The rise of digitalisation and automation in the shipping industry and their impacts on training and system safety

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ABSTRACT

The ubiquitous application of digitalisation and automation within the maritime shipping industry will create disruptions that will have profound effects on how work is performed in the industry. The practice of safe navigation will require an evolution and subsequent evolvement of how operators and technologies interact in a complex sociotechnical system if a better understanding of system safety is to be achieved. Predictions of how actors and agents in the same workspace will emerge. This paper focuses on the current levels of automation prevalent in the navigation sector, a futuristic prediction and foresight of challenges related to the emergence of technologies, automation and artificial intelligence, and the competencies required related to the training of future seafarers.

I INTRODUCTION

Artificial intelligence (AI) has presented the world with many innovations and solutions to address very complicated problems. Proponents of AI have offered much foresight into more changes to come.[1] Like other transportation industries, the role of AI and procedural automation in core activities of shipping are developing at a rapid rate; perhaps a rate that creates as many problems as it does solutions. However, digitalisation, AI and automation are desirable technologies because they can support stakeholders in the management of operational complexity, time constraints, uncertainty and anomaly detection beyond the functional capacity of normal human decision-making. The ubiquitous application of AI in vessel navigation is rapidly garnering the attention of innovators, researchers, regulators and shipping companies alike.

The International Maritime Organization (IMO) began work to examine how safe, secure and environmentally sound maritime autonomous surface ships (MASS) operations may be evaluated in today's shipping industry.[2] MASS is defined as a ship that, to a varying degree, can operate independently of human interaction. To facilitate the progress of the regulatory

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1 K Schwab *The Fourth Industrial Revolution* (New York: Crown Business 2016)

2 International Maritime Organization (IMO) '*IMO* Takes First Steps to Address Autonomous Ships' IMO 25 May 2018 (available from: <https://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx#:~:text=For%20the%20purpose%20of%20the,operate%20independently%20of%20human%20interaction>).

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scoping exercise, the degrees of autonomy are organised (non-hierarchically) as follows:

- Level 1: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.
- Level 2: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.
- Level 3: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- Level 4: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

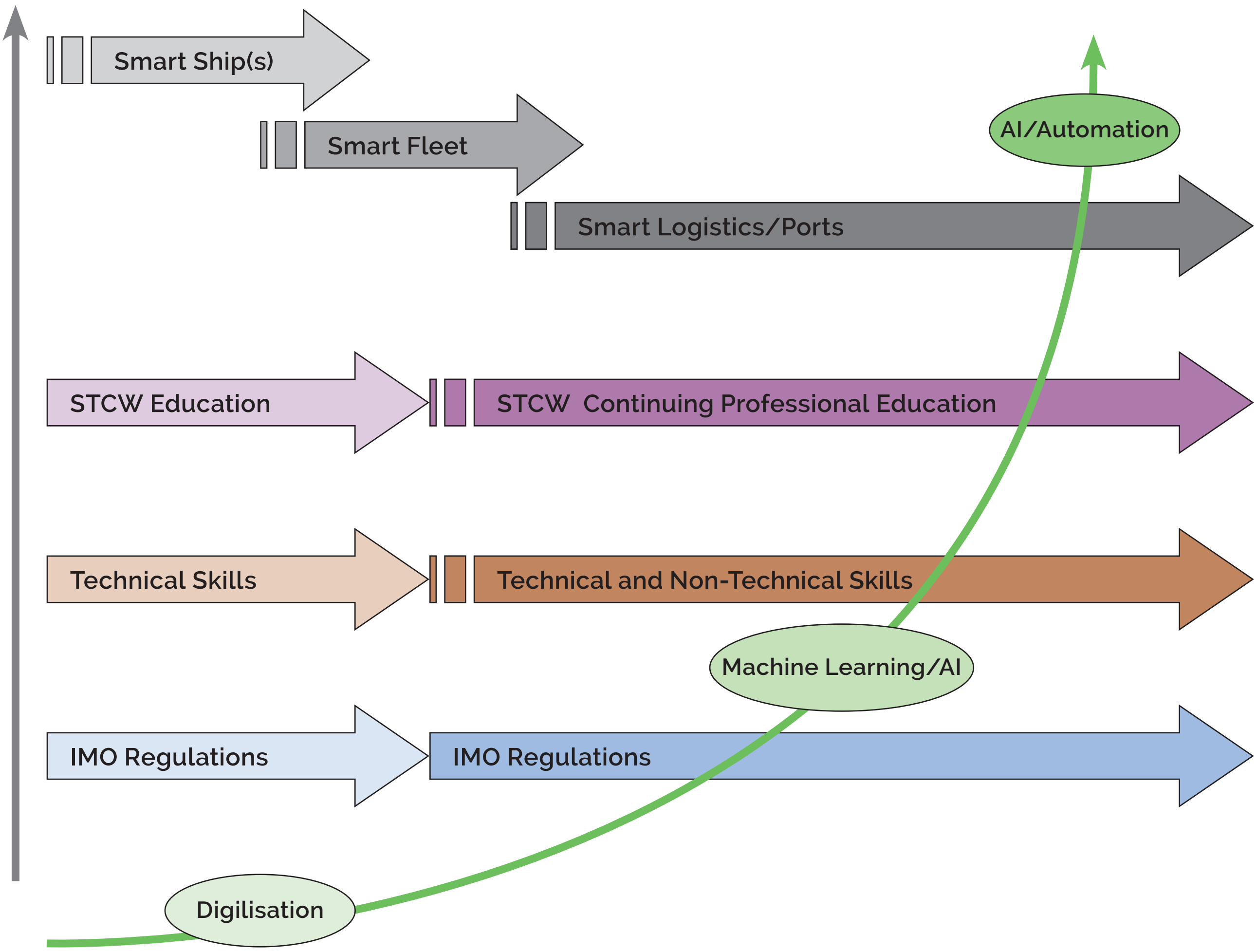

Figure 1: Interaction of Elements Implicated in the Safety of Navigation[3]

To progress through these levels of autonomy will require significant reliance upon continuous advancements in sound AI and ML and Human-Machine Teaming decision support systems. To achieve these goals, several research groups in both the academic and professional domains have identified the elements

[3] Modified from MacKinnon & Lundh op cit note 3.

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to be examined for autonomous technologies to be successful in their application within the industry.[4] These foresight papers identified that the future of an autonomous shipping industry requires a foundational step, an analysis to determine the most appropriate approaches to address MASS operations, 'taking into account, inter alia, the human element, technology and operational factors'.[5] Taking this foundational step would formally set the stage for guiding the innovation, digitalisation and automation race in the new age of shipping (Shipping 4.0), looking to automation and AI to conquer this wicked problem (see Figure 1).

However, there are researchers who forewarned that the growth of automation may create more problems.[6] Humans will always be involved with autonomous agents, regardless of what the public media suggests. There will always be a trade-off between a machine's capacity for self-directedness and self-sufficiency. The need for human–machine collaboration will forever be required because, in any safety-critical sociotechnical system, the human operator must make the final decisions, particularly in critical fail-to-safe situations.

II CAN AI BE THE METHODOLOGICAL PARADIGM TO ADDRESS SAFETY OF NAVIGATION NEEDS?

The successful development of 'general' AI (the form of AI that could have a remote possibility to autonomously navigate a vessel in highly autonomous traffic situations) is decades, if not centuries, away from realisation. One might think that lessons learned and methods derived from AI applications that have consistently beaten human champions in the games of chess or Go, or on multi-player gaming platforms, could be exploited to solve these complexities of increasing levels of autonomy. However, these lessons and methods are not easily transferable to navigation because the objective of these particular AI methods applied to a gaming environment is to win, in other words, to beat an opponent.[7] Traffic safety within a highly complex sociotechnical system requires creating a 'level playing field' so that the environment for all agents (eg ships, vessel traffic services and recreational crafts) is sufficiently equitable for a successful outcome.

III AN EXPERIMENTAL APPROACH TO UNDERSTANDING LOW-LEVEL NAVIGATION AUTOMATION

The following is a summary of the results of an experiment undertaken to understand the influence of low-level automation on collision avoidance.[8] To prevent collisions (or near misses) in traffic situations, navigators are bound to follow the International Regulations for Preventing Collisions at Sea (COLREGs), which are the 'rules of the road' for ships and other vessels at sea, that is, making it clear as to which ship is the 'stand on' ship and which is the 'give-way', ship and what correct action should occur in order to avoid a collision. To support the navigator in ascertaining whether a risk of collision exists, an automatic radar plotting aid (ARPA) and an automatic identification system (AIS) are used. ARPA is a radar system with the capability of tracking and obtaining information about plotted targets (TG), such as (among others) the closest point of approach (CPA) and the time to CPA (TCPA), and

4 See D Lane & R Clegg, R 'Foresight Review of Robotics and Autonomous Systems: Serving a Safer World [online]' (2016) Lloyd's Register Foundation (available from: <https://www.lrfoundation.org.uk/en/publications>); SB MacKinnon & N Lundh 'Gaps in Regulations, Pedagogic Needs and Human/Automation Interactions in the Shipping Industry' *Lighthouse Reports* 20 March 2019 (available from: <https://lighthouse.nu/2019/03/02/gaps-in-regulations-pedagogic-needs-and-human-automation-interactions-in-the-shipping-industry/>); and World Maritime University (WMU) 'Transport 2040: Automation, Technology, Employment – The Future of Work' (WMU Reports 2019) DOI: 10.21677/itf.20190104 (available from: <https://commons.wmu.se/lib_reports/58/>) as examples.

5 IMO 2018 op cit note 2.

6 L Bainbridge 'Ironies of Automation' (1983) 19(6) *Automatica*; JM Bradshaw, RR Hoffman, DD Woods & M Johnson 'The Seven Deadly Myths of "Autonomous Systems"' (2013) 28(3) *IEEE Intelligent Systems*.

7 SJ Russell *Human Compatible: Artificial Intelligence and the Problem of Control*. (New York: Viking 2019).

8 R Weber, K Aylward, S MacKinnon, M Lundh & M Hägg 'Operationalizing COLREGs in SMART Ship Navigation: An Algorithm-based Decision Support System Study' Ergoship 2021 Conference, Busan, Republic of Korea, September 2021 (available from: <http://www.ergoship2021.org/eng/main/files/ERGOSHIP_2021_Proceedings.pdf>).

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includes a trial manoeuvre function, where the effect of an own ship (OS) manoeuvre on all tracked TGs can be simulated. AIS is an automated tracking system in which a ship transmits information about itself, such as name, position, size, course and speed, to other AIS-receivers (and vice versa) and can be depicted on the radar and on the electronic chart display and information system (ECDIS). AIS is regarded as an useful source of information supplementary to that derived from other navigational systems (including radar) and is often considered an important 'tool' in enhancing situation awareness in traffic situations.

A decision-support system, currently under commercial development, provided AI-driven navigation suggestions for collision and grounding avoidance in a simulated bridge environment. This decision-support software is being developed as a smart addition to standard ARPA and TM, with functions covering all working cycles of operations, including situation monitoring, problem detection, suggesting a manoeuvre and monitoring the execution of the manoeuvre based principally on mathematical calculations. Based on the assumption that other ships keep their course and speed, this system provides a graphical solution on how to solve a given traffic situation either by changing the own ship's course or by reducing speed. The platform includes an additional feedback system that 'plays ahead' the manoeuvre before its execution, in other words, a depiction of the traffic scenario in the near future. It should be noted that, at the time of data collection, the software was being further developed and that the following description is based on the available software version used during the trials. The application performs the following functions:

- Producing a system analysis and informing the watch officer of situations in which a collision of ships is possible.
- Calculating a manoeuvre recommending the course and/or speed required in order to avoid a collision with dangerous targets, in compliance with the COLREGs.
- Displaying manoeuvring suggestions graphically and textually on the screen (see Figure 2).

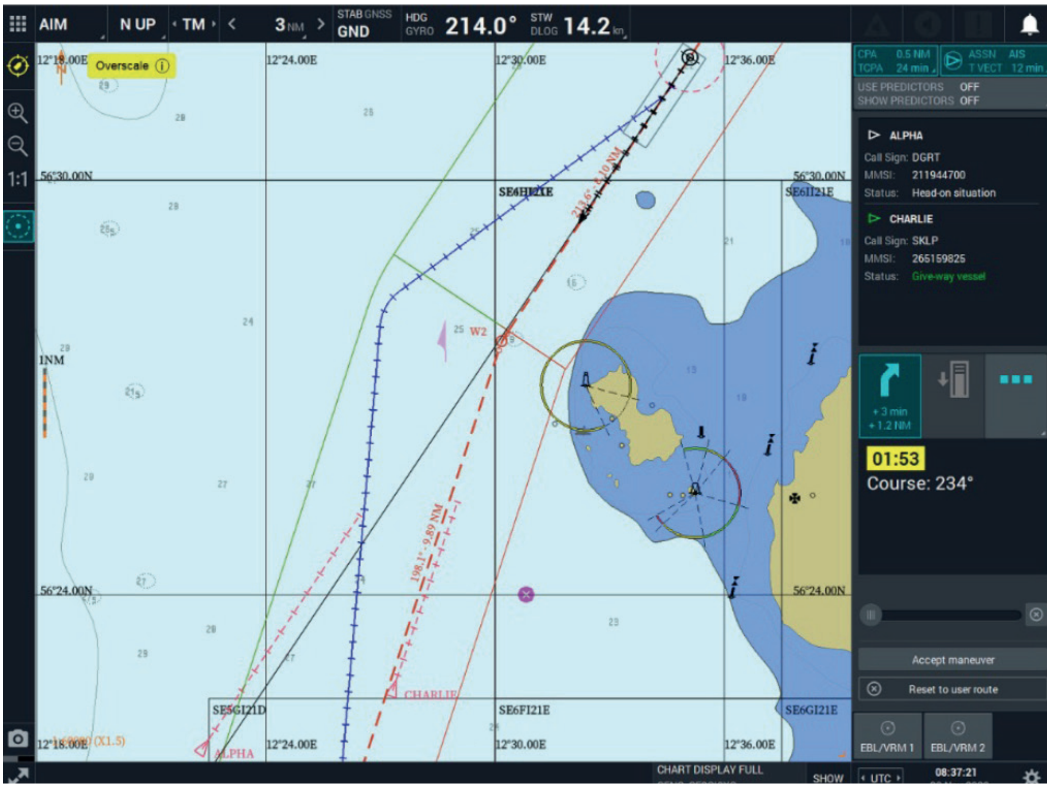

Figure 2: Example of a Change-of-Course Suggestion (blue line) Provided by the Support Tool

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For reasons of property rights and commercial considerations, the software developer did not disclose the algorithms used in the decision-support system in any detail, only stating that the system is based on COLREGs, anti-grounding and the normal 'behaviour' of ships according to statistics obtained from piloted research. The decision-support system presents suggested manoeuvres based on:

- the application of the COLREGs based on all identified vessels (AIS, ARPA and other connected sensors), including their course, speed and navigational status as received by AIS
- nautical chart information
- the ship's route
- The manoeuvring capabilities of the vessel, that is, ship dimensions, maximum speed, stopping/acceleration values, ship loading and turn parameters.

Subject matter experts (SMEs) were involved in creating, implementing and testing various traffic scenarios for this research in a full mission bridge simulator (FMBS). The goal was to develop scenarios that were realistic and somewhat challenging for both the participants and the software. The scenarios had to meet the following criteria: include meeting, overtaking and crossing situations; within a geography described as 'semi'-open waters, good visibility, calm weather conditions, manageable for one single officer on the bridge; and have a duration of approximately 20 to 25 minutes, allowing the test person enough time to assess and act upon a situation. All scenarios involved three ships, namely Alpha, Bravo and Charlie, and each scenario was set in three different geographical areas: the Anholt, Fehmarn and Halland areas.

IV HUMAN–AUTOMATION INTERACTIONS

Blunt but useable system

This research identified two seemingly contradictory themes when the participants were debriefed on the support software, namely (1) it is a blunt tool and (2) it is user-friendly. It was evident among the participants that the software was limited in what it could do, resulting in the blunt description. The support system was effective from the bridge operator's perspective in that it had an 'egocentric' perspective but lacked a birds-eye overview of the entire traffic situation in order to consider situations between other ships. This was seemingly something the participants had hoped for from this type of technology.

Automation transparency

Participants identified that, in order to develop trust in a technology, there must be a proper foundation laid and training regarding the system's opacity, with a clear understanding of the capabilities and potential risks of the system. This would lead to better human–automation interaction, where an appropriate level of reliance can be placed on the technology.

Decision support or decision-making?

According to the participants, the support tool allowed the navigators to check whether their plan agreed or conflicted with the rules, and that one of the primary benefits of this decision-support system was to be able to visualise a manoeuvre in a potential future traffic situation, based on suggestions generated by the software. This feature, called 'play-ahead;, can contribute to a more complete overview of a situation and the ways in which it could unfold, while keeping in mind that this function is based on the target vessels keeping their course and speed (which may not always be a correct assumption). Although the support tool was described as a blunt tool that primarily contributed to the mathematical calculations or strict application of the COLREGs, the participants believed that even its basic functionality has an important role to play in the safety of navigation. The participants also described the support tool as an 'option generator', 'buddy' or 'co-pilot', aligning closely to the synonyms presented for such systems. It is interesting that the participants almost seemed to humanise the technology, an indication of some level of trust in the automation.

V CAN HUMANS BE REPLACED ALGORITHMS?

One of the core rules in the COLREGs is that any action taken to avoid collisions shall, if the circumstances

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permit, be positive, made in ample time and with due regard to the observance of good seamanship (Rule 8). This rule states that if ships meet and there is a risk of collision, the action of the give-way ship shall be timely and readily apparent to the other ship.

While the wording of the COLREGs is sufficiently precise regarding what action(s) ships should take to avoid collisions, the lack of quantifiable distance and time values for what is deemed to be positive, ample time and good seamanship requires interpretation by the navigator. These safety margins depend on many factors, such as traffic density, geographical area, ship hydrodynamics, weather and sea state, which, in practice, results in different safety limits throughout the course of a voyage.

By being able to adjust the CPA and TCPA, the support tool does provide some means to actively set values that may reflect the operator's interpretation of at least 'positive' and 'ample time'. The CPA value in the support tool can be regarded as the ship's safety domain (meaning that no other ships or collision threats should be within this zone) and may be depicted as a surrounding circumference; whereas the TCPA value may be considered as the timing device useful for when the operator receives a suggestion. The TCPA value is not to be confused with the same term used in ECDIS or ARPA as, among others, a threshold limit for generating alarms. As soon as other ships are within the CPA/TCPA parameters, the support tool starts calculations and provides a solution. The implication of the TCPA setting is that the higher the value, the earlier a suggestion is provided; while the higher the CPA value, the more distinct the manoeuvre suggestion will likely be, that is, greater course and/or speed changes (Figure 3).

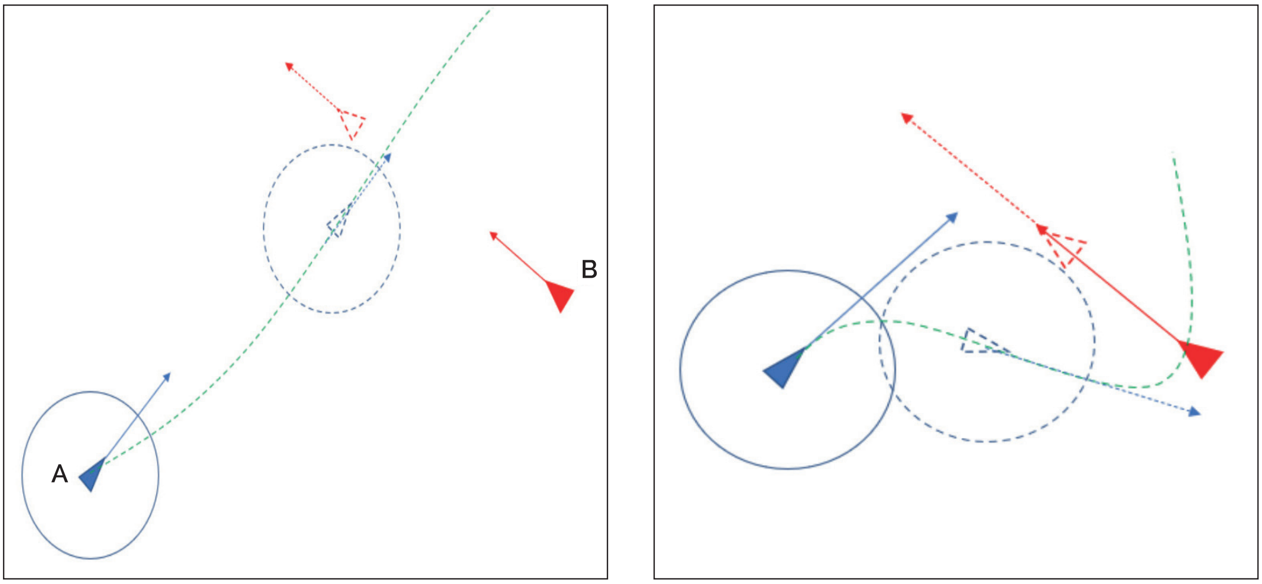

Figure 3: Effect of TCPA Setting (high value left, low value right, dotted lines are predicted states)

As these values are presently set by an operator, a fully autonomous algorithm will need to have the capability to 'choose' reasonable and safe settings, reflecting the deliberations made by an experienced navigator. With sufficient historical voyage data and appropriate machine-learning methodologies this 'may' be possible, however, it may result in traffic situations that involve autonomous ships with different values, established from different operational limits, as to what is deemed 'ample time' and 'positive', with unknown effects.

VI WHAT IS GOOD SEAMANSHIP?

The term 'good seamanship' could be synonymous with the expression 'ordinary practice of seamen', as reflected in Rule 2, which states that:

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> *Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case.*

Using the terms 'good seamanship' or the 'ordinary practice of seamen' will not contribute to the development of a fail-proof algorithm because these terms are even harder to define than 'positive' and 'ample time', and may only be intuitively meaningful to a navigator. Virtually all navigators associate something with good seamanship and ordinary practice of seamen, and potentially assume that other navigators have the same understanding and interpretation of the terms. Unfortunately, this is not necessarily true and there may be traffic situations involving conflicting interpretations of 'good seamanship' or different views on whether the situation requires to be solved 'by the ordinary practice of seamen' at all, instead of applying the steering rules. The art of good seamanship may become even more opaque as the implementation of higher levels of automation occurs.

Deriving algorithms that do not consider the factor 'good seamanship' will not necessarily be a solution either, as traffic situations are sometimes solved (or even must be solved) under the 'good seamanship' umbrella in a more safe and efficient way, rather than by a literal application of the steering and sailing rules stated in the COLREGs. In one of the experimental scenarios, ship Alpha was overtaking ship Charlie, but also meeting ship Bravo in a head-on situation (see Figure 4). All ships had their projected CPA off the island.

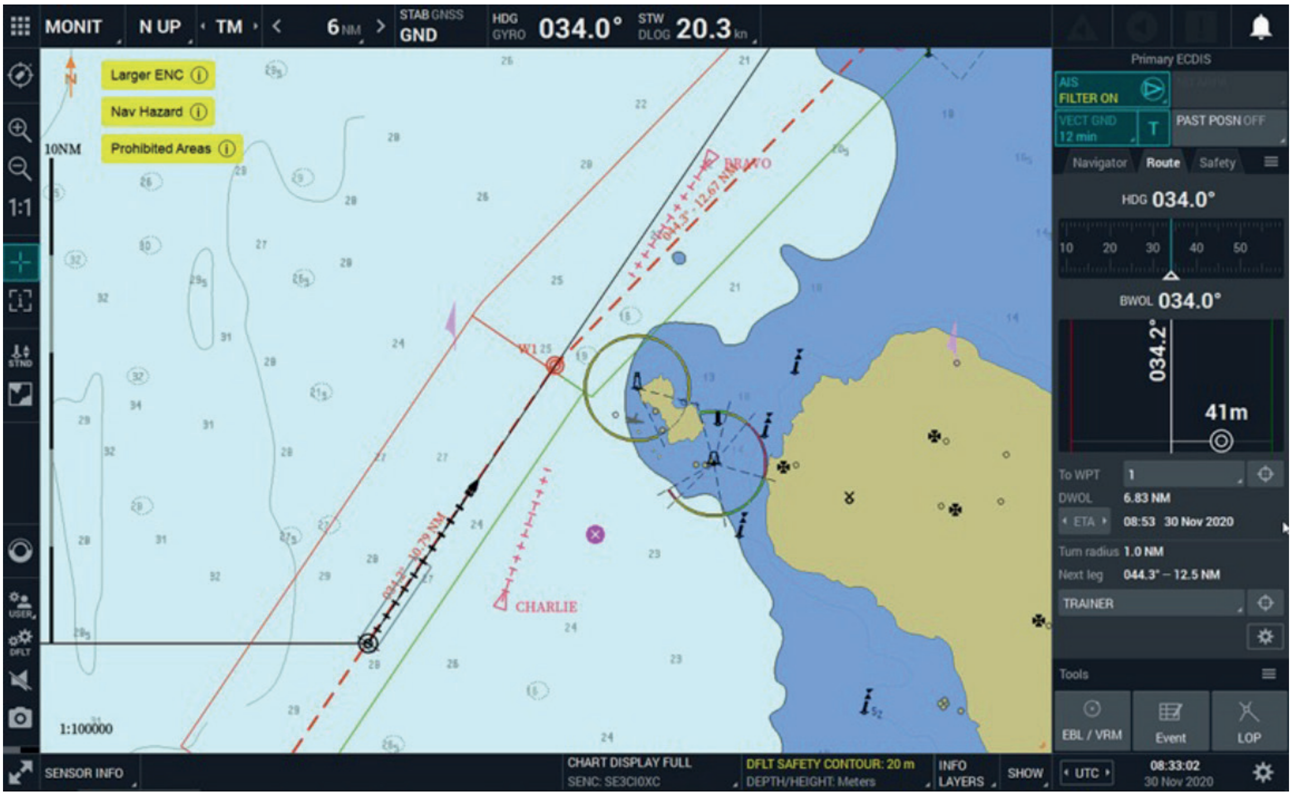

Figure 4: Traffic Situation in the Halland Scenario as Seen on Alpha

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The situation that ship Alpha faces is that she was a give-way ship to both Charlie (overtaking situation) and Bravo (head-on meeting situation). According to the rules, overtaking can be done on either side (Rule 13) but a head on meeting is to be solved by both ships changing their course to starboard (Rule 14). However, the problem Alpha faced is that she would need to alter course quite a bit to starboard to overtake Charlie and meet Bravo, according to the rules. That manoeuvre would take her close to the shore and shallow waters. The support tool suggested as the primary manoeuvre a course change to port and, as an alternative, to starboard (see figures 5 and 6).

Figure 5: Primary Support Tool Suggestion on Alpha

Figure 6: Alternative Support Tool Suggestion on Alpha

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The support tool's suggestion that Alpha changes course to port may be against Rule 14 but, considering that Bravo was at a distance of 12 NM, it may be argued that, although the ships were in sight of one another, the COLREGS do not (or should not) apply at such distances, or that making a bold alteration in course to keep away from land would be acceptable from the 'good seamanship' point of view. However, looking at the support tool's primary suggestion on Bravo (the head-on meeting ship) (see Figure 7) such a manoeuvre would not solve the situation but rather create another situation, as both ships were still likely to be in a close-quarters situation.

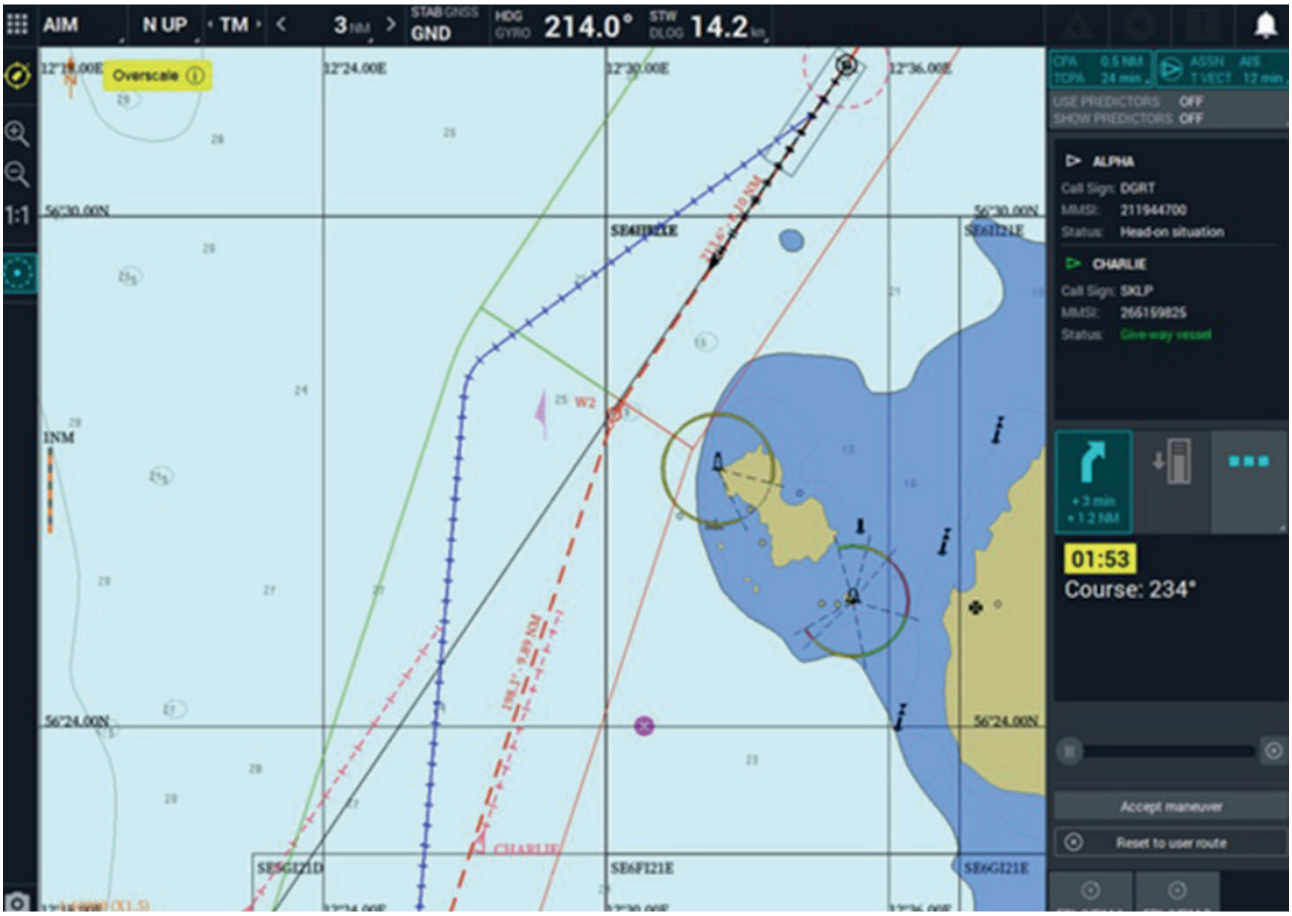

Figure 7: Primary Support Tool Suggestion on Bravo

The preferred option taken by most participants to solve this traffic situation, according to the logged tracks, seems to assume that Bravo, having due regard to the constraints of Alpha and Charlie (having land on their starboard side), would sufficiently alter course to starboard, allowing Alpha to overtake Charlie on her port side with a safe CPA. Figures 8 and 9 show all the simulation tracks of Alpha and Bravo, where the thin red and green lines depict the suggestions made by the support tool and the thin white lines depict the monitored route of the respective ships.

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Figure 8: Tracks of Alpha from Simulation Runs (runs with support tool in yellow)

Figure 9: Tracks of Bravo from Simulation Runs (runs with support tool in yellow)

The data from the trials are not statistically significant due to the limited number of trials, but it raises the question whether the assumption that Alpha may rely on Bravo's distinct action can or even should be programmed explicitly into an algorithm. It also needs to be remembered that the suggestions provided by the support tool were based on certain CPA/TCPA values being identical on all involved ships and different pre-selected settings for each vessel would have resulted in different suggestions and solution approaches. Regardless, humans may rely and act on potentially well-founded assumptions that other ships act according to the poorly operationalised and possibly geographically dependent term 'good seamanship'. Algorithms will need significant data based on deep machine learning, which is likely difficult to obtain. However, even if such data may eventually become available, the fundamental question of what is considered as possibly violating the steering and sailing rules within the COLREGS versus acting according to 'good seamanship' remains.

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VII IS ADAPTABILITY CRUCIAL?

Before starting the exercise, the scenario was uploaded on the bridges and set to pause mode. Each participant was given approximately 10 minutes to complete the pre-scenario questionnaire, which was an assessment of the situation, including the OS plan of action and expectations of how the other ships' navigators in the scenario would act. The results show that in 57% of the cases, participants followed their intended plan and in 12% of the cases they needed to change their original plan, that is, make a different manoeuvre. However, in 31% of the cases, a moderate change or adaption of the original plan (which could be by way of changing the course and/or speed to a lesser degree) was deemed sufficient to solve the situation. Whether this was due to participants being careless in drafting their original plan, or whether such flexibility and moderate adaption of a plan constitutes a major factor in avoiding a close-quarters situation, could not be answered in this study. However, considering the inherent dynamics in traffic situations with multiple ships, one may safely assume that the adaption of planned manoeuvres and flexibility are critical ingredients for safe navigation. Whether appropriate machine-learning algorithms could or should be tuned, or not, to incorporate such flexibility and minor adaption capabilities is not necessarily self-evident and needs further investigation.

VIII TRAINING SEAFARERS FOR A DIGITALIZED AND HIGHLY AUTOMATED WORKPLACE

Given the challenges digitalisation and an increase in automated functions striving towards fully automated and autonomous operation of ships, the training requirements and vocational competencies should be revised.[9] Recent research has made attempts to identify future training needs for seafarers by comparing the shipping industry to other domains, such as aviation, rail, nuclear and mining.[10] Three key areas within these domains' training needs were identified:

- **cognitive**: the skill to think faster and learn easier through exercise
- **communicative**: in addition to read and write, the nonverbal communication by way of observing to infer the meaning
- **operational**: the skill that includes analytical thinking, effective communication and taking efficient action.

The authors argue that the future training of seafarers would also has to focus on these three key areas. The Human Maritime Autonomy Enable (HUMANE) project[11] identified important future skills chosen by experts within the maritime domain. The top seven important skills listed are (a) emergency response; (b) communication; (c) well-trained and multiskilled; (d) safety awareness; (e) seamanship; (f) tool handling; and (g) IT and cybersecurity.[12] These skills are considered to be related to the need for the ability of future operators´ to learn and relearn, and to adapt and manage new situations, such as those resulting from emergent AI-based technologies and resultant operational procedures. Scanlan et al.[13] have also identified cybersecurity as a skill gap and suggest a revision of the existing bridge and engine resource management courses as a way of providing the necessary skills and awareness to address these challenges.[14] The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)[15] mainly focuses on technical and operational skills, although the Manila amendments to the STCW Convention and Code added changes to the training requirements concerning, inter alia,

9 MacKinnon & Lundh op cit note 3; WMU 2019 op cit note 3.

10 GR Emad, H Enshaei & S Ghosh 'Identifying Seafarer Training Needs for Operating Future Autonomous Ships: A Systematic Literature Review' (2022) 14(2) *Australian Journal of Maritime & Ocean Affairs* 114–135 DOI: 10.1080/18366503.2021.1941725.

11 <https://www.hvl.no/en/project/591640>.

12 A Hynnekleiv, M Lützhoft, & JV Earthy 'Towards an Ecosystem of Skills in the Future Maritime Industry' The Royal Institution of Naval Architects International Conference on Human Factors 19–20 February 2020, London, UK.

13 J Scanlan, R Hopcraft, R Cowburn, R, JM Trovåg & M Lützhöft 'Maritime Education for a Digital Industry' (2022) 7(1) *NECESSE*.

14 International Maritime Organization 'Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention and Code' (London: IMO 2011) (available from: <https://www.imo.org/en/ourwork/humanelement/pages/stcw-conv-link.aspx>).

15 Ibid.

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leadership and teamwork, together with modern training methodology, including distance learning and web-based training.[16] These recommendations are detailed in Tables A-II-III.[17] However, given that the above-mentioned research results mainly focusing on soft-skill development, one might argue the necessity to revisit the SCTW Convention to be able to meet the anticipated future training needs for seafarers operating in a digital and highly automated environment.

IX POTENTIAL FOR DESKILLING

The participants almost unanimously agreed that, while seafarers remain on the bridge and in control, education, training and "core navigational knowledge" remain essential. It was further identified that the potential dangers associated with the use of any automated system, including complacency and over-reliance, should be taken seriously. These risks are also present with existing navigational aids, including ECDIS and radar, which were clearly noted in IMO MSC 82/15/2.[18] The participants were clear that the technology manufacturers should not market these systems to inexperienced, fatigued or poorly educated officers. Instead, at early adoption stages of automation and operational integration, decision support should be advisory in nature and provide well-trained officers with rule-based information (COLREGs) to make and execute a final decision for safe navigation. Paradoxically, even with the risks described eloquently as the 'ironies of automation'[19] in mind, most participants argued that knowledge of the COLREGs might be even more critically considered when using similar support tools. As such, the core knowledge of navigation in education may be improved because of these types of supportive technologies.

X CONCLUDING REMARKS: THE REGULATORY ELEMENT AND THE ROLE OF CONTINUED PROFESSIONAL EDUCATION IN MANAGING HIGHLY COMPLEX AND DIGITALISED SOCIOTECHNICAL SYSTEMS

In many respects, navigation is social in nature. Is this because navigators project themselves into the 'shoes of a navigator on another vessel's bridge'? Is the human operator trying to use past data or experiences from the other vessel to try and understand the future intentions for both bridges? What about the next vessel to be encountered? Does a navigator necessarily allow the ship to be placed in a vulnerable position, one that relies on the 'common sense' of other agents in the traffic situation to remain safe? Tacit knowledge, critical thinking and other non-technical skills are clearly required to answer these questions. Current regulations and training tend to be more explicit and prescriptive in nature. It would appear that a more constructivist approach to the education of future seafarers and other maritime stakeholders (eg shore control systems and intermodal logistics) will be in demand.

Will ships and the shipping system become fully autonomous in the future? Given today's state of technology development and training paradigms, the answer is a considered 'NO'! It would likely be too dangerous to create an environment in which humans may be barred from making safety decisions. Decision-support systems will have some utility in the near future, but not without considerable reflection of the current regulatory, environment and the training standards. Continuing professional education will also be critical to solving these issues, in order to identify how the continuous disruptions brought about by new technologies will be managed.

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16 Ibid.

17 Ibid.

18 International Maritime Organization (IMO) 'Role of the Human Element' MSC 82/15/2 (London: IMO 2006) (available from: <http://merchantmarine.financelaw.fju.edu.tw/data/IMO/MSC/82/MSC%2082-15-2.pdf>).

19 Bainbridge op cit note 6.

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