From the perspective of the respondents, because autonomous ship technology is still in an infancy stage and not yet matured, technological advancements will be the main trigger determining its rate of adoption. The technology will have to be robust enough to ensure the safety of people and systems as well as the environment. Once the technology eventually matures, the next hurdle will be to provide a regulatory framework under which autonomous and unmanned ships can operate. Even with a sound regulatory framework in place, the operation of autonomous ships will to be proven profitable in the long run before shipowners decide to invest in building and operating them. Similarly, it is only when the safety standards are met that regulators will give the go ahead for the operation and marketing of autonomous and unmanned ships.

b) Major codes under the training and skills uncertainties theme included:

- Training administration;
- Preparation of maritime institutions; and
- Future skills.

From the overall perspective of the participants, the industry will witness an evolution in training from localised (i.e. from technology providers) to generalised (i.e. training in maritime institutions). That is, training will first be administered by the technology providers or vendors. As different variants of the autonomous technology emerge, training might be administered through workshops and seminars. Once the technology has stabilised, courses syllabus will be developed by STCW and thereafter maritime colleges will be able to administer the training. Although, currently maritime colleges are aware that something might need to change, their preparations are hindered by uncertainties in terms of infrastructures and competences that they will need for training future seafarers. As a result, they can only speculate on the future skills that will be needed. Again, it is only as the autonomous ship technology matures that the exact skills will be known.

After this holistic view of the results, emphasis will now be on answering the main questions which were the focus of this project. As stated in this project's initial proposal, the following four questions were to be answered at the end of this project:

i. *What types of skills and competencies are required to perform shore-based operations of unmanned and autonomous ships?*
ii. *Are MET systems ready to provide those skills and competencies?*
iii. *What qualifications should future trainers possess?*
iv. *What are the regulatory gaps and statutory actions required to make sure that the workforce will be ready to meet the demand?*

Each of these questions is analysed below, providing distinct answers when possible from each of the interviewees' groups. The distinctive views from the following four groups were distinguished when possible: seafarers (including deck and engine), maritime educators, regulators, and maritime businesses. Selected excerpts from respondents was chosen to illustrate their perspectives.

4.1 Answer to the first question: What types of skills and competencies are required to perform shore-based operations of unmanned and autonomous ships?

4.1.1 The perspective of seafarers (both deck and engine)

Overall, all the seafarers interviewed are of the opinion that the seafarers of the future that will be sitting in shore-based control stations will require information communication technology (ICT) and machinery operation skills. For example, of the participants who were an experienced engineers mentioned:

> *"Definitely, I should say that there should be a training on ICT, about machinery operation. They are not dealing with the navigation but any problem with the machinery space, they should be able to deal with it. They should know basics about artificial intelligence and troubleshooting skills."*

Seafarers' data also revealed their opinions on three key areas:

- The educational/training background of future shore-based operators of unmanned and autonomous ships;
- The technical competencies they think they will need; as well as
- The non-technical competencies for operating unmanned and autonomous ships from shore-based controlled stations.

With regard to their educational and training background, a strong case was made that these future operators should have a seafaring background, as illustrated by one of the master mariners with over 30 years of sailing experience in the below excerpt:

> *"The people that will be either part of the operation crew or sitting in shore-based stations will have to be ex-seafarers. They should be like master's licence holders at the minimum because they need to*

know exactly, just like you are controlling the ship, they need to know when to take over. They should be just like a master taking over the manoeuvring".

This finding is interesting as some seafarers expressed fear of loosing their jobs when ships become increasingly autonomous and unmanned as one of the research participants mentioned:

"My perspective of view is I'm not happy with this autonomous shipping because most of the seafarers will miss their opportunities due to remotely operated ships".

If adopted by the maritime governing bodies as a measure that shore-based operator of autonomous and unmanned ships should exclusively be ex-seafarers, this might help absorb seafarers that will be made redundant when ships with increased levels of automation and unmanned ships gradually come into operation.

Concerning the technical competencies, the interviewees foresaw that in future in order to effectively operate shore-based stations training of operators should cover the following areas:

- Electronic and computer engineering;
- Information technology systems;
- Satellite communication technology
- Artificial intelligence and machine learning;
- Troubleshooting; and
- Integrated systems between shored based and onboard operation.

As illustrated below, one the respondents, a marine engineer with over 12 years of sailing experience identified some training gaps that will need to be filled while training seafarers for operating ships from shore-based stations.

"Generally, the seafarer, marine engineer for example like myself, of today is very skilful in terms of mechanics and electric failures. We have to bridge the gap in terms of electronics. I think it is critical to diminish the focus on mechanical and electrical training and focus more on electronics in the short term and on artificial intelligence and machine learning in the future, that is the real future".

The integration of these skills into the training of future seafarers will provide them with an understanding of the underpinning technologies behind the systems and machinery they are operating, enabling them to troubleshoot when necessary. This complete training will increase efficiency in addressing systems failure since no third party will need to be brought to fix them, as the seafarers themselves will have such competencies.

Research participants also mentioned that the non-technical skills, of the future seafarers includes:

- Communication;
- Problem solving; and
- Leadership.

Just as it is currently the case onboard manned ships, communication, problem solving and leadership skills will also be required for effective functioning of shore-controlled stations. These skills will even be more critical for interaction between shore-based stations and the skeleton crew that will likely be onboard autonomous ships in the first years accompanying their introduction (Deling et al. 2020). The excerpt below from a marine engineer with 10 years of experience highlights the need for seafarers of the future to be trained in terms of their communication skills:

“It’s going to require very clear communication because dealing with people via the internet or via some sort of remote link, it’s much more difficult than face to face. Seafarers, they train like at the university level, but they are not always good communicators”.

4.1.2 The perspectives of maritime educators and training providers (METPs)

The opinions of METPs were closely similar to those of seafarers. They also provided information on the training background, technical and non-technical competencies required to perform shore-based operations of unmanned and autonomous ships. Starting with their background, a strong case was made by METPs that shore-based operators of ships should possess traditional seafaring as illustrated by the two excerpts below from the course coordinators for master mariners and senior engineers, each with over 30 years of experience in maritime industries respectively:

“They will still need the traditional seafaring skills. In addition, I think they will need the basic skills of how to operate a computer, computing skills, gaming skills”.

“I think many of the same skills will need to be there even if the seafarer of the future is someone that programs the autonomous systems for the vessel. They will need to understand the environment, they will need to understand cargo and stability, they will need to understand all of the engineering”.

This view corroborates with seafarers argument that only ex-seafarers should be trained to operate autonomous and unmanned ships. With regard to the specific certification that future shore-based operators should hold. It was suggested that a smart ship’s (i.e. autonomous/unmanned ships’) licence could be added above the traditional licence as illustrated below in a quote from master mariner with over 20 years of experience:

“What I can foresee is that maybe they will come up with a licence which is tailored around the master’s licence. Maybe you can call it like a smart ship operator’s licence. This licence will be a level above the normal traditional licence”.

In such a scenario, seafarers will follow their traditional training and obtain a traditional licence for operating manned ships. Afterwards, they will be able to obtain a smart ship’s licence enabling them to operate autonomous or unmanned ships. Ideally therefore, future operators in shored-based centres will be able to steer both manned and autonomous/unmanned ships.

In addition to ICT skills, METPs emphasised the need for future operators in shore-based stations to know the underpinning technologies of the equipment they will be using in order to troubleshoot if need arises. Their opinion is well captured by the below statement from one of the METPs, talking from the perspective of a marine engineer and educator with many years of experience on board ship and as an educator:

“Just the operating skills, to have the operating skills, an engineer should know the engineering involved with that piece of machinery, like main engine, generators or pumps, or boilers. They should know thoroughly how this piece of machinery operates and what sort of troubles can I expect with this piece of machinery and how I can correct them. He should be able to know how to operate that software part and to troubleshoot. The training need will be how to operate, not how to repair”.

Also highlighted by METPs was the need for future operators in shore-based to have high cognitive skills, which will allow them to deal large amount of information on the screen displayed in shore-based stations:

“They should have good brains. They should be very sound, theoretically”.

Leadership, communication, decision-making, information management, risk analysis and task allocation were also among the soft skills that METPs think will be needed by shore-based operators in order to effectively do their job.

4.1.3 The perspectives of regulators

Interestingly, there is a high level of convergence between regulators opinions and those of seafarers and METPs with regard to the background and competencies that will be required to work in shore-based stations for autonomous and unmanned ships. The necessity of having a traditional seafaring licence (deck of engine) as a prerequisite for taking a smart ship's licence was also emphasised as illustrated in the two excerpts below from two regulators (one from Australia and the other from Russia) sitting in IMO committees:

> *"....So, the understanding of the technical side of the job, whether it's collision on board, navigation, or engineering, or something electro-technical, or the cargo temperatures of whatever it might be - it is still a fundamental piece of education and knowledge that the individuals will require to develop. Now, they not only will need that technical knowledge, they will also need a new set of skills in terms of being presented with that data in a different way".*

> *"In my opinion, all these persons should have seafaring qualification and seafaring background. Even those people who will operate from ashore, it is like a VTS. In my opinion, people that operate vessels or operate autonomous and unmanned ships should have deck officers qualification, education, training...The second of course, the people will need digital qualification."*

Taking various examples from the aviation industry to illustrate their opinions, some regulators argued that future operators of shore-based operators of unmanned and autonomous ships should have a complete understanding of the systems and technologies behind the machineries present in shore-based stations. For a Norwegian regulator, the recent Boeing 737 Max crashes highlight the necessity for understanding such technologies:

> *"There is a lot of technical knowledge you need to really understand what is happening now, what inadequate system behavior is. Why and what do you really need to do. And if you don't have the full understanding of the system you are not really able to do anything. I think Boeing MAX really showed what happens when you don't have the full understanding of such systems....At the same time, you need an operational experience in navigation. To understand the weather, the situation, what to do and such. These two needs to be combined".*

The argument for this skill combination is further illustrated in this excerpt from an Australian regulator:

> *"...So, I think that the seafarer of the future needs two distinct skillsets: one is the seafaring ability and the other is the quite in-depth knowledge of the systems and technologies that supports automated shipping".*

This skill combination will ensure that shore-based operators are not just there to press on buttons but can intervene in case of machinery dysfunction, as well articulated below by another Australian regulator:

> *We've got to be careful that seafarers don't rely 100% on the systems and trust the systems implicitly. They always need to be suspect of the systems and make sure that they can check if those systems are running correctly. Understanding the underpinning technology so, if something is not right, they can detect that."*

From the perspective of regulators, artificial intelligence, machine learning, and satellite technology were also mentioned as technical competences that will be required by shore-based operators. In addition, they identified data analytics, communication and information management as potential soft shore-based operators will need. Again, these speculated skills are closely similar to those mentioned by the two other groups (seafarers and METPs) previously discussed.

4.1.4 The perspectives of maritime businesses

Our research participants involved in various maritime businesses reiterated the need for shore-based operators to have a seafaring background, topped up with an autonomous or unmanned ship's qualification, as illustrated in the statement below by a European ferry operator:

> *"So, I assume beside… or instead the today's skills and competencies from, for example, a master mariner, to lead the vessel, to lead the crew, it will be more important to understand how the technical systems are integrated with each other, how (they) react on each other, and, of course, how the interfaces can be connected or can be done, and can be disconnected".*

The allusion to having a seafaring background by all five groups shows a very high level of convergence in the opinions of maritime stakeholders. This high level of convergence is also reflected in businesses opinions on the technical and no-technical competencies of future shore-based operators of unmanned and autonomous ships. ICT, deviation management, and troubleshooting skills where among the technological competencies and communication skills as soft skills mentioned by maritime businesses.

Overall, it can be inferred that these technical and non-technical competencies of shore-based operators will fit within five broad groups: 1-cognitive; 2-operational; 3-leadership and teamwork; 4-decision-making and 5-communicative skills. The potential indicators for each of these groups will be discuss in detail in the recommendation section. This finding is consistent with other studies on automation in the aviation, automotive and nuclear plant industries (Casner & Hutchins 2019; Kim, Kim & Jung 2014; Rondon & Fontes 2017). Automation researchers in these industries have also emphasised the need for operator in controlled stations to have a good knowledge of the technology underpinning automation (e.g. Casner &Hutchins 2019), which is also confirmed by the maritime industry stakeholders interviewed in this research. The finding is also consistent with the research on crew resource management (CRM) training in the maritime industry where leadership, decision-making and communication skills have been identified as key skills that seafarers should possess (Wahl & Kongsvik 2018).

4.2 Answer to the second question: Are MET systems ready to provide those skills and competencies?

Data analysis showed that overall, METs current understanding of autonomous and unmanned ships is very limited, providing an indication that MET systems are not well prepared to provide the skills and competencies required for operating these types of ships. This limitation of understanding is expressed in the following statement by a maritime educator:

> *"The number of things that we know about autonomous ships is only on the surface".*

A key factor limiting maritime institutions from putting in place the systems is the stage of development of autonomous shipping technology itself, which as discussed is still in its infancy. Therefore, although a conversation on how autonomous ships will affect maritime institutes has started in maritime colleges and some initiatives are being taken, maritime colleges are limited in what they can do in terms of equipment for training future seafarers and syllabus to include in the courses. This point was well expressed by a maritime educator in the following excerpt from a course coordinator for senior seafarers:

> *"…We have started that discussion. I told our lectures to start to improvise with what we have to "introduce autonomous to our students". For autonomous vessels, we are going to need a new set of simulators. We have people who are in that area but we don't know what to get for that...*
>
> *….Actually, my idea is to introduce a unit on autonomous vessels in the syllabus as an elective that students can take but it looks like they don't have much yet".*

It is only as technology matures in the coming years that maritime institutes will gradually know about the available technologies, acquire them and introduce the necessary training systems. However, because the syllabus used for training seafarers need to be approved by the STCW convention, this pose another problem for maritime institutions which will be limited in what they can offer to students. Even when the technology becomes ready, legislation will likely be another hurdle. Given for example that ECDIS took 30 years to get through legislation, it is unknown when MET systems will have the go ahead to acquire the systems needed for training operators of unmanned and autonomous ships.

4.3 Answer to the third question: What qualifications should future trainers possess?

Linking this question to the first one where five broad areas where identified that should be focused on while training operators of autonomous ships (cognitive, operational, leadership, decision-making and communication), it can be inferred that future trainers should be well equipped to provide these competencies. From an operational perspective, these qualifications will have to be tailored on the technologies that have been accepted and validated by maritime authorities. These technologies are still in their testing phase. Therefore, it is difficult at the moment to speculate on the technical qualifications of future trainers other than to say that they will need to have a background in automation systems.

With regard to cognitive, leadership, decision-making and communication qualifications, each of these categories cover vast and different areas of competencies. Therefore, trainers with the ability to administer training in these areas might come from variety of fields and not necessarily seafaring. Insights from the CRM literature (Wahl & Kongsvik 2018) suggest that for each of these soft skills, future trainers should be able to enable seafarers to acquire the skills listed in each of the categories below:

- Cognitive *(critical thinking, assertiveness);*
- Leadership *(creativity, humility, trust, confidence, learn from failure, transparency);*
- Communication *(ask questions, share information, listen and respond to concerns, give feedback);*
- Decision-making *(Identify risk, assess options, select options and plan action, review outcomes).*

Once the technology is ready and the programme implemented in maritime colleges, further research could be carried out to identify how these set of skills could be refined.

4.4 Answer to the fourth question: What are the regulatory gaps and statutory actions required to make sure that the workforce will be ready to meet the demand?

> *"That's a hard question and I don't really have the answer. We are in a situation with the maritime industry in particular where we know that regulations need to change, or to adjust in some way but we don't know where that change is or what needs to change at this stage. And that's difficult because the whole understanding of what autonomous shipping means to the maritime industry is not really being defined or the scenario doesn't necessary exist quite yet for us to know what we need to change from a regulation perspective."*

The above answer by one of the regulators (most of whom sat on various IMO committees) and other respondents sums up the views of the interviewees on this question. Addressing these regulatory gaps is not an easy task as many automation projects in the maritime industry had to be abandoned due to failures to address regulatory issues. As pointed out by one of the respondents, a marine engineering educator with over 30 years of experience, in the following excerpt, unmanned bridges (a key feature of future ships) were tested back in the 1970s but the idea was quickly abandoned due to regulatory issues:

> *"Unmanned bridges were tested way back in 1974 but the idea was abandoned due to legal implications... Because, if there's no one onboard, who is responsible when there's an accident?*

A close look at the respondents' views on the potential regulatory gaps could classified into two mains areas: legal challenges and complexity involved in designing and implementing regulations at the world stage.

Regarding legal issues, the responsibility in case of an accident poses a big legal challenge, as expressed in the preceding statement. Dealing with this issue is even more complicated given different levels of autonomies that have to be covered. While some autonomous ships will still have a crew onboard, others will not. Developing regulations covering this wide range of ships will likely be of great challenge to regulators as illustrated in the below excerpt from an Australia regulator:

"... And you know, the scenario that are presented to us today and what we think autonomous shipping might look like in the future, the range of those scenarios are really quite vast. We are talking about ship that remotely controlled or we are talking about ships that are autonomous, we are talking about unmanned vessels. That's a huge scope of a different type of maritime operations that we are seeing. But where do we actually go with that? It's a little unknown at the moment".

It is only as technology matures that the unknown will become clearer. The legal challenges are also complicated by the fact insurance policies are designed to cover manned ships rather than those with nobody onboard. The complexity related to insurance issues is well expressed by the below a European regulator.

"In terms of the role of insurance, I think it gets equally complex. I think a lot of people have recognised that we do not have a regulatory framework certainly in international waters for autonomous ships. There is certainly a lot that needs to be done in that area. Insurers and legal councils will be looking very closely at what the legal provisions and the entitlement to operate ships in particular modes are. Because that goes along those risks and liability, that will be important as well".

As per the complexity involved in designing and implementing a new regulatory framework, the most difficult for the IMO is that currently, SOLAS, STCW and COLREGs guidelines require constant physical presence in the navigation bridge. Therefore, most of these guidelines will have to be rewritten to accommodate autonomous shipping. For example, SOLAS Chapter 5, regulation 14 on ship's manning needs to be completely rewritten. Also, the requirement to respond to distress calls in international waters (COLREGs Part D – Rule 37 and SOLAS regulation 33) and many other issues, and the rules that require human intervention will have to be rewritten.

Given that the IMO is a complex organisation which lacks the required agility and slow in response to changes and the fact that there is often a time lapse between adoption of regulations and their entry into effects (for example, COLREGs regulations were adopted in 1972 but came into effect on five years later), it might take years before a regulatory framework ratified by all countries is approved. As suggested by one of the regulators who chairs an IMO committee in the below excerpt, a way to facilitate this might be to create code that sit along various conventions:

"The IMO is a very slow-moving organisation; I believe they might come through a realisation that it's going to be a very difficult task if we are going to go with individual conventions to accommodate autonomous vessels. I suspect where we might end up is some sort of code, that complements and sits alongside the various conventions to allow autonomous ships to function. So, we need a very safe framework to allow degrees of automation to advance".

The outcome of the IMO scoping exercise which is currently ongoing will provide insights into the regulatory approach to be taken. Considering the many hurdles that will have to be overcome, this is not a small task and will requires cooperation from IMO members to ensure that an internationally recognised framework is in place under which autonomous vessels will operate. This framework will be a big step towards tailoring training the types of ships that will be allowed to operate.

Insights from regulators also suggested that although achieving an international regulatory framework for operating autonomous ships will be difficult to achieve, national and cross-country level regulations might allow them to operate on short distances in coastal waters. Many countries around the world have already/or are in the process of modifying their regulations to enable autonomous ships to operate. For example, the world first autonomous barge Port-Liner is planned to soon operate between Amsterdam, Rotterdam and Antwerp (https://www.portliner.nl/). In the Australian oil and gas and hydrographic survey sectors there are various types of autonomous and unmanned vessels already in operation through exemptions provided by the national regulatory framework. As explained by an Australian regulator:

> *"…We've got quite a lot of flexibility that goes into our domestic regulatory framework for domestic vessels and that allows us to survey vessels that might be unmanned, that might be autonomous or that might be remotely controlled. But it's about building in a safety management system that reduces the risk to something that is acceptable for the safety of that vessel, and other vessels and the protection of the environment".*

As mentioned by this regulator, a challenge for regulators at the IMO and country levels is to ensure that regulations when implemented guarantee the safety of people, the autonomous vessel and other vessels in their vicinities as well as the safety of the marine environment.

5. Conclusion, limitations and recommendations for future research projects

The aim of this project was to provide IAMU members and maritime industry key stakeholders (IMO, national marine regulators) with guidelines and a recommendatory framework for training future operators of autonomous ships. To answer the four questions of interest, interview data were collected from representatives of the maritime industry from around the globe.

A holistic analysis of the data allowed the identification of two major theme: readiness gap and training and skills uncertainties. The major codes under the readiness gap included technology, regulatory framework, business case and safety. Those under the training and skill uncertainties included training administration, preparations of maritime institutions and future skills.

Regarding the specific questions that this project attempted to answer, it emerged following analysis of respondents' answers on question 1 that:

a) Many of the current seafaring skills (both technical and non-technical) will still be needed in the era of autonomous shipping;
b) The future adopted technologies will determine the new skills that will be needed to operate the autonomous and unmanned ships of the future; and
c) Future operators of autonomous and unmanned ships must ideally first follow the traditional seafaring training before upskilling to be able to work in autonomous ships and shore-based stations.

From question 2, it emerged that MET systems are not yet ready to provide the skills and competencies that future seafarers will need, the reason being that autonomous ships technology is still in an infancy stage. As a result, potential preparations are hindered as there are uncertainties about future technological developments. Just as is the case for question 2, technological advancements will also determine the qualifications that trainers will need (question 3). As highlighted in the result section, future trainers should be trained to administer the adequate operational, cognitive, leadership, communication and decision-making skills to the seafarers of the future. Finally, regarding question 4, the complexity involved in achieving an international regulatory framework for autonomous and unmanned ships addressing the various autonomy levels acceptable by all IMO members was highlighted. Because the current regulations are all written on the base of having someone onboard ships, examples of regulatory gaps identified that should be addressed in current regulations included SOLAS Chapter 5, regulation 14 and 33, and COLREGs Part D – rule 37. In a nutshell, all regulations where the presence of human was a *sine qua non* condition for operation will have to be rewritten. A difficult task thus lies ahead for the IMO.

Following these findings, a recommendary framework for training future seafarers has been proposed and is attached to this report. Also attached to this report is a separate document providing recommendations to the IMO regarding identified challenges of the STCW convention in addressing the training of future seafarers and a framework for future development.

Like every research project, this project has some limitations. The first relates to the methodology used. Due to the limited timeframe, a qualitative approach was deemed more appropriate. Although qualitative research is often criticised for having biases, its reliability and validity as a research method has been demonstrated over the years. As such, the conclusions of this report are reliable and valid. Building from the findings of this project, future projects could follow quantitative or mixed method approaches in order to supplement the findings of this project. The second limitation relates to the scope. Ideally, insights from respondents of all IMO members shall have been collected in order to have a wider view on the investigated topic. However, this could not be achieved, given the time constraints. Future projects might target a broader scope of respondents. Another future area of research will be an investigation into the evolution of autonomous shipping technology. Now, this technology is still in at an infancy stage. It will be interesting to investigate how this technology evolves and the processes leading to its adoption.

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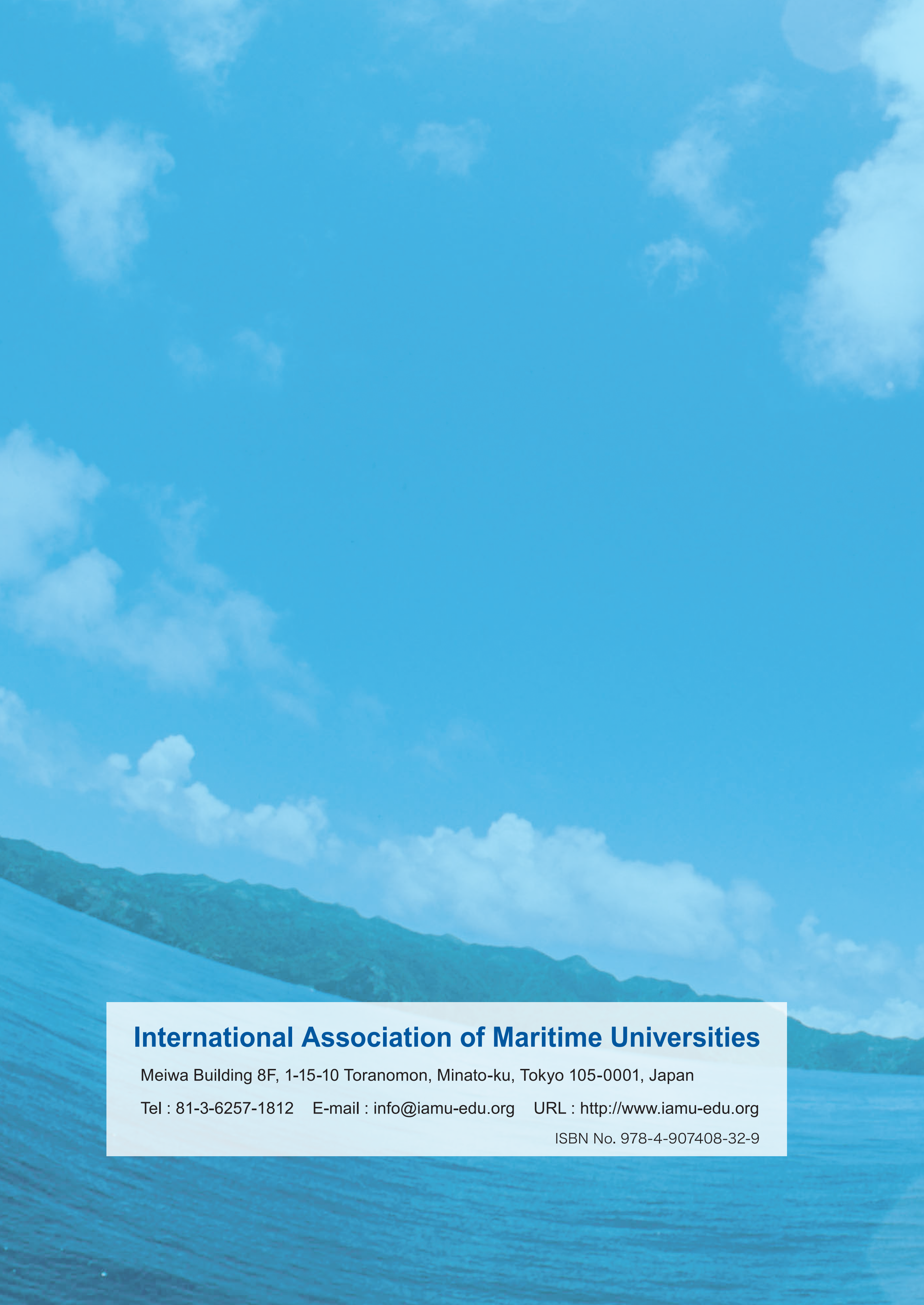

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