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ARTICLE

Identifying essential skills and competencies towards building a training framework for future operators of autonomous ships: a qualitative study

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Abstract
Past and ongoing research in the design, development, and implementation of fully autonomous and unmanned ships has revealed operational, environmental, and financial benefits for the maritime industry. However, with the benefits of being highly intuitive and intelligent systems, there are risks of mistakes and failures caused by their operators i.e. the unavoidable human element. With predictions of both seafarers and non-seafarers to be involved in the critical operations of autonomous vessels, it was imperative to identify key maritime stakeholders and conduct research which would investigate their beliefs and perceptions on the training requirements of the future shore-based operators. The key maritime stakeholders were 37 participants who were a mix of seafarers, maritime regulators, maritime education and training providers, and persons involved in other facets of the maritime business. The qualitative research involving in-depth interviews with the participants provided key insights which helped in identifying essential skills and competencies towards building a recommendatory framework which can be used as a basis to reform the Standards of Training, Certification, and Watchkeeping (STCW) Code in order to make seafarers future ready.

Keywords Autonomous ships · Maritime education and training · MASS · Seafaring · Human-automation interaction · Industry 4.0 · Shipping 4.0

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1 Introduction

Industry 4.0 is characterised by the convergence of digitalisation, cyber-physical systems, and technologies such as the Internet of Things (IoT) to produce highly intuitive and intelligent systems. Through the introduction of unmanned and autonomous machines, these intelligent systems have transformed the nature of work and the understanding of human-automation interaction. The maritime industry and shipping were no exception. Since 1964 when the first automated systems were installed on ships, technological advancements have led to more automations being introduced. However, the introduction of Industry 4.0 in the maritime industry referred to as shipping 4.0 is foreseen to disrupt the shipping business and its workforce in an unprecedented way (Bavassano, Ferrari & Tei 2020; Deling, Dongkui, Changhai et al. 2020; Kavallieratos, Diamantopoulou & Katsikas 2020). Since the introduction of Industry 4.0 in 2011, there has been 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 (Emad, Enshaei & Ghosh 2021, Deling et al. 2020; Munim 2019; Rødseth & Nordahl 2017). However, although valuable but, the automation systems can pose challenges and have negative consequences on human performance (Lee, Park, Jeong et al. 2020). This is mainly because the systems are designed and operated by humans and hence liable to create mistakes or fail occasionally.

To avoid errors and failures in operations, it is imperative to emphasize on the importance of educating and training of system operators.

Past and ongoing research (Alop 2019; Deling et al. 2020; Edler & Infante 2019; Emad & Shahbakhsh 2022; Emad, Enshaei & Ghosh 2021; Shahbakhsh, Emad & Cahoonema 2021; Hogg & Ghosh 2016; Pazouki, Forbes, Norman et al. 2018; Streng & Kuipers 2020) on unmanned and autonomous ships suggest that seafarers 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 safe operation of these ships.

Therefore, based on a qualitative research, 37 maritime stakeholders from various facets of the industry were interviewed to identify essential skills and competencies towards building 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.

2 Literature review on autonomous ships

A close examination of the literature reveals that there are very limited publications that specifically address the future maritime education and training (MET) in relation to autonomous ships (Ahvenjärvi 2017; Emad, Khabir & Shahbakhsh 2020; Vidan, Skočibušić, Pavić et al. 2019. The other papers, though focusing on issues such as 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 briefly refer to MET. The lack of interest in training can be justified by the below statement by one of the respondents in the study of 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, Lundh, Porathe 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. However, they failed 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 maritime autonomous surface ships (MASS) is reiterated by the other papers, yet without specifically mentioning the type of training that will be needed neither proposing a framework for developing the future skills of seafarers.

Maritime expert's opinions gathered by Nguyen (2018) suggested 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;
- science, technology, engineering, and math (STEM) competencies 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; and
- 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 persons operating the ships of the future, Baldauf, Kitada, Mehdi et al. (2018) and Mallam et al. (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, Miwa, Ranmuthugala 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 the proof of concept stages.

3 Methodology

3.1 Data collection

This paper reports on the outcome of a qualitative research conducted to investigate the seafarer training needs for operating future autonomous ships. The 37 research participants interviewed were from Australia, Norway, Germany, the Netherlands, the UK, and Ukraine. The details of the participants are outlined in Table 1 below. Table 1 classified the participants by detailing their role in the maritime industry (e.g., maritime educator, seafarer, and pilot) and experience in the number of years under the broad category of the country of origin. The participants were coded as:

Table 1 Details of research participants (country of origin, role in the maritime industry, years of experience)

Australia (role code, experience)	Norway (role, experience)	Germany (role, experience)	Netherlands (role, experience)	England (role, experience)	Ukraine (role, experience)
4, 27 years	5b, 32 years	5b, 11 years	5a, 15 years	4/3, 28 years	4/3, 35 years
4/3, 30 years	5b, 17 years	5b, 9 years	5b, 17 years		
1, 35 years	2, 22 years	5c, 23 years			
1, 47 years	2, 19 years	5d, 29 years			
1, 40 years	2, 21 years	5e, 26 years			
1, 30 years		5c, 25 years			
1, 28 years		5f, 18 years			
1, 25 years					
5d, 19 years					
6a, 15 years					
6a, 14 years					
6a, 17 years					
6a, 17 years					
6b, 22 years					
6b, 19 years					
6c, 11 years					
6c, 14 years					
6c, 9 years					
6d, 12 years					
6b, 18 years					
6d, 10 years					

- 1 (Educator in Maritime Education and Training (MET) Institutes);
- 2 (member of classification societies);
- 3 (member of International Maritime Organization (IMO) committees);
- 4 (Maritime regulators); and
- 5 (Professionals in various maritime businesses) [5a (maritime logistics), 5b (ship manufacturers), 5c (port authority), 5d (maritime pilots), 5e (ferry operators), and 5f (ship owners).
- 6 (Seafarer) [6a (Master Mariner), 6b (Chief Engineer), 6c (Deck Officers other than Master Mariner), and 6d (Engineer Officers other than Chief Engineer)]

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 a variety of stakeholders of the maritime industry are considered in the research.

Invitations to the participants were sent via email after obtaining ethics approval from the University of Tasmania, where the research team was based. The participants were sent a "Participant Information Sheet" detailing the objectives of the research project and a "Consent Form" for them to share their consent or discuss concerns, if any. The participants were assured that their details would be shared via non-identifiable data only, and the data collected from them would be used for research purposes only. Although invitations were sent to an untallied number of people, either through personal contact or via "cold calling", data was collected from 37 participants who responded within the limited time frame the research was conducted.

The data collection was based on responses to a structured interview which comprised of the following four open-ended questions:

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

All the interviews were conducted online using Zoom or Microsoft Teams.

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 established techniques 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
- safety

From the perspective of the respondents, because autonomous ship technology is still in the 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 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
- 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, the course syllabus will be developed by the Standards of Training, Certification, and Watchkeeping (STCW) Code, 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 competencies 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, the emphasis will now be on answering the main questions which were the focus 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?*

Selected excerpts from respondents were 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?

Overall, all the respondents currently employed as seafarers on ships were of the opinion that the seafarers of the future who will be sitting in shore-based control stations will require information communication technology (ICT) and machinery operation skills. For example, the participants who were 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 losing 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 of 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 will include:

- 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 the effective functioning of shore-controlled stations. These skills will even be more critical for the 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".

The opinions of educators in MET institutes were closely similar to those of the respondents currently employed as seafarers on ships. A strong case was made by the educators that shore-based operators of ships should possess traditional seafaring qualifications 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".

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 the 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, the educators from MET institutes 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 the need arises. Their opinion is well captured by the below statement from one of the respondents, 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 educators was the need for future operators in shore-based control stations to have high cognitive skills, which will allow them to deal with a 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 educators think will be needed by shore-based operators in order to effectively do their job.

Interestingly, there was a high level of convergence between the regulators' opinions and those of seafarers and educators from MET institutes 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 or engine) as a prerequisite for obtaining 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 Ukraine) 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 officer's 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 behaviour 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 switches but can intervene in case of machinery dysfunction as 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 the maritime 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 skills shore-based operators will need. Again, these speculated skills are closely similar to those mentioned by the currently employed seafarers and educators from MET institutes.

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 respondents showed 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 non-technical competencies of future shore-based operators of unmanned and autonomous ships. ICT, information management, and troubleshooting skills were among the technological competencies and communication skills as required 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. 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 an 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?

Stakeholders, other than current maritime educators, had limited understanding and knowledge of MET institutes' preparation and readiness for the future. Data analysis showed that overall, MET institutes' 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 implementing new training requirements is the infancy in the development of autonomous shipping technology. Therefore, although a conversation on how autonomous ships will affect training has started in maritime institutes and some initiatives are being taken, maritime institutes are limited in what they can do in terms of investing in equipment for training future seafarers and developing a curriculum 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".

Respondents, other than the educators, implied that as the technology matures in the coming years, t maritime institutes will gradually know about the available technologies, acquire them, and introduce the necessary training systems. However, because the curriculum used for training seafarers needs to be approved by the STCW convention, this poses 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. For example, the Electronic Chart and Display Information System (ECDIS) took 30 years to get through legislation, and 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?

Based on the responses to question 1, where the stakeholders identified the skills required by future operators of autonomous ships, five broad areas were identified that should be focused on while training operators of autonomous ships (cognitive, operational, leadership, decision-making, and communication). To answer question 3, the stakeholders 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. However, 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 a 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 institutes, further research could be carried out to identify how this 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 International Maritime Organisation (IMO) committees) 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 be classified into two main 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 the 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 the technology matures that the unknown will become clearer. The legal challenges are also complicated by the fact that 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 challenge for the International Maritime Organization (IMO) is that currently, Safety of Life at Sea (SOLAS), STCW, and Collision Regulations (COLREGs) (key conventions introduced by IMO) guidelines require a 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 is slow in response to changes and the fact that there is often a time lapse between the adoption of regulations and their entry into effects (for example, COLREGs regulations were adopted in 1972 but came into effect on 5 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 a code that sits 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 require 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 the training needs for the different 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's first autonomous barge Port-Liner is operating between Amsterdam, Rotterdam, and Antwerp (The Loadstar 2018). 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 national 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

The aim of this project was to interview key stakeholders (maritime training providers, IMO, national marine regulators) of the maritime industry to identify essential skills and competencies towards building a recommendatory framework for training future operators of autonomous ships. To answer the four questions of interest, interview data was collected from representatives of the maritime industry from around the globe.

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

Analysis of respondents' answers on question 1 revealed 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 institutes are not yet ready to instil the skills and competencies that future seafarers will need, the reason being that the technology for autonomous ships is still in the 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 basis of seafarers being onboard ships, examples of regulatory gaps identified that the absence of the human element should be addressed in current regulations included SOLAS Chapter 5, regulations 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 and challenging task thus lies ahead for the IMO.

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 have been demonstrated over the years. 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. A more in-depth study should explore the opinions and perceptions on the expected skills and knowledge of different shore-based roles and positions. Another future area of research will be an investigation into the evolution of autonomous shipping technology which is still in the infancy stage.

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