Human-Centred Autonomous Shipping

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Tracing the development of autonomous and automated shipping from a hype of unmanned ships to a more realistic use of automation to augment humans in maritime operations, this book shows why human factors and human-centred design are essential to the endeavour.

Themes addressed in the book include technology and cybersecurity, regulation and classification, and competence and skills. It combines commentary and insight from experts across the industry as well as academia and describes a roller-coaster ride from conceptual idea via a period of hype where technologists and engineers enthusiastically advocated a rapid development as many others in the maritime industry felt compelled, but struggled, to follow and finally to a more measured view as cumulative experience started to show the limitations, risks, and the lack of a generic business case.

This book is intended for anyone working in, researching in, or simply interested in shipping and the maritime domain and the evolution of autonomous shipping. The target audience includes regulators, educators, researchers, engineers, and manufacturers.

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Abbrevations

AAIP	Assuring Autonomy International Programme
ACO	Ant Colony Optimization (algorithm)
ADP	Adaptive Dynamic Programming
AI	Artificial Intelligence
AIS	Automatic Identification System
ALARP	As low as reasonably practicable
AMR	Autonomous Mobile Robots
ASV	Autonomous surface vessel
BAS	Beetle Antennae Search
BBN	Bayesian Belief Networks
BWM	Best–Worst Method
CAL	collision avoidance logic
CAS	Collision Avoidance Systems
CBF	Control Barrier Functions
CFD	Computational Fluid Dynamics
CGS	Closed-loop Gain Shaping
COLREGs	International Regulations for Preventing Collisions at Sea
CONOPS	concept of operation
CRIOP	Scenario Analysis in a Crisis Intervention and Operability
CUS	Continuously Unmanned Ship
DGPS	Differential GPS
DLR	Deep Reinforcement Learning algorithm
ECDIS	Electronic Chart Display and Information System
ELF	Electronic Lookout Function
ER	Evidential Reasoning
ETC	event-triggered control
EU	European Union
FMEA	Failure Modes and Effects Analysis
FRAM	functional resonance analysis method
FSA	Formal Safety Assessment
GNSS	global navigation satellite systems
GPS	Global Positioning System
HAT	Human-Autonomy Teaming

HAZID	Hazard Identification
HE	Human Element
HMI	Human–Machine Interface
HITL	Human-In-The-Loop
HOOTL	Human-Out-Of-The-Loop
IALA	International Association of Lighthouse Authorities
IAMR	Industrial autonomous mobile robot
ICS	International Chamber of Shipping
ICT	Information and Communications Technology
ISF	ISF
IMO	IMO
JIPDA	Joint Integrated Probabilistic Data Association
LIDAR	LIDAR
LOS	Line Of Sight
LSA	Life-Saving Appliance
LTA	Lost time accident
MASS	Maritime Autonomous Surface Ship
MASS CG	MASS Correspondence Group
MCDM	multi-criteria decision-making
ML	Machine Learning
MLP	Minimal Learning Parameter
MPC	Model Predictive Control
MSTE	Maritime Smart Technologies Ecosystem
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
MUST	Maritime Unmanned Systems Trust game
OCAG	Obstacle Collision Avoidance Guidance
OIPD	observation-inference-prediction-decision
PID	Proportional-Integral-Derivative
PKI	Public Key Infrastructure
P&I	Protection and Indemnity Insurance
PSSS	Product-Service-Software Systems
QA	Quality Assurance
QGILD	Quickly Getting into The Loop Display
RBN	Rule-based Bayesian Network
RCC	Remote Control Centre
RCS	Remote Control Station
ROC	Remote Operations Centre
RRT*	Optimized Rapidly exploring Random Tree algorithm
SACAS	Shipborne Autonomous Collision Avoidance System
SOLAS	SOLAS
SRC	Supervisory Risk Controller
SSC	shore control centre
STCW	Standard of Training and Certification of Watchkeepers
STPA	System-Theoretic Process Analysis

TBA	Trajectory Base Algorithm
TCR	time-varying collision risk
UAV	Unmanned Air Vehicle
UNCLOS	United Nations Convention on the Law of the Sea
VDR	Voyage Data Recorder
VO	Velocity Obstacle

Chapter 1

Introduction

Margareta Lützhöft and Jonathan Earthy

Well, here we are. All sitting around a cosy fire and reflecting on the HUMANE project. We invite you to join us for some storytelling about the project, about the future at sea, about seafarers, academia, and industry. About a rapidly changing world and a near-impossible undertaking of predicting the future.

This is not about technology. It is about what we do with it, and how we get the benefits without the downsides. It is about smart shipping. Smart is defined by ISO TC8, and it has been decided that *smart* is the word to use in relation to shipping. There is thus a clear understanding that *smart* is going to be the term that we use. It basically means it is systems that appear smart to humans or humanity. The clever reason why ISO has chosen it is that it is introducing something which is new and developing in many dimensions.

Originally, and intrigued by the widespread conversation about "autonomous shipping" (and now smart shipping) which had recently gathered momentum (2018), the HUMANE project was instigated with a wish to contribute constructively to such a future. During preparatory talks between project members, it quickly became clear that the various visions of increasingly autonomous maritime operations, as it was presented in the media, at conferences, and as parts of company communications, were all building on different sets of expectations, assumptions and preconditions, and mostly of a varied nature. Often, these expectations were however not very explicit, and their span was – and remains to be – very wide, ranging from being purely of a technological capability nature to the other end of the spectrum, where certain human skills and actions were expected in a variety of contexts. In between, there were, and still are, underlying expectations for future legal aspects, training aspects, economical aspects, safety aspects, security aspects, and maintenance aspects, to mention the major areas in play.

In the HUMANE project, the underpinning understanding became that these expectations, assumptions, and preconditions were crucial components in a more autonomous maritime future. Indeed, if the visions presented were to become true, the fundamental assumptions were required to become true first. In other words, such assumptions were not just to

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be seen as convenient but were entirely necessary parts of the foundation for a future where the work at sea had changed, or perhaps is changing, at a higher pace than what has been the norm in the past. This drove the direction of the HUMANE project, highlighting that any contribution to a future such as that envisioned would need to be grounded in an in-depth understanding of the implicit and explicit expectations, because they are more than that: they are the prerequisites, the enablers of change.

To gain the best possible insight into the enablers of change, the HUMANE project partners saw only one reasonable approach: to listen to the visionaries, to the key stakeholders driving the autonomous agenda forward, to the businesses capable of providing the tools and technologies, to the legislators and rulemakers, to the shipowners, to the mariners, and to academia. Basically, anyone having the knowledge and the open-mindedness required to contemplate a radically different maritime industry. An ethnographically inspired method became the choice, where themed workshops gathered stakeholders to discuss, in a semi-structured fashion, a number of baseline scenarios from different vantage points. Themes were originally planned to revolve around the subjects of technology and systems, legal and regulations, training and education, as well as job design, but each workshop was also expected to provide improved understanding outside of the main theme since participants brought their own set of expectations – their anticipated enablers of change – to the discussion.

The first three workshops were, as planned, held as physical meetings, but the Covid-19 pandemic caused a slowdown in project data collection as well as forced a change to the data collection approach, the latter being a result of the restrictions in international travel and the limitation of large(r) gatherings. To mitigate this, an additional, virtual workshop was held in the middle of 2020, the subject being "Maritime SMART technology ecosystem", while the final workshop, originally planned to focus on job design, human-technology interaction and human skills, and training and education, was replaced with a series of virtual "fireside" conversations between knowledgeable participants and a few HUMANE project partners. Further elaborated in Chapter 2, these informal meetings not only brought the project team up to date on current thinking but also proved to be very promising from a methodological perspective in qualitative science.

In way of results, one main contribution of the HUMANE project is to distil the assumed enablers of change from all the data gathered, to refine them and to communicate them to anybody who wishes to participate in making the change come about. In other words, the HUMANE results could be seen as a list of near-term research and development subjects, all to be addressed and progressed to the benefit of the maritime industry of tomorrow. By being as objective as possible, refraining from interpretation and prejudice, it is our hope that readers can use our results to shape their individual perspectives and plans, and thus help facilitate a more autonomous maritime future.

The ambition of the HUMANE project is, however, more than this. Supported by the voices we have been listening to, the HUMANE project members continue to believe that humans will remain to be "in-the-loop" of maritime operations going forward, in some capacity and with some role or roles, despite the commonly anticipated change towards a different balance between humans and technology. For that reason, the HUMANE project has examined how guidance to achieve a more usable change (i.e., more usable future enablers of change) can come about, whether of a purely technical nature, or possibly in a legal, or knowledge and skills dimension. Detailed in Chapter 10, "Maritime autonomy fit for people", the point is that these three dimensions necessarily must be in harmony for the entire work system to function as intended, and we regard it as correspondingly critical to seamlessly integrate the future enablers with the social context in which they are to operate, to ensure that its operation does not disrupt the social and cultural fabric of the application environment. Not surprisingly, ergonomics – in the widest possible sense of the word – is our suggestion for "getting it right" sooner, with lower risk and less investment. Our claim is that future maritime change-enablers developed and introduced, following human-centred principles, will offer:

- Improved integration and support of human tasks and activities.
- Improved ability for users/humans to take control when required.
- Improved platforms for effective change management processes and procedures.
- Improved acceptance and integration of Robotic, Intelligent and Autonomous (RIA) systems in human teams.
- Improved user experiences.

The content of this book is all about autonomous ships but with a human focus. Chapter 2 describes what ships and shipping are like now and an outlook for the near future. In Chapter 3, we present the story of this project and how we collected the information. The following three chapters present the industry views from 2018 to 2019 – Chapter 4 contains the views on technology readiness and needs, as well as a brief discussion about cybersecurity. Chapter 5 focuses on legal and regulatory matters, whereas Chapter 6 elaborates on future skills and competence needs. Chapter 7 covers the more recent views of the industry on the same topics as Chapters 4–6. In Chapter 8, we provide a look at what happened in the world outside the HUMANE project, from an industrial and regulatory point of view, and Chapter 13 reviews the scientific progress for the same period. In Chapter 9, we take a step back and discuss the larger maritime ecosystem, which is followed by an examination of how we can make maritime autonomy fit for people in Chapter 10. For a special perspective on autonomy in the maritime domain, Chapter 11 unpacks the views from an ethnographical perspective. Chapter 12 summarizes the observations of experts who validated our findings in a final online conference, and Chapter 14 is the epilogue where we review the findings and look forward.

By presenting a snapshot of current thinking about a more autonomous maritime industry, as well as a series of thoughts and suggestions on potential enablers of change and how ergonomics methods may be of aid, it is our ultimate hope that we can provide some inspiration about the suitability and applicability of such methods, and how we believe they can be applied successfully.

Chapter 2

Life at sea, 2020 and in the future

Margareta Lützhöft and Thomas Porathe

Standing watch on a ship's bridge has conceptually not changed for decades, perhaps never. The primary purposes of bridge watch-standing are twofold: the first being the task of collision avoidance, and the second being that of voyage monitoring. These two activities are intimately connected, since a manoeuvre to avoid other ships or obstacles could result in a conflict with a key aspect of voyage monitoring, which is to avoid running aground or otherwise entering waters that are unsuitable for navigation.

In the actual situation, the watch-stander acquires and maintains a mental image of the traffic and environmental situation around the ship, primarily by combining visual observation with information from weather forecasts, RADAR, ECDIS, and AIS. The voyage progress is checked periodically, using either positioning devices connected to charting systems, or, when possible, through direct observation, and the progress is recorded in this ship's log and on the chart. When no traffic causes a change in the ship's course, the automatic pilot or track-following device is usually engaged to keep the ship's heading or to follow a particular route. As required by traffic density and the assessment of the situation, the watch-stander builds and maintains contingency plans to follow if an onboard incident or malfunction happens, as well as plans evasive manoeuvres according to the international COLREGs whenever needed, duly taking account of restrictions in navigable water, if any are relevant. The watch-keeper's understanding of navigational constraints is sustained by the nautical charts, whether electronic or printed, carried by every sea-going ship, and when closer to the shore, chart-based information is usually augmented by physical lighthouses, physical buoys, and other markings.

Standing watch in the ship's engine control room has undergone a more radical change since around the middle of the last century. Whereas the smooth running of a ship's machinery originally was facilitated by manual actions of skilled professionals, remote control of valves, pumps, motors, and engines has increasingly been introduced. Hand in hand with vastly increased monitoring of the physical conditions of a ship's machinery, and the associated generation of alerts in case of abnormal running conditions or events, the present-day situation is such that ships' engine rooms and

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engine control rooms are designed, built, and approved to be periodically unattended. The engineering crew on ships are still engaged in maintenance, and some still prefer to do certain operations with humans in the loop, but by and large, the actual running of the engine plant providing propulsion and power is left to the alert, monitoring and control system.

It is important to note that while the electronic systems in modern ships usually faithfully and dependably maintain the course, speed, and correct functioning and working of essential systems, the maritime legal and regulatory requirement and the following design philosophy is that human operators are invariably the backup solutions. If and when the increasingly advanced systems become unreliable, unable to cope with a certain situation or outright fail, the onboard teams are trained to make do, using lower-level backup systems, which are mandatory. Ranging from electrical backup systems, via mechanical backup systems, to directly manipulated controls like handwheels on valves, devices are available with which the human operators can retain control and operate the ship, perhaps inconveniently but still safely and aligned with the rules and regulations. In a similar fashion, the human operators are also the frontline persons to correct faults in either mechanical, electrical, or electronic systems on ships that are underway.

LIFE AT SEA: THE NOT-SO-DISTANT FUTURE?

Arguably, watch-standing and other primary job functions in maritime operations may be changing from what we have known from the past, if the intensity of debate about "autonomous shipping" in the most recent period (since 2018) is anything to judge by. One of the first publicly known projects to air the idea of a material change in seafaring was the Norwegian MUNIN project.

The *Maritime Unmanned Navigation through Intelligence in Networks* (MUNIN), 2012–2015, was a collaborative research project, co-funded by the European Commission under its Seventh Framework Programme. The MUNIN project's aims were to develop and verify a concept for an autonomous ship, which here was defined as "a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control station". The use case was a 200-m long "handymax" bulk carrier in liner traffic between the UK and the Orinoco delta in South America. The pilot and a port crew would take the vessel from the departure port to the pilot drop-off station and vice versa and the ship was to be unmanned during the 14-day voyage across the Atlantic. There could be maintenance teams or other personnel onboard, if necessary, but the goal was that the ship would be under autonomous control during the main part of the ocean voyage, remotely monitored from the shore control centre. Only in exceptional cases was the shore control centre expected to step in and take direct remote control of the ship.

As we see it, the MUNIN project did important groundwork for the blooming interest in autonomous shipping experienced from 2018 onwards, created a baseline for further research and development, and was overall a harbinger of the discussions now more widely undertaken, for instance in the HUMANE project. Considered to be ahead of time – perhaps even a "moon-shot" – Professor Thomas Porathe, then at Chalmers University, Sweden, presented MUNIN to the 108 committee members from 29 countries of IALA's eNAV committee, in March 2013. Reportedly, the delegates all listened amused, and afterwards all laughingly said *"Come back in 25 years"*.

It went a lot faster than that. At the international level, the IMO (2021) is now studying a legal framework for IMO member-state testing activities of "Maritime Autonomous Surface Ships" (MASS), and commercial initiatives with various maritime autonomous solutions are seen and discussed. A number of these pivot around an idea of entirely unmanned ships, perhaps inspired by the Google Car, but conceivably, even if such ships are entirely unmanned during a part of their voyage, or indeed their entire voyage, they will have regular interaction with human beings. In more concrete terms, they will be owned by humans, they will be designed, built, tested, and validated by humans, their operations will be decided upon by humans, and they will be maintained and serviced by humans. Someday, humans will decide that they are obsolete, and they will be dismantled – most likely by humans. Throughout their lifetime, they will "meet" humans manning more conventional ships and working ashore, and there is as yet no defined code for this collaboration and co-existence between robotic systems and human beings.

Less all-encompassing or far-reaching ideas about increased autonomy in the maritime business still involve some interplay between humans and the autonomous entities of what is potentially tomorrow's working environment. Such scenarios reportedly include various schemes for shore-side supervision or interaction (Rolls-Royce, 2018), or convoys of ships where one is manned and the others are drones directed from the manned one, or they are simply anticipating ships with either a full or a reduced crew (compared to today's manning levels) but where increasingly autonomous systems on the ship are undertaking tasks that by today's standards are performed by humans (Farnsworth, 2018; Orange, 2017; Rolls-Royce, 2018; Tervo & Lehtovaara, 2020).

Seeing the novel technology as not only here to stay but also embracing the opportunities for safer and more efficient maritime operations presented by increasingly advanced solutions, the HUMANE project initially moved to understand the landscape of solutions being considered by stakeholders, using the methods described in Chapter 3. A varied, maybe colourful, and perhaps even slightly puzzling set of results ensued; indeed, stakeholders were having the same overall technical solutions and visions of a more autonomous maritime future in mind, but a shared context – or taxonomy – appeared to be missing. Hynnekleiv, Lützhöft, and Earthy (2020) elaborate on this and suggest that the human–machine relationship described by ISO (ISO TR 9241-810 *Ergonomics of human–system interaction — Part 810: Robotic, intelligent and autonomous systems*) is at least a part of the missing, shared context needed for a better aligned conversation.

The notion of understanding and designing the most effective, efficient, and satisfactory human–system relationship is one that usefully can be examined to a greater depth since it appears to be central to "getting autonomy right". Considering the human–system relationships described in ISO TR 9241-810, it appears reasonable to consider that each bit of an aggregated work system can be described in these terms. This, however, also means that not only does that bit need to exhibit the qualities and characteristics required for the particular context-of-use and human–system interaction, but the total work system, as the bits are aggregated, also needs to be better than the sum of the parts.

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Chapter 3

The HUMANE approach

Margareta Lützhöft

AUTONOMY WITH THE HUMAN AT THE CENTRE: THE HUMANE PROJECT

Potential scenarios and views on autonomous ships and maritime operations are changing rapidly, reports of progress (as well as challenges and delays) are frequent, and the pace of analysing, validating, writing, and publishing is hard-pressed to keep up. Based on the data available, timeline shifts are however mostly to the future, and evolution, rather than revolution, seems to be the outcome of the work being done. To the HUMANE project, it seems clear that for a period of time, there will be mixed traffic, where conventional ships as we know and build them today (2023) will interact with ships of a higher degree of automation. The replacement rate for commercial ships is usually quoted at 3–4% per year and is likely to be less for the introduction of autonomy as not all owners see a reason to make this change. It seems that some people subscribe to movement through levels from manned to remote control to more automation or autonomy. However, in discussion, it becomes apparent that these distinctions do not exist in most stakeholders' minds, neither as steps nor as final state descriptors. Be that as it may, from a holistic vantage point, we appear to be getting closer to autonomous vehicles and ships, and there are experimental drones already at sea. As yet, however, no comprehensive and integrated approach for the human element has been presented, tested, and validated. We, for our part, do not claim comprehensiveness, but we do assert a view of inclusiveness. In particular, the HUMANE project is interested in how (in credible scenarios) the human collaborates with, hands over to, and takes over from the technology/automation to achieve a safe system state. Methodologically, HUMANE is rooted in performing an *ethnography of the future*, whilst accepting the possibility of observing "past" problems.

There are many technology-focused, human-replacement projects in progress in the area of maritime automation and autonomy, but there are also political dimensions to pursuing this relatively recent phenomenon. If we go back to before 2016 when Rolls Royce presented their video of a future ship control centre, there was no mention of "autonomous ships".

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At the time of writing (spring 2023), there seems to be a further shift in thinking about what will be automated, especially with regard to liability. Having humans provide the backup (whether in a vehicle or on shore) is becoming the preferred option. However, ensuring that humans can act as the backup for autonomy is not a trivial task. For example, Volvo's head of safety and driver assist technologies, Coelingh says:

> A car with any level of autonomy that relies upon a human to save the day in an emergency poses almost insurmountable engineering, design, and safety challenges, simply because humans are for the most part horrible backups. They are inattentive, easily distracted, and slow to respond. That problem's just too difficult
>
> (Wired, 2018)

Humans have capabilities and limitations, and the question becomes what will future maritime workers need to know. Be good at handling tools (but not touch the systems), have basic skills in many areas, and specific expertise (but needed only now and then). They do not need deep knowledge (but may need a PhD), they need to be fluent in English (to communicate with?), and have Master's papers (but there will be no need to navigate). In the HUMANE project, we are asking ourselves a number of questions: do people with these traits exist? How do we train them? Will they be seafarers? Is it conceivable that we will "end up with a 'Seafarer' of the future that may never have actually set foot on a ship", and part of our worry is that "we do not have the right educational establishment to produce these people. I haven't seen the universities teaching these things. We need educational establishments, that teach at much higher levels".

This indicates that any technology design must either be inclusive of humans or so safe and redundant from the start that humans do not need to step in at any stage, for any reason. The design philosophy of nuclear power plants is that humans should be able to do nothing for 30 minutes in order to get a full picture of what is going on. Thus, a 30-minute latency should be designed into the system. The MUNIN project, briefly mentioned above, concluded that, for shipping, it would mean that the machine must be always in control – which would be the engineers' challenge (Porathe, 2021).

Only a few appear to believe that a transition from today's maritime operations to an end-state where the machine is always in full control can happen in one giant leap, and even if that could be the case, humans would still interact with fully autonomous ships in some shape or form, during building and commissioning, through goal-setting while in operation, during maintenance, and, eventually, during end-of-life activities. It is important to note that autonomy does not necessarily mean removing humans from the ships. According to the IMO working definition and degrees of autonomy (2021), autonomous systems can be dynamic and shift between levels of autonomy. They can be temporarily supported by humans (located onboard or ashore), remotely operated, or fully autonomous, all in one voyage. Dynamically shifting systems imply different roles and sets of tasks performed by humans. The correspondingly required skills are inseparable from the job tasks and should be considered within the context. Moving people across the system challenges the existing definition of a crew (a particular structure of suitably certified staff physically located on board the ship).

In other words, it seems unavoidable that the design of future technology needs to be inclusive of humans. The concern that the HUMANE project addresses is the almost exclusive engineering/science focus of the ongoing initiatives, which nevertheless all appear to depend on human interaction and/or human intervention under some conditions or circumstances, but do not seem to take due account of the feasibility of such human–machine cooperation from a human factors perspective.

TAKING THE HUMAN FACTORS PERSPECTIVE: THE HUMANE STORY

It's early morning in the fictional town of Northberg, and the HUMANE research team are finalizing the planning and set-up for the day. The participants in the workshop – the experts – are either having breakfast in their hotel or are on their way to the meeting room. Yesterday evening there was a meet and greet dinner which started with the project team presenting some information about all the participants, some known and some lesser known; Joe is a member of a wine club, Mary likes skiing, Peter's favourite movie is Casablanca, and so on. As the experts find their way to the meeting room in the morning, they are given a name tag and a small pack of documents. They are directed to a seat at one of five to six tables in the room and meet their table moderator and the rest of their work group for the day. The groups have been set up so that each group has participants from different segments of the maritime industry to provide a broad base for the data collection that is going to be taking place as they discuss.

The project leader welcomes them and describes the project, their task for the day, and the informed consent form to be signed. It becomes clear that the conversations will be recorded but no one will be identified by name in any outcomes from the project, unless they don't mind, of course. The overarching topic is the human role in autonomous shipping, and the focus area for the day is technology and cybersecurity with a focus on the role of the human. We are setting the stage for understanding the skills, training needs, and, indeed, the likelihood of successful human interaction with autonomous systems. Participants are asked to think individually about a question, make some notes, and then take turns presenting their thoughts and discussing them within the group. The moderator gently shapes and directs the discussion and the turn-taking.

There are refreshments breaks and this is where we and the participants start to see another benefit. There are around 20 experts in the room. For a full day, you can discuss with contacts, network, and get a broad overview of what is happening in the field/over and above the discussions at the table. After a few hours, there is a lunch break – informal discussions proceed – and new contacts are made.

The meeting continues and the format of the discussion changes. The groups are encouraged to share their information with the rest of the room, to broaden the perspective. According to how the morning session develops, the project team adapt the afternoon's discussion and methods. This format is kept for the first three thematic meetings – this one on technology, and the two following meetings: legal and regulatory and skills and education. A fourth was planned on organizational issues, but then Covid-19 happened.

With potential conversation partners located across Norway and the rest of Europe, as well as researchers being confined to their homes in Bergen and Haugesund, Norway, Southampton, UK, and Copenhagen, Denmark, creativity was required to move the HUMANE project forward despite the pandemic. Aimed at replacing the traditional format of physical workshops – the chosen format of the HUMANE project – we invented an informal, semi-structured interview style, quickly nicknamed "fireside conversations" to convey the idea of a relaxed talk between friends. It is a term that will be used throughout this book.

In these 1.5–2-hour events, 10 in all, which were conducted in the course of the late winter and early spring of 2021, the HUMANE researchers spoke to 12 participants spread among people we believed represented four perspectives of the maritime autonomous agenda: technology; training and education; legal matters, including rules and regulations; and maritime operations. It should be mentioned that while we find such labels useful to organize data and responses, we are aware that they are also prone to fault, and are seldom clear-cut, considering how people move around in the rather narrow circles of the maritime industry. Among the HUMANE fireside conversation participants, one such example is a captain (i.e., operations) presently working in training, while an engineer (i.e., technology) was presently involved in rule-making. Thus, we have for such reasons avoided putting much weight on the orientation of particular participants other than to organize responses, and – where we subsequently in the HUMANE work believe there is an important point to be made depending on the orientation – we have been careful to avoid cross-matching, and thus drawing incorrect conclusions.

Observing GDPR and research-ethic protocols and obtaining informed consent from the participants prior to the talks, all conversations were conducted in English, recorded, and subsequently verbatim transcribed by a professional transcription service.

The presentation of this type of qualitative data is invariably cumbersome, and it is difficult even to provide a narrative of the sense-making process. Our ambition is however clear: we are aiming at providing readers with a direct view of the raw data while adding as little analysis as possible; our work has mostly been about grouping data relating to the same aspects of autonomous shipping, and trying to provide brief statements in objective, uncoloured language which we believe capture the essence of the input we have received. We realize that even this work is prone to bias, and we suggest that readers should carefully examine the direct quotes provided to build up their own conclusion on the topics and subtopics being discussed.

Our intention is to present the discussions with as little interpretation as possible to get the voice of the experts. This also means that the direct quotes may contain grammatical errors. The quotes reflect the thinking of the time and words like “we” can mean anything from “my company" to “the maritime domain”.

Concerning the layout of the chapters, several attempts to provide structure, order, and an array of perspectives have been undertaken prior to what is now included, with varying degrees of success, resulting in many internal discussions as well as research into potentially better and more effective formats.

Finally, the last event of the project was also an online meeting, not a conference as was originally envisaged. We invited two experts to give a short presentation of the state of the art within their area of expertise – one technology-centred and one human-centred. We also invited a panel of six professionals to receive and read the most up-to-date HUMANE results and prepare some comments based on a set of topics. The data collected there is, like all other data in this project, presented in the voice of the participants. The two expert presentations are included in their entirety, and the panellists’ views have been summarized and included under the main topic headings.

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Chapter 4

Technology, cyber, smart ships, and humans

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INTRODUCTION

This chapter covers the first HUMANE workshop which had the joint themes of system safety/technology and cybersecurity. System safety in this context was intended to be about machinery and hardware, and cybersecurity to consider the software and IT perspective. Having said that, the main theme in HUMANE is always the role of the human in the sociotechnical system.

The first workshop was held in October 2018 in Trondheim, Norway. At this workshop, the needs of the maritime industry in the future were discussed. Four groups of participants were moderated by one person each. A scribe was also present at each table. The discussion was open-ended, guided by a series of scenario prompts with no descriptions, definitions, or assumptions provided by the researchers. The scenarios were an unmanned bridge, unmanned engine room, ultra-low manning, shore-control/monitoring/support centre, and fully autonomous.

As a backdrop, at the time the thinking about autonomy was almost exclusively controlled by the Rolls Royce video, where a futuristic control room staffed by experts provided support to a ship. Yara Birkeland was said to be capable of operating, unmanned, in traffic, which as of the time of writing (2023) is still to be accomplished. HUMANE wanted to replace the story about technology focus with a humans and technology focus.

MAKING SAFETY

The safety argument was strong at the time and humans were seen as part of the problem. Will it be safer? The section talks about other ships, failure of IT, remote control, and emergency management.

Other ships

Autonomous and remote-controlled ships will need to cope with all possible behaviour from all other traffic. Autonomous ships will be the minority for a very long time, the traffic system must work.

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> If a manned ship has a traditional bridge and not a good lookout it doesn't matter what you put on the autonomous ship. I don't care from a third party if the vessel coming over there is manned or autonomous it has to act the same way – they have got to be integrated and sail together.

Failure of IT

The causes and consequences of IT failure may be different from issues that seafarers are used to and trained for. Crew members need competence before attempting to "fix", and systems should support repair.

1. Ships don't actually sink if software fails, they just sit there and wait for someone to press the restart button.
2. That is the other problem – people go and fix their IT systems. Not always wise.
3. Now it's tightly integrated systems! They lock cabinets and don't give the key to the crew. Do I get highly trained people or remove them?
4. You don't need to have a deep understanding of all the systems, but you need to be able to deal with the mechanics, electronics, and software.

Remote control

Remote control was a topic that raised many views. Some thought that the master works as a buffer and there are wide-ranging thoughts about competencies and skills, and the need for experience from the sea. It was not clear whether people would be on board or on shore or both, and what that would mean. Unsolved issues concerned knowing when to intervene and assigning responsibility and blame, and how to guarantee communication when needed. The number of ships per person, how to plan work hours, and how to ensure attention and awareness were also of concern.

1. How do you train people to react?
2. Need seamanship.
3. And then you need cybersecurity skills.
4. I mean, how to handle tool[s].
5. Like planned maintenance, who is going to do the main daily tasks? That means they have to be well-trained, multi-skilled.
6. Know more about all systems.
7. You need less skills on board.
8. They need to understand and speak English.
9. Don't necessarily need a navigator, but the sea demands certain insight and skills to handle [navigation].

10. The role cannot be the same, maybe, but the action of the control centre is not necessarily the same as on board a ship. Imagine you must suddenly take over, you don't have situation awareness, it would be really difficult.
11. If you have an operator in a remote-control centre that doesn't understand the automation functions and intervenes when they shouldn't.
12. How long can the system keep within a safe state before some other party has to step in? What is a permissible break in communications?
13. Remote-control operators have two sister ships, they behave differently and you expect them to behave similarly.
14. If you have a ship and a shore-control centre and the master is in the control centre and you lose track of your ship and it goes on automation, can you blame the master? And if the master in a situation is able to intervene, will he do so if the ship goes on automation? [The blame might be on] the people that design the ship and algorithms, but they [would] shift the blame. And then [you've] got human trust, over-trust, under-trust problems, and everything – yeah.
15. I think it [i.e. the answer] is moving the responsibility; it will be the man in the control room.
16. We need communication costs. We need high bandwidth to achieve similar situation[al] awareness.
17. Do you need to communicate constantly? No, just when the ship has made its own assessment that something is wrong, and it does a procedure and contacts [someone].
18. Today you have a captain as a barrier so it's your problem as a captain to be on the ship and handle [everything]. If you don't have the captain as a barrier, someone else needs to experience this problem. I think that if [it] is going to be pushed to a shore-control centre handling managed vessels, you can't get 2000 alarms going off constantly because it would be impossible, so you force system integration in a way. Maybe [you would] not [be] liable as to what you have, but they will be more responsible for having good system integration, maybe [that is of] more interest for it.
19. Different work dynamics – how to regulate? Can you work 1 hour on, 1 hour off?
20. As long as you have got some activity and [are] not staring at the screens waiting for something to move, actually you are running a complex part of a control room.

Emergency management

What happens when there is an emergency on the autonomous ship and there is a need for assistance, and also to what degree an autonomous ship can offer assistance to another party.

1. I'll just put one [comment], it's practical. Emergency situations. You will always … any kind of technical stuff, you will have, especially at sea, you will have emergency situations, you can have fire, you can have a collision with grounding, bad weather, [or] damage. What happened then? There is nobody out there. And you will have the risk against all the vessels in [the] nearby area, drifting vessels.
2. How long can the system keep within a safe state before some other party has to step in, but what is [a] permissible break in communications?
3. Yes, of course. Again, you have the legislation, because, at sea, if somebody is in an emergency situation, you have to come and assist them. That's the legislation thing.

WHAT IS NEEDED FOR TECHNOLOGY TO SAVE THE DAY?

We need technical systems that are approved – the manufacturers who are driving innovation claim to have this now. However, assessment organisations will increasingly struggle to keep ahead. Many of the technological "parts" already exist but the industry is not integrating and connecting a system with a human-centred view. The experts listed a number of aspects that need further attention, including new ship design (there is agreement that retrofitting will not work), new maintenance models, and a working system approval process. Going into some detail, there was a need for better sensors, for example for collision detection and decision making. Our IT and cybersecurity systems were immature, and our competence and readiness level were low. Technology needs to communicate but it does not do it well. Last but not least, we kept coming back to the cost of resilient systems versus the business case.

When discussing artificial intelligence, the participants with knowledge of AI were carefully positive, reminding us that machine learning and intelligent agents cannot (yet?) manage the whole complexity of the world. Experts from the aviation domain also warned us that it may not be achievable, and computers are not as clever as we think … yet? Then again, some believed that computers were close to perfect. Whatever the case may be, the collaboration needs to work. The section discusses knowledge management and support.

Knowledge management

There was an assumption that knowledge acquisition is unproblematic and that seafarers are repositories of knowledge which can be transferred to machines. Machines were seen as faultless, given that they can be properly programmed and trained. However, there were also concerns about AI understanding context to interpret regulations which are codified knowledge about safe practice.

1. How to assure quality? You said training, but 80% of dockings had a mistake. So it will take [a long time] to get good data to train.
2. It is not that hard, the system is as good as the best captains, far better than the average, so what you do is lift the level to that of the best.
3. Align the ferry and transfer it to [an] automatic system, the computer will do the same. The computer will be as good as the best [human].
4. COLREGS needs human interpretation, difficult for computer[s] to do. It would be double the time travelled if they had artificial intelligence follow COLREGS.

Support

Even the best systems can, and do, fail. Many comments spanned the skills needed to perform the work that will still be needed. Whether it is a mechanical system or a digital system, it would be important to have some understanding of it and the human presence necessary to attend to its daily needs, expected and unexpected events.

1. Occasionally you put people on board, you put a maintenance crew on board.
2. You can get [an] additional person on board, easy.
3. You don't need to have a deep understanding of all the systems, but you need to be able to deal with the mechanics, electronics, and the software.
4. And then you need cybersecurity skills.
5. That is the other problem … people go and fix their IT systems. Not always wise.
6. Like planned maintenance, who is going to do the main daily tasks? That means they have to be well-trained, multi-skilled.
7. Basic skill set in many different areas.
8. You need to know the most important troubleshooting when things go wrong.

NEW BUSINESS CASES AND MODELS ARE NEEDED

The majority of shipowners had concerns about the business case for autonomous technology. New skills would cost everyone in the industry money. Large investments needed to be made by companies and seafarers alike to prepare and reskill for ultra-low manning. In order to maintain dependability, people were still assumed to be onboard, permanently or temporarily. The section is about business case, ultra-low manning, and skills.

Business case

The cost of redundancy to be safe is high, and there were concerns about expensive ships and cargo sailing unattended. What ship functions could be cost-effectively automated and at what voyage stage? There was a broad range of opinions about the cost–benefit of the crew.

1. Safety-related systems have tough standards, for example redundancy, but four to five times redundancy to replace humans doesn't make sense.
2. Multi-million-dollar assets, an autonomous ship would have someone in a control room.
3. Sailing in the middle of the ocean – this is exactly where you need an automated system, [it] can be very low tech, just beeping when something comes closer than 12 nautical miles.
4. International waters are not good for trials. There is no business case to do automation in the middle [of the ocean].
5. It's cheaper to add one man, not a captain.
6. For deep sea shipping, we will of course automate things more and more on board with the objective of having fewer people on board.
7. It is not requesting to remove the crew by putting a sensor on board, he can, say, remove five and save money, [and] it can sail by itself.

Ultra-low manning

The reaction to ultra-low manning was that it would be inhumane, as well as difficult to decide what function this minimal crew should have. Riding crews for maintenance were expected.

a) It is evil to have [just] one person on board.
b) It's hard to define what ultra-low manning will be … you would have to identify the key functions to fill. I think that would be interesting because it doesn't have to be a captain or a chief engineer … maybe one key function out of three is the guy who makes the food? So, would it be a navigator, an engineer? Or a communicator who has some role in communicating with shore – and all the other vessels on [a] collision course […] get them to go as well.
c) Occasionally you put people on board, you put a maintenance crew on board.

Skills

The skills needed are both specific and specialized. It seems that the common denominator is a problem solver with maritime experience. (This theme pre-empted the HUMANE workshop on skills. These are comprehensively discussed in Chapter 6.)

1. You don't need to have a deep understanding of all the systems, but you need to be able to deal with the mechanics, electronics, and the software.
2. Need seamanship.
3. Future skills for seafarers must be IT literacy.
4. Basic skill set in many different areas.
5. You need to know the most important troubleshooting when things go wrong.
6. You need less skills on board.
7. You'll never get a master that will be an expert in IT in addition to everything else. Then we're talking about super humans.
8. Humans have to waylay Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) to keep the schedule; they do it every day efficiently.
9. We can't just put an ordinary seafarer there. It is a completely different environment.

Human skills are regulated and validated by the Standards of Training, Certification, and Watchkeeping (STCW), a comprehensive code, but are lagging behind technology development, and not providing details for complete validation.

> What would they need to do for certification. SOLAS doesn't work for shore-based work. STCW gives no baseline for shore personnel.

INTEGRATION

In general, there are two ways of conceiving of a robot–human system. We can separate humans and robots, so that they "never" meet (think of factory robots in cages or ships in corridors), or we can integrate. The latter is more complex and may be the most difficult issue we face when devising the autonomous ecosystem/sociotechnical system. It is about augmentation rather than replacement. A challenge is to keep the work as a whole and to augment humans in their work. The message we heard is that a lack of integration between stakeholders stops development. A lack of integration between technical systems and humans is also problematic. In unintegrated systems, humans work as the glue. The technical system must communicate with humans, but the way development seemed to be going, humans would be supervisors – a role for which they are utterly unsuited. The section is about augmentation, working practices, allocation of function, monitoring, and handover.

Augmentation

A large shipping company clearly stated that they will augment humans with automation and not remove them, which seemed to be a counterstatement to the prevailing opinion "until we can get rid of them".

1. We will be there. And we will be needed.
2. If you are using duff information, it doesn't matter if people are on the ship, people are off the ship or totally autonomous.

But how to allow humans to control the system *and* bring their ingenuity to the system? Integration and augmentation can support humans, remove some of the tasks that are unsuited to human limitations, and allow them to keep tasks that are challenging and motivating.

1. Our members see an opportunity to augment our trained seafarers – to preserve the ingenuity of humans. Augmentation doesn't need regulatory change.
2. Automation is a tool, not the goal.
3. Computer[s] cannot have an argument or have a discussion but allow you to look into the future by spotting issues.
4. If things go wrong in the future [when] systems are integrated, one thing that will be more positive is the transparency of what has actually happened. And the absence of shame as the machines don't have that problem. And cultural difficulties to question your superior or whatever. The machines will be super clear on what has happened and why of course.
5. People cannot cope and are hitting quayside.
6. We need auto-docking and undocking because they are 80% of minor accidents.
7. Automation made navigating less exciting; we become squashed into a corner with all these burdens that are less exciting.
8. We want to take away human errors, or more precisely human operational errors; all errors are human by system design or operational. It is human error, you can remove some of it.
9. Need better sensors, like humans need vision, sound, all that a human does, it's a challenge to see stuff on the horizon.
10. You should have a platform where you can still work without having to be at the station.

Working practices

There was discussion of the sharing of work and reduction of workload that leads to boredom and inattention.

1. It would perhaps be better to have the guy sleeping at night, just work[ing] at daytime for fatigue. In chess, man plus machine beat machine. That's a good argument for having support. You can allow people to sleep at night, working dayshifts.
2. If we try to keep the same number of crew … we are still already overworked. So, we would like to relax the workload. We can comply with the labour conventions and improve safety.
3. Why the hell do we have someone standing on the bridge at two o'clock at night in the middle of the Pacific at ten knots? Because we need someone to blame.
4. Humans would still have the fun part of just going in and out of port.

Allocation of function

And comments on the consideration of task sharing and allocation, based on mutual benefit and individual strengths.

1. We are reducing tedious tasks, and they are transferring the focus for the person to more important items.
2. [A] really positive item [is] that we hopefully at least get the technology to do more of the tedious tasks, one of these examples is of course the maintenance bit.
3. Although you can see visually some of the marks and navigation marks, it is much more difficult to imagine an autonomous vessel or a remote-control vessel seeing those in the same perspective.

Monitoring

Participants also discussed the difficulties of understanding technology, working out what systems are doing, and intervening.

1. Humans need to understand the machine; we need transparent technology.
2. Just look at it and try to understand what the technology is doing and when to intervene or predict what it is doing; it is impossible.
3. If you have an operator in a remote-control centre that doesn't understand the automation functions and intervenes when they shouldn't.
4. Remote-control operators have two sister ships; they behave differently and you expect them to behave similarly.
5. How do you train people to react?

6. Imagine if they turned around and said, do you want to interact with the system itself? What is your password? I can't remember my password from last week; never mind in six months' time. Imagine if you have to log in to take control.

Handover

The model for exchanging control with or providing assistance to the technology should be as familiar as working with a human crew member. The interaction between humans and advanced technology can take many forms. It spans augmentation (improving human performance) to conceding governance to the AI.

1. We might need to put the human back in the loop, but the system has to tell the operator things, at a minimum.
2. The computer has to do what the second officer has to do, explain to the guy coming up, this is the situation, this is what I have observed, this is the problem I have, please tell me, I can't handle this myself.
3. No difference whether it is a second officer or a computer who [makes] this explanation, but it has to be done in a way that is possible for the guy coming up to [make] sensible decisions.
4. How do you train people to react?

This issue is related to comments on the difficulty of making intelligent agents, and the rigidity of traditional computer "thinking". With a structured and rule-based context computers would be almost perfect, but as it is, human skills will be needed to complement with their experience and competence. Artificial intelligence is available to some degree but is not mature and not well regulated. It is anticipated to be trained by humans on human datasets, these can be regarded as corporate knowledge and there is a risk that they will not be shared across companies or nations.

1. We need a world model and a controller. This is the typical design of [an] autonomous agent. In a limited context, we can design. In an unlimited context, it's very difficult to design such an agent.
2. From my perspective fully autonomous means that even fallback is done by the system. Then the discussion is similar to traditional AI issues. Can it have common sense? So it's an endless discussion on ethics. I can't see the answer to solve the issue … maybe if we limit the context, a boundary, like firefighting and those cases.
3. Computers are basically dumb (bad at making decisions) – we don't have AI yet.
4. 99% of what [a] computer does is right.

Human error or barrier?

As technology develops, humans may be moved ashore. And with them moves human error. For the time being, it is assumed that some humans will still be on board. Who are they? The range of opinions was wide and contradictory. On the one hand, the crew could be system experts, while on the other, VR-guided drone workers. Most agreed that there will be fewer on board, but some aim to retain crew numbers and increase automation to reduce workload. What the experts also agreed on is the need for effective skills management, maintaining the existing skills will be difficult with increasing automation. There were suggestions about flexibility through multi-direction training, systems for skill sharing, and demands for deeper IT and cybersecurity knowledge. The range of skills would also vary according to the relationships between humans and technology.

1. Occasionally you put people on board, you put a maintenance crew on board.
2. You can get [an] additional person on board, easy.
3. It is evil to have [just] one person on board.
4. Why the hell do we have someone standing on the bridge at two o'clock at night in the middle of the Pacific at ten knots? Because we need someone to blame.
5. We are reducing tedious tasks, and they are transferring the focus for the person to more important items.
6. [A] really positive [is] item that we hopefully at least get the technology to do more of the tedious tasks, one of these examples is of course the maintenance bit.

Responsibility

The discussion touched on the master's responsibility, the commercial driver being irresponsible, the question of testing AI as a responsible entity, and what happens when humans as the hitherto responsible actors were moved or removed.

1. I'd just like to add more on legislation. Both of you kind of mentioned the master. I think today there's a lot of dumping on the master, so the captain, he is responsible for everything on board. He's the one that sort of gets locked up when things go wrong. Using the sort of slightly, jokey language here, but so if he's not the dog's buddy, then who is gonna be the dog's buddy? I don't know, they'll have to put the responsibility somewhere else. So that has to be so solved as well.
2. I have one [another comment] and it's commercial. So, you know, again, for a ship management company, and, of course, our clients keep hammering us to lower the cost. Okay, we'll give you a really low cost. [The] alignment of a proposal is no crew on board. I think

there's a long way to go before it's genuinely accepted. It's a barrier, that we [are] gonna have to work on. It's like the Tesla cars.

3. I think AI [has] come in, in order to do what humans are doing, I mean, it's hard to break us down into algorithms. Like individual algorithms, manually, it has to be done more automatically. And that's why I think we need artificial intelligence to do it, and then we also need this test bed and verification. I don't think you can have approved AI, you can just do it, that's, what you would do with a human, subject them to some tests. If you pass the test, you're ok. I think you have to do something like that.
4. This is an interesting aspect because we said that humans are the glue. But also humans are responsible; they are in control of operations as it is today. But here we are removing humans as the glue because systems are communicating more efficiently. But where is the human?

The human contribution

Some stakeholders regarded humans as a problem: "they don't look outside anyway", but most agreed that humans add safety to the system. Humans are an important part of safe operations in more ways than is obvious to technologists. Humans perform integration, interpretation, and repair work, which are all positive human contributions. They are good at finding patterns and interpreting unclear information. Humans onboard can also easily fix things that go wrong and can perceive much that may be lost to a shore operator located far from the ship. Agreeing on what skills might be needed turned out to be difficult, but centres on being a generalist, a MacGyver or a Jack of all trades. Seafarer skills and competence are discussed in more depth in Chapter 6.

1. Humans are doing a lot of interpretation of the situation that we need to automate in the future.
2. Unmanned engine [rooms have been the case] for many, many, many years already. So it's not that good. But if you don't have any engineer on board, then I guess that's the scenario. Because today it's unmanned but we have them on board, so we can say, when the alarm goes off, they can just run down. But this is the same as before, but also [a] loss of communication when something goes wrong. Who will do something?
3. Just to follow-up a little bit on this – like, who's left, you know. This "Jack of all trades" in Norwegian – someone who knows how to mend the nets and make the food, and know[s] the way around along the coast. That would, like, be one job description. In the old days, you could see this kind of thing in the newspaper. So this "Jack of all trades" is nothing new. I guess, probably we were there before, and then we got specialized. Now, maybe you have become more generalists again.

4. Thinking when you are sitting at shore centre. It will easily be like video games, because anyway, you will not have the feeling of the weather, typically if you have [the] vessel sailing on the Norwegian coast, from A to B, with the environmental … you know in the bad weather, most likely you will have [a] smaller engine if it's fully autonomous. Low speed. And you will lose the feeling that, what board has to do, you know, approaching the safe way. And also other vessels, in the same condition. You're far away.
5. What is happening around and also other vessels and all this kind of stuff. Because not being there on the bridge physically but sitting in a comfortable office somewhere, it does something with your mindset and also I think you have to be even more forced into taking the situation in the account, because it's so easy to fall back in your own thoughts and in whatever is happening at home because you're like five minutes away from home. And it keeps calling, you know, it's kind of like, you know, you're not on board of the vessel. It does something with you. I think.
6. If you go on a bridge today, you can see [there] are many systems, many screens, from different vendors, different alarms, and different bells and whistles. It might have some single alarm system going to inform, but the fact is that most of the time the human is the glue.
7. So you don't need glue. So when the problem occurred, he come up from the coffee shop, and when he was to glue, he was constantly building on situational awareness.
8. But the [other] group, they had [a] different perspective on it. I'm not sure if you picked up on that. They were discussing that these people that are left, MacGyver or just doing what they are told. On the one hand, it could be a MacGyver, know everything, while on the other, to be someone else, not say dumb but not skilled, they are just the hands and they are doing different things and you need to choose which path are we going.
9. Still, you need to have big skills, I think. I mean, you need to be able, anyway, to interact with the user interfaces.
10. Yeah, you need to know the most important troubleshooting when things go wrong, rebooting of systems, fixing small little bugs.
11. Of course, you don't need to really have a deep understanding of all the systems, but you need to be anyway able to deal with the mechanics, electronics, and the software. You can't be afraid of updating the software.

Human limitations

We are only human, after all. We have limits. The simple arguments were presented: no humans on watch – no fatigue, no injuries, and should the worst case occur, only the ship goes down. There is misinterpreted information and over-trust, there are people who think they know better, there is lack of experience or practice, and cybersecurity risks. On the other hand, if we removed people from the ship – would we remove human error? Possibly, from some of the operational phase of a ship's lifespan. But there are people everywhere, in design, in build, in operations (ashore), and "human error" just moves with the people. If technologists took the time to think about it, would it not be reasonable to consider some human fallibility and make systems that mitigate human limitations?

1. Effective. You can operate 24/7 without worrying about fatigue. [about unmanned ships].
2. No people – that means no injuries. No lost time accident (LTA).
3. If the vessel goes down, it's just money, not people.
4. Elimination of errors. No more human error on board.
5. There's now a term and the industry called Electronic Chart Display and Information System (ECDIS)-induced accident, it's a real thing; if you google, it's there, 32,100 hits last time, I checked. And it's basically navigators who misinterpret the information on the electronic chart. And again, when you need to do systems that provide you with some support for making decisions, there's always the added uncertainty of whether the person will make the right decisions because they can misinterpret. People have gone ingrained when you can see that you know those little waves on the surface of the water, they don't believe what they see at the window because the ECDIS tells you … you know, there's nothing there and well, there is.
6. But I think it's the port areas, congestions, and so on. They have a big challenge. Shanghai, you have hundreds of vessels, everybody's moving and drunken captain and Costa Concordia … and those who don't really follow the convoy. Humans.
7. This may be related to what I mentioned before about this equipment awareness, that you really know the equipment and how it works. And the further distance you have from the equipment, the more difficult it is. The less competence you have about the equipment.
8. To me that's where standard and segregation comes into the picture. You need to isolate the systems where humans can do their things. And you need to have standards. That couldn't be, I think it's the only way.
9. Because you get [the] whole human-out-of-the-loop problem. You get disarranged from what you are doing, in a way.
10. But you're also talking about when we are reducing crew, then we have accidents at sea. I don't remember the accurate number but like 70%, 80%, 90% is due to human error, failure. So can we also say that on most of them, we can increase safety, or is it too dramatic? If we say that system is better than human, it's always awake, always alert, never falls asleep.

Humane workplace

Significant parts and functions of ships are already automated and periodically unattended. Extending this to the bridge could be considered realistic and beneficial. However, the social implications of extreme reductions in manning, leading to single-person crewing, were of concern, for example, isolation, injury, and lack of conflict buffers. This is likely to cause difficulty in attracting, protecting, and retaining the necessarily responsible and highly skilled staff. The alternative of some staff supported by well-integrated systems was preferred. This provides the additional benefit of support in a crisis and the ability to deal with unforeseen problems.

1. And we need [to] also have fault-tolerant systems. Fault tolerance [on the bridge]. That also if you say that we have it already, the requirement is that you have the engine run for six hours without human interference. If you're crossing the Atlantic, the time span is quite different. So, there's a big thing to go from six hours to six days. But still we have coal plants that are unmanned for four months, even.
2. I guess one thing, when it comes to this unmanned bridge [which is periodically unattended], actually for several days, you know, with this thing I've been pushing – integrated systems, is that today on a vessel the human is like the clue between all the systems, because the only thing that many of these systems have together is the same human in the middle. When you managed to integrate these systems, the systems can talk to each other in a much more efficient way than what you do with a human in the middle all the time. So, the human can take more of this supervisory role. And don't have to be the messenger all the time. So, in this way, you get increased safety.
3. On the other hand, I think that removing the last person on board will be the most difficult part. And it will require also the most in business. Actually, I think that ultra-low manning can have a bit of value proposition. Because you can address the people [who] handle the most difficult parts.
4. You always feel that you have somebody to call on in a crisis, do something. Or blame.
5. If you've got a MacGyver on board, that means they have to be well-trained, multi-skilled. But there is always gonna be those tasks that have to be done.
6. I think what you [are] addressing there is actually really interesting. That maybe there's a big leap between ultra-low manning and no people on board. But I would say operating the vessel with just one person on board will be evil. From at least [the] shipping company, to send people on. You know they could be at sea for her for months on and it's like being in the national space station, right, people do go lonely after a while. And how do you handle that? If someone through

isolation becomes ill? They make a loose cannon on board as well, but that's not really the topic for discussion, but just throw it in. [There] might come a time when that's not an attractive job for anyone, so that one person we have on board of the three people we have on board, we have to pay so well that it breaks the business case again. And then you might as well just have unmanned ships.

7. If this happened, just how to keep [the] sailing profession attractive for young people leaving school? So, if contractors dropped, disappeared, if they see this is a risk, they might not [be] in the industry. They might choose something else.
8. So highly automated vessel with crew onboard? Supporting the crew instead of removing them.

An irony of this development is the variety and inconsistency of the remaining (unautomated) tasks, requiring knowledge and experience over many topics as well as the ability to take action. This disparity calls for the human to make sense of and integrate the systems and skills.

EVOLUTION: TIMELINE

The timeline estimates ranged widely; some said we are there, others said it will never happen. Remember, this was in 2018.

1. We already have unmanned vessels (drones).
2. We are almost there.
3. In a few years, we will have partially unmanned with increased automation.
4. We have been developing it for 40 years and are not there yet.
5. We will go from radio control to full autonomy.
6. We will do autonomous later.
7. We are not there.
8. It's going to be 100 years before we see fully autonomous ships sailing whole voyages.

SUMMARY

In line with the intention to not interpret too much, we have chosen three quotes to summarize the attitude and outlook that these discussions have left us with. The major question is "why do we need it?" and the natural follow-up is, "for whom should it be created?" The outcome is that it should be created by humans for human benefit, and the human is the top priority (or centre) of the development.

The major question is why we need it and what is the purpose of these technologies that are coming? I think that that is the major result that we are looking for.

I think in this ecosystem the humans are on the top of it. So, the main focus should be on the humans. And I agree with that.

Human-created systems for human benefit. That's something we sort of forget. It's almost about taking responsibility for what's happening in the industry.

Chapter 5

Legal, regulatory, and humans

Tore Relling and Jonathan Earthy

OVERVIEW

Maritime rules and regulations developed and implemented in the past century were established in a different world to that in which ships operate today, and maritime autonomy will further challenge the validity of these regulations and the associated legal framework. Rules and regulations are a required contributor to maritime safety, and providing concepts that are as safe or safer than the existing ones is a prerequisite for maritime autonomy. Consequently, legal and regulatory aspects are crucial to future maritime autonomous operations.

The HUMANE project has consulted visionaries with a wide range of experience about regulations to identify changes or developments that are considered necessary. Topics included the variations of changing regulations to fit with expected autonomous concepts to adapting autonomous concepts to existing regulations. In the discussions, the visionaries were asked to elaborate on how different perspectives on autonomy affect the requirement for future regulations, if and how future regulations are different from present regulations and how changes to the human role need to be reflected in regulations. In the discussions, the visionaries were encouraged to keep the human role central.

INTRODUCTION

This chapter presents the visionaries' expectations for regulations from a workshop in 2018. The authors have treated the data very carefully, avoiding interpretation and judgement to allow the visionaries' voices to speak clearly. Readers of this book will see that some of these expectations were closer to reality than others, and this in turn might guide us to project one future that is more likely than others. It also points to non-technical barriers to the adoption of technologies or changes to the industry.

However, there was not one single answer to the questions above, and the expectations span from autonomous/automated concepts that could operate

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within existing regulations to solutions with significant self-governing capacity that are more disruptive to regulation. While the former is expected to become a reality within a few years (and indeed is already the case for many ship systems), the latter is considered to be many years into the future.

Visions of autonomous maritime operations build on expectations (of varied origins) spanning from technological nature to human skills and actions. Nine years ago (2014) we had different expectations than today. We had not heard of autonomous shipping, while today autonomous concepts are seen as a significant part of tomorrow's shipping. The world will be different, and the future of regulations might be different. However, we can be sure that there will be both new technology and humans engaged in maritime trade and that rules and regulations will be required to keep them safe and secure and minimise environmental impact.

This chapter summarises the expectations for the legal and regulatory domain, interpreted broadly. Assumptions about the future are essential to allow progress (assumptions before reality). Understanding these expectations is a prerequisite for change (or enablers of change). To gain insight we have tried to understand the visionaries and distil the assumed enablers.

> We can see applications. short sea ferries "nice gimmick but what do they really change?" 10K GT worldwide – that's a long way off.
>
> Is ocean traffic the end game?
>
> So, it is somewhere between 5 years and 100 years depending on what kind of ship and that isn't even saying whether it is cost-effective for all types of ships,
>
> Who is benefiting and who is the losers and what barriers, look at the big picture. What is the aim or goal of making shipping autonomous, is it just to throw out the crew? That is the least reason to do this. So, what are the other benefits of the society or the global or whatever you say?
>
> Obviously if there is any point in any of this there must be some benefits including to the maritime industry and not only the ships but the transport industry as such and how we can mould our transport industry. We have some destructive movers here, there might be new players Amazon might become the largest shipping company in the world and so on. On the other side is the losers, smaller companies that are unable to enter, the barrier to enter[ing] shipping could be raised, not necessarily a bad thing for the global community for safety.
>
> If you go to a conference and it is all about ships my advice is to get up and walk out. Likewise, if anybody turns around and says it is about cyber security, get up and walk out because it is an inherent part of a software-based solution.

THE OLD WAY OR THE NEW WAY?

In the workshop, each discussion began with the contextualisation of autonomy. The ambiguity of what autonomy would be is a core element in the discussion of future maritime regulation and could be extracted from the question "how is it possible to make rules before knowing what to make regulations for?" The workshop visionaries highlighted that the term autonomy is challenging and includes a variety of potential ship types. On the other hand, the understanding of autonomy does not exclusively point to future ships. The term includes functionality on existing ships, such as machinery functions, and as such, autonomy is not something completely new. However, the visionaries agreed that autonomy indicates a shift to something new compared to traditional shipping today. This shift suggests that we will discuss systems rather than ships, with fewer people and more sophisticated technology. An interesting aspect of the system perspective is that although the visionaries transfer the perspective from ship to system, they do not foresee an autonomous ship. This implies that autonomy is a shift where sophisticated technology will be used in some functions, and the effect is that fewer people get involved in the system of which the ship is a part. This does not mean less people in the industry overall, but it does suggest changing roles and possibly locations.

> The first thing is that is all about the whole ship and we are not seeing the whole ship.
>
> A totally unmanned fully autonomous ship that goes from A to B and the two leading technologists said it is 100 years away.
>
> Do not talk about ships systems, "bunch of stuff" the International Maritime Organization (IMO), or functions, or engineering.

The technological shift has implications for regulations, whereof the most outspoken is how to make rules and regulations regarding autonomy before knowing what autonomy is. From a human factors perspective, there is no reduction in responsibility for the crew, but several significant changes, including expected knowledge, team structure, a different relationship to technology, and place of work. When debating this, the visionaries pointed out that the role of national authorities would be to facilitate the development of future maritime concepts, including autonomy. This invites a close connection between all stakeholders, or at least for regulators to understand the application of technology from developers.

> I think it is kind of hard to – there are so many different kinds of autonomy states or what we're calling them. And also the different kinds of ships – potential ships.

The role of national authorities was discussed. They are expected to make future transportation possible, and safety is an inherent part of this. How to develop regulations when we do not know what "autonomous" technology is being offered to the maritime sector has several dimensions for the national authorities: what applications are being automated, how self-willed will these applications be, how will they be characterised, what degree of control will they take, what scope of control will they have, what sectors of shipping will they cover, how mature is the technology, what will be the role of seafarers, etc. The only answers we have at the moment are in the form of "prototypes" and "trials". Regulators need to work closely with, but avoid being affected by, the industry – that is, to learn from, but not be influenced by industry capabilities.

From the discussions we could see three development pathways: keep the regulations, change the way we interpret them, or change them completely. Changing the way we interpret them would probably have started in the legal world.

> Is it possible to say no, stick to the regulatory framework and instead change the technology to fit within the regulatory framework?
>
> Need support from precedent – not law.

If maritime autonomy is different from the existing concepts, the present regulations could become obsolete. Technology-neutral regulations, or two streams of regulations (the old way, the old rules – the new way, the new rules), may be needed to allow for both approaches. In other words, if the autonomous system is close to traditional use, autonomy must adapt. If the application is new, regulations must adapt.

Regardless of whether existing regulations are relevant or not, the visionaries elaborated on the additional parts of future maritime systems, such as control rooms and performance monitoring. These parts of the system must fall under regulations and/or a certification regime.

> Last thing we need is prescriptive requirements. Because of fast change[s] in technological development.
>
> Performance standards [don't] work for [learning] autonomous systems – static vs [dynamic] human machine [interaction] is different when it starts to when it ends.
>
> Certify control centres, what would they need to do for certification?
>
> Why not safety of technology?
>
> I hope we all concluded on that most regulations/conventions are technology neutral … whether it is applied by machine or human, as long as it is done, it is okay.

EXISTING REGULATIONS

A central question when discussing whether it is possible to keep the existing regulations is if autonomous and conventional vessels should be treated differently?[1] Consideration of this topic fluctuated with respect to the degree of change, conventional or new. The discussion about the evolution of autonomy could be summarised in two main directions. On the one hand, we might expect the development of autonomy to aim for being as close to conventional vessels as possible. On the other hand, autonomy can be considered as something different to existing, traditional vessels. The existence of these two points of view is an important precondition that will affect the development of regulations, particularly if both must be accommodated. The former perspective will require less adaptation of existing rules, while the latter requires new rules and regulations to be developed around autonomy. However, there was discussion about the scope and use of the existing regulatory framework. There was agreement that conventional and new regulations must inter-work at the ship-to-ship and ship-to-world levels, that is, all ships, whether autonomous or not, must appear the same to an observer:

> But actually, there's been a lot of change before which we've managed to cope with through the regulatory framework.
>
> Some very clever people over the years put all this stuff in place, despite the commonly held belief that the regulations are a complete load of rubbish made by idiots, that is probably not true.
>
> So the question is what is actually covered? To go forward to a new set of regulations for something that is different when you don't know what you are covering now is kind of like a large step forward from the edge of the cliff.

A NEED FOR CHANGE?

The regulations the visionaries think would change which were considered central are Standards of Training, Certification, and Watchkeeping (STCW), International Convention for the Prevention of Pollution for Ships (MARPOL), International Convention for the Safety of Life at Sea (SOLAS), Convention on the International Regulations for Preventing Collisions at Sea (COLREGS), and indirectly safe manning (MSM). The mentions were unspecific, referring to the regulation(s) as a whole. Judging from the number of times a regulation came up in the discussions, SOLAS (30 mentions) seemed to be the most important, representing a recognition by the visionaries that operational safety is important for Maritime Autonomous Surface Ships (MASS). This was followed by COLREGS (16 mentions), possibly indicating a focus on navigational safety. STCW and MARPOL are mentioned five and seven times, respectively. Manning was mentioned 45 times and safety more than 200 times. It was believed that "nothing forbids autonomy" from a regulatory perspective.

The challenge of predicting future regulation grows with the uncertainty in defining autonomy. The International Safety Management (ISM)-code is considered relevant by some, as it covers the organisational responsibilities, while others state that the lack of hardware focus in the ISM makes the code irrelevant. The link between autonomy and the navigation function is apparent when discussing COLREGs and the legal perspective of removing humans from this function. The visionaries noted that the existing regulations were developed in a different world, and some consider it challenging to try to make the future of autonomy fit to the old world's regulations. When debating the relevance of SOLAS, we were reminded that the regulation is based on common understandings and assumptions that might be obsolete for autonomy. This leads to the regulation being effectively incomplete because many of these assumptions are not included in the text and additional explanations are necessary.

> It is important from a legal point of view to bear in mind that all these conventions that we have now, they have been developed in a different world where some of these ideas weren't on the table and it is kind of artificial to try and squeeze these new ideas into the regulatory framework and look for loopholes or look for areas of tensions and conflicts and try to make conclusions on the basis of this new development plan and the old they all conflict because they were never made for each other anyway.
>
> If you read SOLAS there are lots of stuff in SOLAS that assumes a lot of things, we probably can say two-thirds of SOLAS has never been written down because it is based upon [our sharing] a common understanding of how a ship looks like, how a ship is built.
>
> We are not going to change it [SOLAS] we are going to as you say adapt technology, but first and foremost we are going to adapt the way we read the conventions, we are going to adapt the understanding of the wording.

WHAT TO EXPECT IF WE DO NOT UNITE AROUND ONE UNDERSTANDING?

The discussion on the regulation of autonomy includes many variables. One approach is that the industry clarifies where we are heading and agrees on terminology, properties of autonomous vessels, and human involvement. A different approach is that the industry is not united, and the development takes different directions, which could cause local rules to be implemented in different parts of the world. The implication of this is also discussed by the visionaries.

Local regulations are seen as "a pain for the industry" compared to global regulations. Rules developed for local, self-governed consortia (consisting of manufacturers, owners, small numbers of flags) for particular applications are not necessarily generalisable. It is important to note that consortia are not a traditional maritime arrangement. It may be better to consider autonomous projects as something different to maritime, like an offshore installation.

Eight member states are really interested. One-hundred-and-forty+ states. If they do not get the data – they will not let you into their territorial waters.

It will start off locally, and local regulation has always been an absolute pain for ship owners, we do not like local regulation.

We are talking very happily around here about risk models as low as reasonably practical etc. etc. Those terms are not recognised in 80% of the work and we have to realise that.

Some of the international conventions might not apply first. As the initial testing might be in the national waters. It could help to have "friends" in IMO.

If he is ashore then you have Norway wanting to prosecute him and [if] he is in Norway it's okay.

Of course, it becomes a global problem the moment you move between countries. But I think it's very clear that going forward now we see a per country approach. Because each authority per country can kind of give exemptions and grant permissions for today to kind of go outside the existing regulations.

We are saying that you should do things as [safely] as reasonably possible and write it down. When I go out and take it to a consultant he says, I am contracted on a fixed fee, [a] fixed amount of money to do this design, the moment I go below the acceptance line I stop work because every single hour I spend on this project after going beneath the acceptance line is going to lose me on my profit. Therefore, as low as reasonably practical means in reality approvable and nothing else.

These new players have not been working in the industry for a long while and they are used to dealing with professionals, and these players are not that old and are professionals in different areas, they have their ambition and way of doing things and they think they can do it just because this is not regulatory.

RESPONSIBILITY AND LIABILITY

A recurring topic throughout the workshop was "who is and who might be responsible?", but with no apparent answer. However, the visionaries agreed that complex systems cannot be maintained or even operated without manufacturer support and cannot be sold as a "fit and forget" product which the operator manages anymore. Communication, databases, software, and learning technology are still evolving and will continue to do so. The visionaries underlined that we also may have shore control/assistance, and certification of ship elements will not be owned or managed by most/any operators.

> This one was an interesting discussion in terms of liability because I would say most manufacturers try and avoid liability, certainly for any third party damage, so you sell it and say, "There is your equipment". If we now have the manufacturers steering the vessel as well how do we now control that asset? Is it not only the liability for the product itself but how that product is actually being used? And that is an open debate that needs to be had by certain lawyers and insurers; they will have a big discussion about that.
>
> It is not about risks being high or low it is about liability. Now you are going to the point that the manufacture[r] who is producing the steering gear is also controlling it. Can the manufacture[r] also have the liability?

The shipowner is identified as the most responsible stakeholder but there is not a lot of discussion of in-service issues, i.e., the use of these systems at either a corporate or individual level. This will be very different to that of established technology or ways of operating. It suggests immature thinking about issues as well as a lack of experience.

> Asking the right questions to get the right answer. What is and who is the "Captain". The core basic responsibility in person.
>
> Yeah, but step back from thinking about the human on the ship and start thinking: There is some responsibility in the design community, in the build[ing] community and things, because unless you get that bit right the rest doesn't matter.
>
> If there is no human to blame, there might be [a] product developer.
>
> So, I think that […] one of the things we would like to see is a stronger systems integrator responsibility. Someone is basically saying "we think this is going to work as a complete package". But there is a big question if the yards will be willing and able to take on that [job], or if there is someone else. But […] I think the role as such is going to be increasingly important.

Models of responsibility

The current model is that the operator is responsible, and an unanswered question is how much will or can Flag continue with this? If a ship is unattended, will the operator be responsible? Operators/companies not used to the maritime sector may find responsibility hard to accept, and solutions such as the aviation model were compared unfavourably with maritime.

> Good point to start with the mapping of [the] responsibility of manned ships today. Actually, the responsibility should not change too much.
>
> I think it is to better understand what the risks are that you are facing in terms of public liability. Or if the ship owner says okay I will take all the responsibility all together.

> Is funnelling of liability towards shipowners appropriate in the autonomous era? IMO questions. Also the national maritime administration – how much slack will they give operators?
>
> Because there is a crew on board, responsibility and duty of care, clearly manufacturers have this duty – when it's foreseeable that there will be no crew.
>
> We see that the new sort of players in the market now, they have nothing to do with the maritime industry whatsoever. They normally [come] from the logistical side and that also means they don't have all these assumptions or even knowledge about how to create a safe environment, etc.
>
> When you look at the aviation model and their safety management system it is actually broken up, so there isn't an overarching one. If you look at shipping responsibility downfalls to the operation. So it is actually quite clever.

NEW REQUIREMENTS FOR LIABILITY?

The visionaries discussed the requirements against which liability will be assessed. The suggestions identified were based on one or more different viewpoints to those expressed in the previous section that asserts that the existing framework is okay.

> What is missing? It is a piece of organisation, which has never been covered, the only attempt has been the ISM code and that really only makes sure the process is in place.
>
> When we buy this stuff, we don't want to be [trialled].
>
> Can you believe that you are going to buy an autonomous system with a one-year guarantee from a shipyard that has no capability to judge it anyway?

The options of either the use of existing regulations/requirements or adding rules and regulations for new technology both depend on the demonstration of operation and safety vs. a reference point which is taken to be what is currently achieved by existing ships. But how this is to be defined and how equivalence could be measured were only just beginning to be questioned.

> That becomes slightly problematic when you don't really know the basis of the rules. It is difficult to be the equivalence for something that you don't really understand.
>
> Admiralty court – what would they do in a collision between manned and unmanned ship. We don't know.

> I think we are still on a roller-coaster, there seems to be a consensus that there will be someone responsible, the concept of the master will be there somewhere.
>
> Liability, can it be programmed?
>
> Trial data is not being shared.

A risk-based approach to liability

Regarding liability and insurance, there is a range of regimes around the world. General policies probably will not cover autonomy-related losses even if they are not explicitly excluded. Specific policies may be expensive or limiting; they need a very aware insurer. This may represent an opportunity for a specialist P&I Club. Who is liable if the shore side and the ship side are under different flags (e.g., the "Scandinavian Alliance")?

> IMO prescribes strict liability, e.g., pollution, then will not need regulatory change "it's not all about negligence".
>
> First time the bifurcation between the ship (flag) and the controller: Many nations etc., Subcontract? Who do you enforce? Extradite?

Two areas were discussed in relation to overall system performance: one was risks from people in the system, whilst the other was the inherently safe design of the system or the technology. Designing for the safety of this technology is new to maritime. In terms of setting acceptable levels of risk, it was noted that the *as low as reasonably practicable* concept (ALARP) is not used much outside of the EU and UK.

> So, this is the fundamental principle for safety. So, responsibility for safety, the prime responsibility must rest with the person in the organisation['s] response for the activities that [give] rise to an intolerable risk, and that would change throughout the life of the vessel.
>
> Well, we are talking about a different safety case now, a different risk analysis because what you need to understand is that the person can be part of the safety case. If the high-level goals are there and then you run the safety case and you turn around and say […] that one of the mitigations is that this person is asleep, can wake up and take control, is that [m]itigation acceptable? And tolerable?
>
> Why not safety of technology?
>
> I think one of the areas here is that if that is one of the goals to produce an inherently safe design that means you actually avoid the key hazards rather than manage them. The argument claim and evidence to support that actual high-level goal, to demonstrate a high level inherently safe design [may be] beyond the capabilities of some of the smaller organisations, we need to understand that is a potential risk as well.

The human, still there, but somewhere else

The focus of the HUMANE project is the role of the human in maritime autonomy and the workshop raised central questions: Will regulations consider humans? How do humans and technology interact within current regulations? Will the master's role change? These questions were complemented by the challenges related to the physical location of the master (and hence command) not being defined in regulation. The visionaries stated that regulations rely on assumptions of common understanding. If we keep the regulation and keep the people, we need to interpret the regulation and adapt the technology.

> Someone needs to be told they're in charge
>
> There is nothing, depending on how you read STCW, actually saying the master has to be on board, that is the problem with the code as we go around in circles because a lot of the arguments coming are not what is in the convention but how we read it.
>
> We are not working to remove anyone, command is on board, cargo – master is a storekeeper.

In colloquial terms, autonomy is often linked to unmanned shipping. Even though this connection is not absolute as autonomous concepts can be manned, it is reasonable to assume the manning will be different. These differences could be that the people are placed at other locations than present; it could be that the manning is reduced or removed in total or a combination of both.

> We missed the Human Element (HE) in the safe operation UK code.
>
> How will they be manned? Lessons about operations as well as technology. Trials with x crew on board, they will need to have x crew later ("you needed them during the trials"). Trials of tug, people on board for safety – so what have you shown? Trials not including people – how will they work in the future – do nothing – ICS wants innovation, not stifled. Need ITF at the table to "address concerns".

Humans will be responsible but in new loops

The visionaries stated that it is necessary to support/recognise the need to keep humans responsible, or at least in the system, and further that regulation should support upgrading, rather than adding to the workload of the crew. In the discussion, it was found that we should not use autonomy to continue the extension of the traditional maritime "throwing systems over the wall" that we have seen, such as delegating shore office administration work to the ship. The visionaries underlined the importance of making the best use of human capabilities.

> That is saying what we have got now is basically a collection of half-developed systems that really haven't been designed to support the people whoever they are.
>
> We are reducing a lot of the tedious tasks, and they are transferring the focus for the person that [is] working with ships to more important items.
>
> Are we looking at the last generation of people who have actually stepped foot on board a ship? You could have end[ed] up with a "Seafarer" of the future that may never have actually set foot on a ship.
>
> You think, I'm not sure how would you deal with fire, it is more than likely to go out of control without people as people do wander around the container ship occasionally.
>
> Human element = help people not to fail.

The visionaries discussed distinguishing between the human role and the responsibility. The human role covers what humans are doing in the future. Making people responsible for things that they cannot do cannot go on being put forward as the standard response for the marine sector. The history of making the crew's job horrible is long. Up until now, there has been no real thrust for human augmentation or system usability, only "maintain, monitor and blame". As an excuse for deep sea-only automation, "we are automating the bit that is boring for [the] crew" is a better argument than "we can only do the easy bit".

> Even with autonomy, it's – you know – as you say, it's human behind the code.
>
> However, we are navigating, whether it is electronically with people on board or remotely, you are navigating large ships with flaky information.
>
> What happens if you have a ship under remote control? It is no longer fully autonomous. It is now within the autonomous framework but the allocation of function is it is being remotely controlled.
>
> There is a tradition of just popping off an alarm and [getting] the good guy to fix something. Now I think the systems need to be able to handle more situations on their own without just firing off an alarm. They need to be robust and have a plan b or a plan c. when something is failing or is not working.
>
> Blaming humans is very cost-effective.
>
> Can't judge how people will react to autonomous boats.
>
> Do manned ships need to know you are now approaching autonomous ships?

Technology beats humans, at least in some areas

People are bad at monitoring and this needs to be emphasised when designing future autonomous systems. At the same time, the visionaries stressed that monitoring is not control, and control is not responsibility.

The discussion pointed to technology needing to engage people and help responsible people to do the best job, not take away the skilled bit of the job and make officers the bored servants of the IT and the ship operator. Further, to refine work to high-value tasks and automate low-value tasks, not vice versa, is important. This needs a deep understanding of the sector and job and the effect on motivation and behaviour.

> From a liability perspective we need [officers to behave as] adults on ships not children.
>
> Technology and Human Factors need to communicate about latency.
>
> I don't think the insurance market is very intelligent. They are saying most of our claims are caused by people, technology will take the people risk out, ergo it is a good thing.
>
> If we have got no-one on the ships to fill the forms in you can bet your life that the people in the office would get some software to do it for them very quickly.
>
> I think automation [...] being a demotivator is probably wrong. Where the challenge is a complex piece of [an] expensive asset, and people generally get quite enthused by it.
>
> Our members see an opportunity to augment our trained seafarers. Preserve the ingenuity of humans. Augmentation doesn't need regulatory change.

Changes in required competence

The workshop discussed various aspects of competence and, in addition to seafarer competence, competence to use, to maintain, to train, ships with these technologies and their effect on shipping were emphasised. The loss of work at sea as a way of gaining knowledge and experience about the performance of ships and current and future systems was raised. This raises the topic of knowledge and skills acquisition as well as human expertise in operating ships in unusual or extreme conditions. New organisational and personal competencies will be required for Class and regulatory surveys, in both the technical and methodological areas, and for ship designers in order to accommodate and take advantage of smart maritime technology.

> We can't just put an ordinary seafarer there. It is a completely different environment.
>
> You'll never get a master that will be an expert in IT in addition to everything else. Then we're talking about super humans as we discussed last week.
>
> Then you have got the problem where the regulatory authority has to be up to assessing it. I think…... we know there are flag states around the world that don't have the capacity to do anything. Some of them are quite big flag states, you've got a bit of a vicious circle running here about the effectiveness [of] establishing regulatory compliance in a

goal-based set of regulations, where you are running under something like a safety case.

So one of the areas to look at [in] these goal-based environment[s]? Do we have the right educational establishment to produce these people. I haven't seen the universities teaching these things. We need [an] educational establishment [that] teaches at much […] higher levels.

I lecture at a number of universities around the UK, there is not one educational establishment that actually covers what we have been [discussing] today. This is about more than just systems engineering in itself, and remember naval architects need to design the systems that these technologies can actually be used for. Is that being taught? I doubt it very much.

It's all IT – and that's a problem

Software is the basis of autonomous systems. All approaches and equivalence depend on verification and validation of software vs. correct quality requirements. The new fundamentals of the maritime context are charts, data bandwidth, software licenses, and liability.

Software came up it is a sort of – it is a bit more than an elephant in the room, it's a herd of elephants in the room, running around pretty wild. Over a period of time that probably isn't that long, it is probably the last 20 odd years, it has got to the point where software has become so pervasive yet it has crept up on us actually, to the regulatory community software has crept in.

But that is about where we are headed, so the mitigation is that you need a solution that delivers to the ship owners and society the comfort that this is being dealt with properly and effectively and continues through life. Remembering that these ships will eventually cascade their way down to [a regulatory minimum owner]. And that is a problem, we know the German ship of the future had a problem when it cascaded down. And so we have to think about these things now otherwise we are just cooking up problems for the future.

Software quality/safety assurance/compliance

The degree of change to ships from technology is overlooked. The function-first design followed by a systems and risk-based approach to development is understood to be necessary. There is doubt as to whether this recommendation would get through IMO and scepticism regarding the current competence in the maritime software industry to develop systems of this quality.

[Regulators'] involvement with the supply chain is not consistent in terms of its depth. So, for a lot of control and automation equipment, you heated up a computer and made sure it worked in salt water and things, but you didn't go and dive into the software. Now, that the importance of these systems components has changed. And the regulation has not recognised that, and it's jolly difficult to find anyone who is going to pay for that. Because suddenly – not only are you looking at the whole pile of welded steel, which behaves perfectly well without software, and some big heavy pieces of metal, there is now all this other stuff. Which is critical to the safety of the ship. And yet, you look at how much effort is made by flag and class in terms of making sure that it complies – not a lot in proportion to its importance.

The airline industry has to comply with DO-178C[2], that is a universal standard for software assurance. If you don't comply with it you are not going to get your airworthiness and that is it. Within the marine industry at the moment we are moving into this area of autonomy with a software-based solution. Do you believe this should be mandated correctly by the regulatory authorities to ensure that we have a consistent approach to a software-based solution?

We were particularly asked are there any losers in that? To be able to prove your safety case you need to have a certain level of knowledge within your industry and the small players don't have that.

We know there is a lot of resistance to regulation but we rely on it and it stops people [from] doing things but we have a lot of small organisations that really can't afford to do this from first principles and we would like something that they can do that is actually a no go compliance thing otherwise life gets too difficult.

Requirements

There are technical barriers that need to be addressed in the regulatory response. The current assessments of equivalence are in relation to prescription. However, the visionaries point to the challenge if there is no standard or example to compare with, especially in a total systems context. This challenge includes bad design of information systems or data modelling, novel sensors, new or derived alarms, and the use of artificial intelligence, to name a few.

I actually like the word "autonomy" being used so much even if it is not accurate at all to what we are doing. Because it indicates a big shift, and with a big shift class can actually make new rules where we can address these problems where we haven't been able to keep up now. This huge shift into autonomy, then we can make a stance on software quality.

The technology will come from China, we will get a "ready-made solution" we don't understand it yet, who will do the Quality Assurance (QA)?

Cyber applies to ALL ships and shore[s], – connectivity rather than autonomy.

Limits to the use of software

Our visionaries elaborated on the limits to the use of software and in particular how to set limits to use if software leads to systems that are too complex, inter-linked, non-deterministic and insecure. Further, they underlined that software behaviours are a result of system interaction and component-based type approval will not work.

> We know there is a sort of coming together of the system functions. And it is very difficult to see you got those barriers in place. Now, what it is like when you get further down the line. It'll just be more integrated, more complex, and more difficult to evaluate.
>
> Cannot regulate at component level, system regulation.
>
> Current framework [is] reticent on cyber – room for development. International Safety Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM), International Ship and Port Facility Security (ISPS) – applies to all ships.
>
> Operational Design mean[s] that our car can drive automatically if there are parameters with the road etc. etc. Could that be a way of saying that we allow this ship to be autonomous given that there are no other ships in the vicinity etc.?
>
> Safe performance envelope, fallback – specified behaviours, limited number of things an artefact can do, non-deterministic element, if I can't know what it will do…
>
> So that is going to be our result, "Sorry guys we have to wait for an accident."

What about the data/information/knowledge?

The discussion raised some very serious points that the regulatory domain has not grasped. Given the purpose of the investigation, the governance of machine learning is obvious, but also operation is becoming more data-intensive and remote from the ship:

1. The need to better manage data within organisations, computers, and communications
2. Governance of data quality ((a) for human use, (b) for machine learning)
3. Meaning in data, especially with regard to safety (e.g., for setting benchmarks and extraction of learning)
4. Identification of near misses to tag data both for statistics and learning

Learning is not only for machine learning but also for the individual, the organisation, the industry, and for informed regulation.

Autonomy takes you towards a generally reduced level of people. But a massively increased level of data – Yes, so you have got a greater incentive to create a better data management system.

If you are using duff information, it doesn't matter if people are on the ship, people are off the ship or totally autonomous.

Some of it is worthy to be trusted, some of it is very old, some of it is just wrong. However we are navigating, whether it is electronically with people on board or remotely, you are navigating large ships with flaky information.

You are not altering the software but you are introducing machine learning, Artificial Intelligence, you never will be able to determine what is actually happening with Machine Learning/Artificial Intelligence but it doesn't mean it is unsafe.

The ship doesn't know it had a near miss, the other party doesn't necessarily know it had a near miss even if they had the will to report, they didn't know. The big near misses they are saying are actually never recognised as big near misses because they don't know it has happened and how do you find out if this near miss has really happened? That may be done by for instance analysing AIS data afterwards. Looking at an area or some particular ships and see what has happened and they can maybe discover we actually had seven near misses in this part of the weather.

Where does that leave the business model?

Given the subject of the workshop, the analysis of the business aspects of MASS was incomplete. Ships will become more expensive because of the investment in technology and reliability required to realise the reduced operational costs. Neither these additional costs nor the increased support costs for the technology are widely discussed. It was recognised that there are also new or increased costs in the area of assurance, and these are likely to be so significant as to present a barrier to uptake in areas such as tramp trades and small ships where the costs cannot be offset by some other gain, for example, reduced environmental impact or research. The promoted benefit for MASS is a reduction or elimination of manning costs, but anything less than complete removal of the ability to carry crew (i.e., all life support and LSA) reintroduces these costs. The use of technology to augment seafarer capabilities requires much more refined cost modelling and possibly new sources of financing.

The thing that drives the cost of that is the rigorous assessment rather than the regulation itself.

[Goal-based is] more expensive than meet[ing] requirements.

[Are goals specified as] risk or quality?

[Is it possible to] certify a small boat to a cost less than the cost of the boat[?]

What you are optimising against is not safety, it is not efficiency, no it is the lowest number of hours used in the design process with a stakeholder who has no interest except producing something that is approved or accepted by the one who purchases it and pays the money and away from the shipyard.

Then you have got the financial driver then because as soon you put the structure on to allow people then you have removed the financial justification for having the autonomous ship. There has got to be a benefit somewhere.

The whole business model up front needs to change when we start dealing with this level of complexity class, regulators, manufacturers, all the stakeholders which we have identified here, you need to pull them in at some point in time. And it all comes together and you are working in a completely different business model, is that industry ready for that?

SUMMARY

Rules and regulations are important to keep the maritime industry safe. However, maritime autonomy could challenge the validity of existing regulations. To ensure that safety is taken care of, the development of regulations and autonomous concepts must be harmonised. Visionaries with a wide range of experience with regulations were invited to discuss how different perspectives on autonomy affect the requirement to future regulations, if and how future regulations are different from present regulations and how changes to the human role need to be reflected in regulations.

The main question to be answered in developing both maritime autonomy and regulations is how to make rules before knowing what to make regulations for? On the one hand, we can consider maritime autonomy as something new that requires a completely new set of regulations, or it could require a different interpretation of existing regulations. On the other hand, the development of maritime autonomy could aim to be as close to conventional vessels as possible, and consequently, it is possible to keep the regulations.

In the workshops, we had several discussions related to the main question and even though we do not have one definitive answer to this question, we have identified several areas for further investigation and sub-questions that need to be raised and answered. A central topic is the human role in future concepts and further, the responsibility and liability of those involved in the operations of a maritime autonomous concept. Technology is an apparent component of future concepts, and a new and different use of technology calls for different requirements for the regulations and for regulators. Finally, new questions are raised:

- What could we expect if we cannot unite around one understanding and way forward in the development of maritime autonomy?
- Will this hamper the development?
- Could we expect local regulations, or do we need to find other alternatives?

This chapter provides a set of questions and identifies problems more than providing a set of answers for the future regulations of maritime autonomy. However, the complexity of the regulatory challenge needs to be addressed by understanding the overall picture and answering the principal questions, while also having the competence to find answers to the more detailed sub-questions. From the discussions, it is apparent that joint development of regulations and autonomous concepts is necessary to find the best solutions to the identified problems.

NOTES

1. Much of the industry discussion at the time of the workshop focused on the navigation function, rather than a completely robotic ship.
2. D-O178C (RTCA DO-178C, Software Considerations in Airborne Systems and Equipment Certification, Standards - RTCA).

Chapter 6

Skills and competence

Agnieszka Hynnekleiv

INTRODUCTION

The maritime industry is one of the most vital and globalised industries, and with the rapid technological advancements in recent years, the need for developing appropriate competence is widely recognised and agreed upon. On World Maritime Day 2021, Chief Inspector Andrew Moll underlined the importance of training seafarers to meet the pace of technological changes in the maritime industry (GOV.UK, 2021):

> Humans are still in charge, but to be effective they need to be appropriately trained, properly equipped, and following procedures that are fit for purpose. Anything short of that is a cop-out.

The following year, on World Maritime Day 2022, IMO Secretary-General Kitack Lim stated that technological solutions introduced for more sustainable and safer shipping must also benefit people (IMO, 2022):

> The technological solutions must consider their impact on seafarers and other marine personnel including the need for training.

The development of skills and competencies of seafarers and other maritime personnel is a prerequisite for successful implementation of Maritime Autonomous Surface Ships. During the HUMANE workshops, the phrase "we need new skills" was echoed countless times, not only by training and education providers, but also by representatives of shipping companies, shipowners, technology manufacturers, classification societies, government agencies, and insurance companies.

Describing the future competence starts with building a better understanding of the human role in autonomous maritime operations. Introducing new technological solutions can change the way people work to different degrees, for example by modifying existing tasks, automating them, moving roles from ship to shore, reducing the size of a crew, or introducing roles that never existed before. Our assumption was that the need for new

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competence is not limited to seafarers but concerns all the maritime personnel working directly or indirectly with autonomous systems, both on board and on shore. In this chapter, we specify what kind of skills were predicted as essential for highly automated and autonomous maritime operations.

METHOD

The results presented in this chapter come from the third HUMANE workshop with the leading theme *Skills, competence, and training.* The workshop involved 16 participants selected on the basis of their work experience and current expertise within the workshop's theme. The participants were instructed to consider the time frame of now and 30 years forward, the context of deep sea shipping, with people still working on board. The imagined technology development was defined by ships being highly automated, to the degree that the ship can sail on its own, and that there is a shore centre. As a departure point for the discussions, the participants were asked to prepare a job advertisement that included formal education, whether it was a part of an existing or a novel programme or course; professional experience and background; and lastly, the qualities that they, as experts, would seek in such candidates. The exercise resulted in a list of qualities created by each participant, which were further discussed.

The discussions were audio recorded, and later transcribed, resulting in 228 pages of text. The transcripts were imported to the qualitative analysis software NVivo and manually coded. The coding was performed with a data-driven, inductive approach. The qualitative analysis started by creating dozens of descriptive codes that were later grouped into higher-level categories.

FINDINGS

Figure 6.1 is a visual representation of the collected data that gives a quick overview of the keywords and the frequency of their occurrence. The word cloud represents the 100 most frequently used words that consist of a minimum of four letters, with the exclusion of words such as "yeah", "have", and "just" that do not carry meaning alone. The overall sentiment of the data set is a change of human roles in the context of the future technological landscape and a need for new skills.

General predictions

During the workshop, the participants shared and discussed their predictions for the development of Maritime Autonomous Surface Ships (MASS) and its implications for maritime personnel. There was agreement among

Figure 6.1 Word Cloud of the most frequent words in the data set.

the participants that ships will remain manned. However, the traditional roles performed on board will be modified, and some of them may be performed from shore. The experts predicted a creation of new roles or entire positions driven by the new technologies, both on board and on shore. Some experts pointed towards a possibility of broadening the competence of the Vessel Traffic Service (VTS) to support autonomous operations. The discussed changes imply tightening of the collaboration between ship and shore. The stronger collaboration was seen not only as a foundation for improving safety and efficiency but also as an opportunity to share knowledge and skills between different professionals.

> There will be some people of some sort on a ship of the near future. The ship […] gets more technology on board. We are talking about companies moving some aspects of management or some aspects of operations ashore.

The participants emphasised that the competence predictions are based on the current developments in the maritime domain and are subject to change. The descriptions of needed competence can only be as detailed and accurate as the current understanding of the human role in future socio-technical systems:

> [I]t is very easy to be subjective and say people are going to need these skills and they are going to need those skills but ultimately what are people going to have to do?

However, the general trends in skill requirements will need to accommodate further developments in technology. According to the participants, the future workforce will be required to continuously update their competence, to a higher degree than today. The experts acknowledge the concept of lifelong learning as a solution to fast-paced changes in the maritime industry. During the discussions, the participants concluded that education and training need to be integrated with everyday work tasks.

> It is lifetime learning. Because the job will be changing, the technology will be changing, the environmental issues will be changing and even understanding what shipping is about will be changing.

The participants forecasted an increasing importance of passing knowledge from one team member to another team member, especially through supervision and mentoring.

> It will be necessary for them, a seafarer, an operator, to be able to take his or her learnings and guide and supervise and mentor someone else. So, create more skills.

The automation of tasks performed on board was viewed by experts both as an opportunity to reduce the workload and to allocate time for training. For many of the participants, the technological changes in the maritime industry are a pretext to rethink maritime education and training.

> We never teach people how to do stuff. We always teach them what to do. Well, I know what to do. I don't need you to tell me. I want to know how to do it.

The general sentiment was that the demand for skills will increase. The experts focused on upscaling, adding, and modifying competence rather than replacing it with technology. There was very little discussion about skills that will become obsolete. Some of the participants proposed removing celestial navigation and some parts of engineering from the curriculum, the latter being a result of simplifying the engine room.

The profile of future competence is expected to expand in both width and depth. The discussions circled around the need to train highly specialised workers as well as generalists.

> Do we start with the assumption that there are going to continue to be specialists, or do we embrace the fact that there might be with smaller numbers of people … and therefore we are going to be looking at a more general combination of skill sets with each individual?

An interesting remark was made that the traditional seafarer training is indeed geared towards being a generalist.

> If you look at seafarer education and training, it is very general anyways. … Stability, navigation, law, finance, it is a very generalist qualification, because it needs to be. When you are out there you are [the] fire service, you are the ambulance service, you are lord mayor, you are everything in between. So, by its very nature it is a multi-skilled role and I think it always will be.

The discussions rarely connected to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (SCTW) as a reference point for future competence. One of the participants stated that STCW offers a specific set of competencies that are difficult to apply to rather general predictions about autonomous maritime operations.

> STCW model is not appropriate for what we are talking about here at all.

The participants agreed that autonomous maritime operations will result in a reduction in the size of the crew. The reduced manning will have an impact on competence needs, imposing a wider competence profile. The general conclusion was that there is a need for widening the competence on board and deepening the competence on shore.

> So, you have a specialist on the ship who is supported even more by sharing of knowledge. The shore centre has an aspect of sharing of knowledge. … [T]he shore centre is going to be looking at many ships, not one ship.

Sharing knowledge was identified as a key task for the personnel on shore. There was an agreement among the experts that the intention behind the shore control centres is that one person will supervise, support, or control multiple vessels. One of the participants pointed out that knowledge sharing can also be initiated between different ships, in a similar manner that conventional vessels are communicating today in an unofficial manner.

> Because I am remembering ships will not just be connected to shore, there will be networks. There is also the possibility of sharing skills between ships.

The participants forecasted that a highly automated vessel with an ability to sail on its own, supported by a shore centre, will require five to six persons on board. The crew would need to have the same basic maritime competence but with different specialisations like meteorology, engineering, safety and security, cargo, or IT. The personnel on board will be first responders with general knowledge, who can be supported further by specialists on shore if the situation requires it.

> Everyone will [have] general knowledge where they can be supported by shore. So, if something goes bad on the cargo side, the cargo specialist on board would interact with specialists ashore and [the] team with that regard.

In the context of highly automated ships supported by a shore centre, two participants predicted that the differences between the competence needed on board and on shore will fade.

> I'm not sure there's a distinction [between ship and shore personnel].

> And I thought the same, because in the future they go hand in hand.

One of the possible solutions discussed during the workshop was the rotation of workers between ship and shore. Such rotation would allow for the retention of skills related to being at sea and possibly facilitate the transfer of knowledge between ship and shore. The rotation between ship and shore would result in more flexibility and overall, less time at sea, which could make seafaring a more attractive career path.

> [S]tudents in Germany and Sweden had one thing in common, the time they planned to stay at sea was a lot shorter than it used to be. [They] see a future from five to ten years on board a ship and then they plan to go to work in the maritime industry ashore to be able to manage family and children and all this responsibility. They see it as a short-term career, like a dream to go out at sea but they don't want to be there lifelong.

The discussion about the rotation between ship and shore brought some concerns. One of them is the capability of an individual to be competent in both roles, on board and on shore.

> I think anybody who is going to be taken off the ship to [work] on the shore, they have to be able to do their job better, otherwise you may as well just keep them on the ship. It is cheaper and safer.

Another concern is the lack of organisational support for developing competence. With the current structure of shipping companies, personal development and gaining sufficient experience is in the hands of individual workers.

> It is just a career that opens the possibility for the people to get the skills and competence to do both, but it is not a shipping company offering this career.
>
> The current structure works to quite a large degree against the development and sort of skills we need.

The participants further questioned whether the current structure of the maritime industry can support the continuous sharing and development of specialised competence connected to MASS.

> And even nowadays, seafarers, most of them are employed by manning agencies. There [are] a lot of things to think about it.
>
> Maybe shipping companies can't do future shipping.

Maritime competence

The role of maritime education in developing appropriate competence for the future of shipping is undeniable. During the workshop, a considerable part of discussions related to the role of educational institutions in developing competence. The participants pointed out that maritime colleges are not able to respond to the swift changes in the maritime industry.

> It is a challenge for the maritime academies [to train for these skills that we need]. Can you really supply the people that the future maritime industry needs?
>
> I don't think universities … can universities respond quick[ly] enough? No, I don't think they can.
>
> Why are we teaching people Morse code? It's an obligatory subject. So how much time are we spending on this […] and not enough on cyber technologies? […] The colleges have to change.

Some of the experts pointed out the need to rethink maritime education, both in terms of responding to the industry's needs and focusing on skills necessary for performing the job, but not recognised as a part of the curriculum.

> I'm saying that the maritime colleges have to be more responsive […] and faster, and particularly what's being taught and what's being researched at the level that you're working at needs to be filtered down more rapidly into the training of the guys. Because […] there's basic skills that they need like navigation […] but there's a whole range of

stuff that we don't teach them. How many people […] have ever been taught how to take minutes? And what do they do? They spend half their time in […] meetings.

The discussion developed further, and the conclusions were more optimistic. The participants generally agreed that maritime colleges must closely follow the changes and adapt, but their main goal remains to deliver universal maritime competence. Even with the development of MASS on a larger scale, conventional vessels will remain the main part of maritime traffic for the foreseeable future. According to the participants, maritime education should aim to deliver a robust competence base that can be later built upon.

> I think the universities and the education programs provide a lot of value to our current seafarers. And if you are looking for something very specific, out of [the] ordinary, then yes, the education system will not deliver that. But if you need a certain level of standardisation, then that is what these education programs are designed for.

The participants discussed future competence by creating lists of qualities that they would look for in maritime personnel working with MASS. One of the first positions on the list was technical competence, understood as a set of skills needed to operate and maintain the equipment. Two participants said:

> We have acknowledged the need for strong technical qualification which is probably acquired through a formal education.

> I think they're going to need technical skills to operate the equipment and maintain it at a minimum level.

The experts predicted that navigation skills are still going to be essential on board, even on vessels with highly automated navigation functions. The consensus was that elementary navigation skills and some experience at sea are needed as a backup for automation.

> So that taking the navigator away from the ship which I think is the core of autonomous shipping at the moment, is something you wouldn't do, you would still have that skill on board.
>
> You need to have a basic, a basic knowledge [in] navigation. You need to have people on board who [are] able to take control of the vessel in case of cyber-attack or something and lose contact with the vessel […] I don't say you need to have a master's licence or anything like that but have to be able to bring the vessel to shore. Or as close to shore as you can get, all the people on board if needed. And also, you have the, if you assume that it is not going to change you need to have one navigator on board and then maybe one or two men as stand by, so you are talking about at least six persons on board.

I think it is essential to have navigators with maybe masters, they don't need to have maybe ten years of experience, but they should have some sea experience [...] I think it might be possible to hand over command to shore control centre occasionally and then take it back, just like we do between captain and pilot.

Another maritime competence listed by the participants was cargo management. The need for cargo management competence was predicted to remain essential for future operations or increase in importance. Autonomous ships are expected to offer further optimisation of cargo management, and shipping companies will need personnel with advanced skills to utilise the advancements in technology.

It's entirely possible that the vessel is operating itself and the cargo is the bit we're looking after. The gas engineers are specialists [...] and they're the ones who can't be replaced in the future.

IT competence

Information technology (IT) competence is central to the future of the maritime industry, particularly in the context of MASS. Shipping companies will need personnel with advanced IT skills to ensure that the digital systems and software that underpin MASS operations are reliable, secure, and efficient. This includes skills in data analytics, computer programming, network architecture, cybersecurity, and artificial intelligence. However, it is not expected of mariners to become IT professionals. The experts discussed the scope and depth of IT competence that will be required for maritime personnel.

The persons on board will not have the chance, like today and before, to repair if things go wrong because they are very much linked with the ICT systems. [The persons on board] have to have the skills in navigation, safety, security and software skills.

[Personnel onboard] has more generalised knowledge about the technical system at large, what his responsibilities are, how the technology can be used in different ways and then shore based personnel that are more specialised will be able to intervene.

The participants proposed a definition of IT competence necessary on board. It includes a good operating practice, sufficient IT knowledge to learn how to operate new systems and an ability to determine when help from an IT specialist is required. The maritime personnel will need to be able to interact with digital infrastructure.

> Good operating practice, operator competence of the systems you are intended to interact with and use. Good knowledge of IT principles so you have got that ability to continuously learn. However, you are not a software engineer and there would be a clear line, as you go as far as the cabinets and you read the lights and diagnostics but you do not open the cabinet because … you could get yourself in so much more trouble. And you know that needs to be left to the people.

Keeping a clear distinction between system users, operators, and IT specialists was also brought up by other experts.

> I think we need to be careful that there is a role for specialists here. So, there are users and operators and there are the back-office specialists. And in my head at least they are two quite distinct roles, and we should be careful not to start blurring.
>
> Particularly where IT is concerned, a little knowledge can be a very dangerous thing. I would be looking for people to have a set of basic competencies around backing up data, ensuring cyber security principles and being maintained on board, be able to use the systems they are required to interact with […] I would be quite reluctant to see a situation where we would be allowing, or attempting to train or educate people so they could start going undercovers of IT systems on board and start messing with them and all the rest of it, that is dangerous territory.

One of the participants helpfully defined the scope of an introductory course in IT for maritime personnel, also emphasising that interfering with data and coding are potential safety risks and should be reserved for IT professionals.

> An introductory course that could be taught as a module, certainly comfortably in one year […] would give people that understanding of how computer systems work, and inputs and outputs and data management […] That is a significant step away from letting anybody loose on code of even, long before code, even with data you need to be careful. Considering how every system is so dependent on data. … Maintaining the integrity of your data is a huge thing, so you really don't want anyone other than highly qualified experienced humans interfering with data.

Another expert made the important point that the operators of MASS need the ability to manage large amounts of data. The ability to retrieve, process, and analyse relevant information was defined as a fundamental part of IT competence:

> [B]eing digitally competent as a user with that technical interface but that the key there is prioritise data quickly. So if you can image what the bridge or operations room will look like in that future environment, it is going to be absolutely filled with data, so if you have one or more humans, how do they process that data and understand what the risks are when you have got a billion flashing different lights. So being able to prioritise, and I think prioritise is probably the key word there, is fundamental.

Cybersecurity is critical for the safety, security, and reliability of autonomous vessels and the data they generate. The participants established that cybersecurity professionals will be based on shore. However, the maritime personnel, both on board and on shore, need to develop awareness of cyber risks and be able to mitigate them.

> We have cybersecurity based on shore and it is all done remotely today so I don't understand why I should have a software expert on board.
>
> Ship and shore, an expert in understanding and mitigating cyber risk. … To understand the complex risks and then being able to manage them are two separate skills that will be required by that individual.

Legal and ethical competence

The legal and ethical challenges connected to MASS were recurring topics raised during the workshop. Traditionally, the shipmaster was dependent on himself and therefore held a legal authority over the vessel and the crew. The International Safety Management Code still gives the master the final responsibility on board today, but the decision-making process can be affected by communication with shore. The participants anticipated that the increasing role of shore management or even forming virtual teams can put further strain on the shipmaster's role.

> There are also some really bizarre mythologies in the maritime world that the master is actually in charge of the ship. I mean, the master […] is [in] charge at the moment, but in fact he does something the boss doesn't like, he's replaced. He's no longer the master.
>
> I genuinely believe one of the biggest problems our masters and chief engineers have is working their way through the politics of the organisation. They spend more time doing that than they do driving ships.
>
> Virtual teams [will bring] diffusion of responsibility and accountability. So poor old masters, I don't envy them at all. Their autonomy has been removed.

Several of the experts included skills related to understanding law and ethics on their lists of qualities required for the future maritime personnel, not only for the shipmasters.

> I think it's going to be really important because we're already training mariners in law. They have to have six months [of law course] because there's so many questions that they have to answer.

A significant comment described legal competence as an ability to make informed judgements in real-life situations. The notion of a link between legal and ethical competence was generally agreed upon.

> I think another skillset that is going to be really important is legal skills, being able to differentiate what you're allowed to do and what you're not allowed to do [[…] I think the ethical skill and the legal skill will meld into one.
>
> Look at the military, how they place focus on ethics and morale. You know, because you have to make the right decisions.

The participants predicted that in the future shipping companies will focus on ethics over results to a higher degree than today.

> One of the things that we [on the list of desired qualities of the maritime personnel] is it's not only achieving the results, it's achieving the results the right way. [A couple of speakers agree] And seriously, I would get the sack if I did things which were unethical even though I achieved the targets […] And that's increasing. Because [a company] sells its share price on its ethical stance as much as anything else.
>
> The public ethical aspect […] is extremely important for the company, so that goes for any individual within that company needs to reflect an ethical value and everybody needs to be able to comply to that.

The ethics of a shipping companies must be reflected by individual employees, and ethics were expected to be a part of professional training. One of the participants underlined the role of ethics in building and maintaining safety culture.

> Another thing we talked about was legal skills, ethical skills. Of course, that's something that you can train to some extent.
>
> You can't have a solid safety culture without an ethical response, which also drives your behaviour.

Core competence

The previous paragraphs described competence related specifically to maritime, IT as well as legal and ethical competence. Another category of findings refers to a non-uniform group of transferrable competencies connected to cognitive processing, communication, and learning. The term core competence has gained recognition in the recent years and was used in projects forecasting future labour markets (National Association of Colleges and Employers, 2022; National Skills Commission, 2020).

> They are not hard skills and they are not soft skills. A set of skills around analysis, risk, diagnosis.

Core competence includes skills and personal attributes that apply to a variety of roles. In combination with maritime-specific skills, core competence assures an ability to adapt, solve problems, and manage in difficult conditions. One of the participants made the significant point that the development of core competence becomes even more important since people are expected to intervene when automation fails.

> More of their job will be responding to unusually situations rather than doing their normal run of the mill things every day.
>
> The real skill is being able to respond to the abnormal.

The participants agreed that the future maritime personnel should be skilled in a way that allows extrapolation of knowledge and quick adaptation to new conditions. This description relates to the highest categories of learning objectives in Bloom's Taxonomy, which is a widely used framework for teaching, learning, and assessment (Krathwohl, 2002). Education and training should therefore focus on cognitive processes such as analysing, evaluating, and creating.

> If someone is appropriately trained, they have the necessary skills to adapt to learn […] If you understand the principles of navigation, anyone can hand you a navigation box of tricks and you can figure out how it works. Whereas if you have been trained on one system then when someone hands you a different system you are going to struggle with it.
>
> The fact that you have been able to adapt pretty much continuously over that period is because of the way you were originally educated and trained.

However, one of the experts underlined that the ability to cope with abnormal situations in a flexible, innovative manner is and will be restricted by procedures.

> The consequence of things getting safer is it removes the opportunity for people to respond to the abnormal.

One of the subgroups of skills that emerged from the data is connected to perception, communication, and maintaining situation awareness both individually and in a team. This subgroup includes skills such as monitoring, observation, verbal, and written communication, integrating information, reporting, debriefing, and conflict resolution. The participants concluded that with increasing connectivity and interdependence between ship and shore, effective communication will become even more critical.

> They should be good at observation, which I don't classify as being the same skill as monitoring […] I think it's a skill you can learn.
>
> Some people have difficulty to describe […] the problem. I think that's an extremely important skill, particularly if you divide work between ship and shore, then you need to be able to communicate with, as you mentioned, several shore centres.
>
> I think they should be good at reporting. One of the issues that we face is that people are not very good at explaining what's happening in a system. They don't have the vocabulary or the ability.

Language is a prerequisite for communication, and the experts agreed that English proficiency will be essential for working in shipping.

> We talked about language and culture, so of course everybody needs to be able to talk the language that the other people understand […] And then we talked about this as it's not only a question about language, it's also a question about culture. Everybody needs to adapt to a culture, [also] to a company culture […] How do you get that skill, the ability to communicate over language and culture barriers?

For effective communication, language proficiency must be combined with cultural awareness.

> How much of a problem is that within this organisation with language? I mean, it's a problem where you read accident reports where people didn't communicate with the Very High Frequency (VHF) (radio) and don't understand each other. But this also a problem on board the ships?
>
> Yeah, it's a problem culturally. It's a cultural problem in that where it manifests itself is in terms of the order-giving. In other words, some cultures are more hierarchical than others.

Another subgroup of core competencies that emerged from the data includes the ability to guide one's own professional development as well as passing competence to others through mentoring and supervision.

> Do we need these skills or do we need people who have got the ability to get these skills?
>
> We need people that are willing to learn in their entire career.
>
> We were never taught how to learn. Well, that's what I was getting at in the nautical colleges, perhaps we should not be teaching these skills, we should be teaching how we get these skills. With learning skills.

> I have used the term mentoring because our education systems are not providing all the skills now, the gender roles, for the future systems, so it will be necessary for them, a seafarer, an operator, to be able to take his or her learnings and guide and supervise and mentor someone else.

During the workshop, some of the participants commented on psychological characteristics desired for the maritime personnel. Their statements suggested that personal testing may become more important in the future. The experts would look for candidates characterised by openness to learning.

> Openness to learning is a personality trait […] But then you've got be careful because if you get too much openness people will experiment and if you don't want them experimenting, you know, ooh, let's see what this valve does. Ssshhh [makes sounds of an opened valve].

The desired personality profile was described as similar to the military, but with less focus on following orders.

> It is interesting you mentioned adventurer and that is certainly one, there are people who are team player but people who are very well socially adjusted who are also fairly resilient in terms of they don't mind being on their own and so on. Hard working obviously, you know, so there are identifiable skillsets, interestingly they tend to be the same kinds of people who succeed in for example emergency management. They are the sort of people who would be great for the military except they are not that good at following orders […] Who like a process but are also creative in terms of problem-solving. So there are a kind of, I think personality profiles there, people who are not afraid to make decisions.

Some of the comments challenged the personality profile traditionally valued in the maritime industry. The experts predicted a shift from an authoritative style of leadership to collaboration and emotional intelligence.

> You need people with the right personalities. If you have your alpha leader, and while traditionally that was the image of the ship's captain, maybe even the chief engineer, it doesn't work anymore. It is not how it works now. You are running a team of people so it is a very different skillset now to how it traditionally was sought for. And it is going to be even more necessary is my sense in the future.
>
> Someone who is cooperative, collaborative, however we need to recognise that they also need to be resilient, in other words, happy being.

Several experts reflected the need to focus on mental resilience, which is an ability to bounce back from negative experiences.

> And we're also not preparing them, so that when they're at college they're given plenty of training on, for example, Morse code, but very little on social management and situational management and emotional skill management, and suicide prevention.
>
> It will be a requirement for shipping companies to have a mental health program in place.

Mental resilience can be viewed both as a personal trait and a skill which can be trained. The concept has received a lot of attention for the last two decades and became a foundation of interventions directed at mental health in workplaces.

The last, and the most discussed, subgroup of core competencies is collaboration. Collaboration is linked to communication, but as a subgroup represents an even wider perspective on competence. It includes collaboration between members of the crew, between personnel on board and on shore, and between humans and technology. Collaboration competence also refers to switching between different modes of collaboration.

> That goes to a certain kind of individual who understands, who is very collaborative, and that I think is a fundamental part of this. If you were going to have successful collaboration between ship and shore, between machine and human, it needs to be a kind of individual who's aptitude fits that.
>
> And the ability to switch between the machine making the decisions and the human making the decisions or ship making decisions and shore making decisions.

For collaboration to be successful, professionals will need to quickly build a shared understanding of a situation.

> I think it might be possible to hand over command to shore control centre occasionally and then take it back, just like we do between captain and pilot, but in this case shore control centre and operators on board.

System awareness, or more precisely, awareness of a sociotechnical system, was mentioned independently by several of the experts. This competence encompasses knowledge about competence and responsibility of other people, as well as the available technology and resources needed to solve a problem.

> It is a very distributed social technical system and the person on board has to have knowledge about each and every part. So when something happened, he or she can call the specialist. And negotiate with them.
>
> It does require a deep understanding of the processes that are involved. And who should be in charge when.

> [We need] a diagnostic generalist on board who then knows who to call in to build the team. Understands the system.

Human technology interaction

The discussions brought some insights about designing the relationships between humans and technology. An analysis of different relationships between humans and technology discussed during the HUMANE workshops can be found in Hynnekleiv et al. (2019). During the third HUMANE workshop, the participants reflected on the impact that technology has on people, especially in terms of overreliance.

> Well, that's the design of the technology. If the people are satisfied, I think it's doing alright. Become reliant on it, become dependent on it. And that's where you need to really be clear about the design of your technology and the impact it has on the person.

One of the experts mentioned that technology should be augmenting humans, especially in areas where human capabilities are limited.

> What I mean about using technology to assist the human is … we need things to remind us what we should be doing [because our memory is flawed].

During the workshop, multiple participants identified a need to develop different skills that facilitate understanding technology, even when technology is evolving. One of the comments signalled the importance of a different approach, namely designing technology to be understandable to humans.

> What you want are people who understand all the technology. Technology that is constantly evolving and changing. How do you do that? It's lifelong learning. I think you do it by giving the people the skills to learn. Or you could design technology that is understandable to humans.

DISCUSSION

The results highlight the need to continuously develop the competence of maritime personnel. Catching up with advances in technology is a challenge for educational institutions, and the proposed solution is lifelong learning. The participants remarked that guiding one's own professional development (for example through a Continuing Professional Development scheme) will remain a responsibility of an individual. However, education and training are not the only tools available for ensuring that humans and technology work together safely and efficiently. Hollnagel (2012) stated that training is a focused solution aimed at improving specific types of issues, like attention span, vigilance, or an ability to gain situation awareness in a short space of time. It is an essential tool to ensure that the technology is fully utilised. However, it cannot solve problems caused by insufficient concern for human capabilities and limitations in the design of technology. During the HUMANE workshop, a few of the participants signalled that some of the issues should be addressed by human-centred design. For example, the challenge of dealing with large amounts of data should be addressed not only by training people to prioritise the right information, but also by designing technology to make the relevant information easily available to the user. Similarly, teaming with technology was viewed by the participants as a skill that needs to be trained, but also as a process that should be facilitated by design. It was assumed that humans will be required to respond to unusual events, and technology needs to be designed to assist them in taking control.

The participants focused on core competence, which applies to a variety of roles, and in combination with maritime-specific skills assures an ability to adapt, solve problems, manage in difficult conditions or with lack of resources. Core competence can be developed through education or training, but it could also be affected by individual and organisational factors. Personal qualities such as intelligence, self-efficacy, and mental resilience are a foundation of core competencies. Organisational factors like hierarchy structure or style of leadership can also play a role in supporting core competence. The International Society for Traumatic Stress Studies emphasises that the most effective ways to enhance individual's mental resilience are assuring a healthy environment and introducing interventions that address different levels of the organisational system (Southwick et al., 2014).

SUMMARY

The third HUMANE workshop was conducted to forecast the skills and competence required for the maritime industry in the context of autonomous shipping. The research involved industry stakeholders, experts, and academics who provided insights on the challenges and opportunities presented by the development of MASS.

The participants identified the need for developing or modifying the competence of maritime personnel. The study emphasises that the demand for skills will increase and require an expansion in both the width and the depth of competence profiles. The participants identified several key areas of competence, including maritime and technical competence, IT competence, legal and ethical competence, and core competence, which includes the ability to collaborate with people and technology, communication and adaptability. The experts also noted the importance of maintaining a human-centred approach to the design of MASS, ensuring that technology is developed to augment human capabilities rather than replace them. To facilitate the acquisition of new skills and competencies, the experts suggested the need for lifelong learning and continuous training. The development of MASS was seen as an opportunity to remodel the maritime education and training. Overall, the results highlight the importance of investing in human capital as a prerequisite for successful application of Maritime Autonomous Surface Ships.

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Chapter 7

Autonomous shipping revisited

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INTRODUCTION

On any scale, the years 2020 and 2021 were highly impacted by the COVID-19 pandemic, the HUMANE project included. Planned physical events, like the HUMANE workshops which were conducted earlier in the project, were cancelled and the overall project momentum was to some degree lost. Among other things, this meant that earlier HUMANE project results were at an increased risk of going stale or becoming out of tune with the ongoing autonomous shipping agenda, which was still developing, virus or no virus. In other words, we saw the risk of the main HUMANE project deliverables conceivably going out of fashion before even being published. For this reason, we decided to do a reality check on our data, trying to improve or even ensure currency and synchronization to the general thinking in the maritime industry. The present chapter reports on these undertakings, to a large extent sharing the raw data with the reader to provide transparency and richness, and to support the reader in forming her or his own opinion; indeed, it has been our intent to refrain from interpretation in this chapter – rather, we have limited our scope of work to collect opinions and knowledge from persons with insights, and even influence, on the maritime autonomous shipping agenda, and by relating these data to each other, to present a themed picture of present thinking.

Eventually, we have chosen to model our data within the framework of the International Maritime Organisation (IMO), Maritime Safety Committee (MSC).1 Circ.1638 (2021), especially using the defined categories of autonomy (Degree 1–4), supplemented with a here-and-now baseline section. Relating to the former, we appreciate that the autonomy degrees of MSC.1 Circ.1638 could be revised going forward, but, at the time of the fireside conversations, they were current and believed to have shaped the direction of the conversations. Considering the latter, we see that establishing the baseline is highly important, considering our assumption that the culture, traditions, and general character of the maritime industry will remain, also in a future with more autonomous and automatic systems being put to use

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at sea and ashore, with the overall result that most of the present values, orientations, and perspectives of shipping are carried forward in time, and continue to define the industry.

HIGH-LEVEL OUTCOMES: AN OVERVIEW

A feature of the NVivo analysis software suite, which was used to code the data gathered from the fireside conversations, is the "Word Cloud" – which, essentially, is a frequency analysis of words occurring in a data set. To make the results more relevant, and to help make the essential topics stand out more clearly, various filter options are available to the analyst, including suppression of short words below a user-defined number of characters, as well as the option to create a list of words also to be ignored. Using a character limit of five for minimum word length, and using the "blacklist" function to filter off names and other frequently used words which did not contribute to illustrate the salient topics of the conversations, word clouds were generated for the four perspectives of technology, legal, operational, and educational (see Figures 7.1–7.4). What immediately struck us as odd was the great similarity between the four figures; indeed, we initially suspected

Figure 7.1 The technology perspective.

Figure 7.2 The legal perspective.

Figure 7.3 The operational perspective.

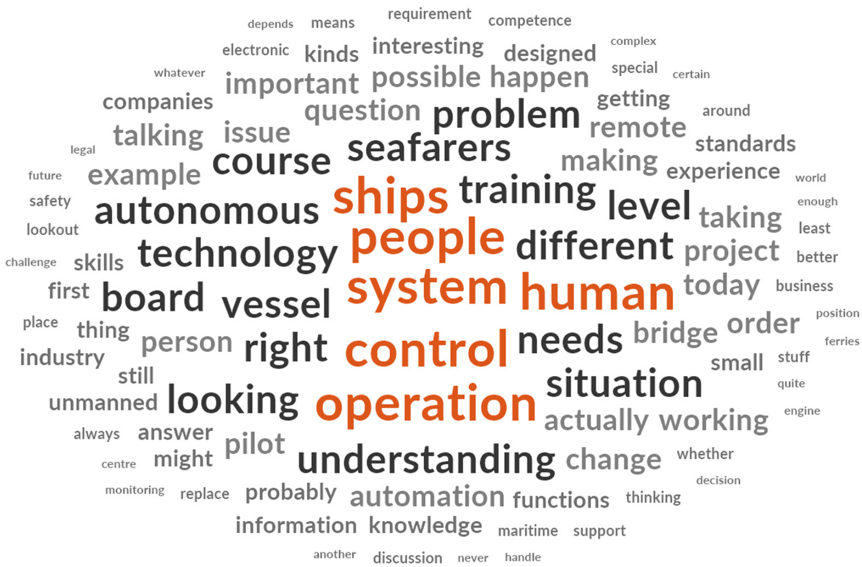

Figure 7.4 The educational perspective.

some kind of error to result in “Ships”, “People”, “System”, “Control”, and “Operations” being the five most frequently used words, independent of the perspectives from which the data came – the only difference seeming to be that three of the four perspectives had the word “Human” as part of the highest-frequency group, while the operational perspective had the word “vessel”. Having satisfied ourselves that no simple error caused this similarity, we started to discuss the meaning of the unexpected match and eventually arrived at the conclusion that it mostly demonstrated – validated – that the ten fireside conversations all focused on the same subjects. In other words, we now see the word clouds as giving credibility to having had ten conversations, resulting in ten comparable data sets.

FIRESIDE CONVERSATIONS: ANALYSIS RESULTS

INTRODUCTION

From the outset, our participants saw the current maritime industry as the foundation on which any move towards a more automated, more autonomous future rests. Being aware of the high-tech maritime initiatives around us, especially focusing on the transport of passengers and goods in cities and domestic waters, a fireside participant however noted that “the world is big. A lot of what we talk about going on in north-western Europe and parts of Asia and how this will influence the worldwide shipping [is open]”.

For this reason, the present landscape is probably best described as consisting of traditional ship owners, ships, and seafarers operating within the framework of current norms and standards, practices, tradition, education, rules and regulations, and business perspectives. Since, in some fashion, novel technologies and solutions are to fit in that framework, we suggest that a number of key points defining the present-day industry are important with respect to what the future could bring. The fireside conversation data below are organized to illustrate what participants thought of how "today" would influence "tomorrow", not having a particular future solution in mind, other than something more advanced than what is typically seen today.

A present-day line in the sand

Considering present operations, an aspect discussed by several participants was that safety to an unknown extent is provided by the seafarers. One participant thought that operations are being "based on the human ability to be flexible and solve problems – But we certainly never find is how many cases [accidents] people have stopped", a view shared by another participant, thinking that seafarers "just do [these things] reflexively because they have been at sea for so many years". Yet another participant saw the mariners adding to safety by spotting faults early, being sensitive to

> something – not reacting the way you expect it to react [and] you can look at it and ask what the hell is going on? I have seen that. That is always my cue – The phrase you always get is what the hell is it doing now?

However, another participant saw a reduction in the competence of a human operator as being a risk, by stating that

> [t]o diagnose what is wrong with the system or that the system even might be wrong – because systems have a habit of keeping working but something is not entirely right – it is more likely now that people will not notice because they just rely on the equipment in front of them and they assume it is working.

Perhaps relating to such reliance on technology, the fireside conversation participants voiced concerns about present-day onboard systems. One participant was of the opinion: "what we need is not to have new systems but we need to have a new system that works", while another stated, "you have too much information and then lose the basic information that you need to steer the vessel. For that reason you have collisions and misunderstandings and things like that", a position being supported by a statement relating to ECDIS, where the participant said that

> you also have possibilities to put layers upon layers above it and at the end you do not see the chart. It is just a lot of information and too much information. Information is blurring and you lose the situation.

The complexity of present-day systems was described as problematic. Systems "are quite complicated. It comes from how the equipment is made and the vessels are made and designed", one participant thought, while another remarked that "Most of the systems are beyond the comprehension of any individual. That is the challenge". In the eyes of another participant, this also related to the componence of the users, reminding that "those that are actually operating the ships – do not have A-levels", and attention was also drawn to the opinion of a participant who thought that present-day systems exhibit "a large number of [failures] where the crew is basically unable to diagnose". Rather, a participant suggested that the aim of equipment suppliers should be to

> merge [systems] into something that is better than we have today more essential information – and not to add information". "We need to make it make sense. We need to figure out how to do it so that we are doing it in a way that increases the usability of the system.

It was stated, arguably seeing current equipment going in the opposite direction:

> The sort of things that are all those nice-to-have is that we keep adding in. Put them somewhere else. Because of the way these things are designed the temptation is to put them all into one block because it is cheaper.

In continuation, participants happened to discuss both the knowledge underpinning new designs as well as the influence of rules and regulations. With respect to the former, one participant asked:

> What kind of competence do people – that are designing this technology have with regard to the human role? We now know that we need an engineer to design and put into reality these technologies. But we also need the engineer to understand what this technology is and what [it] is doing in terms of – what a human could have done.

It is a line of thinking resonating with that of other participants, who stated, "I think it is vital that even the experts of all kinds of details should also have some knowledge of human factors". Also,

> I am hoping also that the autonomy discussion – and the fact that more people have become aware of the human in this chain – can also make the user more involved in the development processes when it comes to bridge equipment – Because it does not help if you have 200 alarms if we can only react to 10 at a time.

Rules and regulations were also seen as contributing to this issue, with one participant stating:

> Of course, the big challenge is that ships are not seen as systems in regulation and that I think is a mistake that has been happening many, many decades ago. It is a real problem and issue. Each device is regulated separately.

Present-day training was also discussed during the fireside conversations, speculatively spurred by the autonomous shipping agenda.

> We need to follow up the training and it needs to come to the modern area. We could drop celestial navigation – I cannot remember the number of hours I would train in celestial navigation and I used it once.

One participant noted, something which was resonating with other views: "You do not have to necessarily calculate everything in order to get that basic understanding", the participant stated. The participant further continued:

> Running a manual plot – we spend ages on that. You probably do not need that anymore – Also calculating shear forces and bending moments. We have a cargo computer doing that for us – Do we actually need to calculate it?

Similarly, teaching the calculation of grain cargo could perhaps be removed from the curriculum, one participant suggested:

> The cargo handling – I am not sure how many grain cargo ships there are in the world but there are not many. The – question is why does every – seafarer that is not very likely to end up on a grain ship – why do they need to be able to calculate grain cargoes?

The time saved potentially being "used instead to understand integration or interfacing or basic algorithms or how communication protocols are working. What is the risk of [–] not connecting?" Starting with the weather, one participant suggested that the key issue was that

> [Students] need to understand how it affects the ship and what kind of dangers it can put them in. What [do] I need to do to make sure that does not happen and what [do] I do when it happens? In order for both [to be] better prepared for whatever task you are doing and be better prepared for things not going as planned. In order to be better prepared for being at sea.

Thinking ahead

Changing the focus to "tomorrow", participants thought that the autonomous ship conversation had evolved since the first thoughts and concepts were launched around 2017 and 2018, arguably to become more realistic. "I also appreciate the maturing – of the theme – three years ago – people actually believed in this robotic way are running ships" noted one participant, while another, discussing deep sea autonomous ships, thought that "I think more people now have a realistic image of what that takes. Which means that the conversation is not so driven by the enthusiasm because that enthusiasm has had the sting of realism into it".

Some participants in particular noted that the ship owners appeared to be less enthusiastic about a move towards more automation and autonomy. "The shipowners have been more like, 'Yeah'. Leaning back and enjoying the show", one participant observed and added that "the shipping companies have not been that up there with everybody else. They have been sceptically awaiting what is going to happen", while another observed that the "shipowners are the most important – and the main reason they are hesitating is that they do not see the economics in this". Participants believed that the added realism of the autonomous agenda perhaps came from this direction. "It is all about the money. It is just money, money, money. All the time", one participant stated, while another echoed this almost exactly by saying "Everybody wants to make money", also noting that "I think also for ship owners it will be a calculation as to whether it pays off". Yet another participant remarked: "It is about economics and business cases". This was a view shared by most participants. "One [motivator] is the business case and this has always been the same. The industry is not going to do this unless they see a business advantage", one participant observed, and another thought that "every business owner I know is concerned about their bottom line and what the result is at the end of the year". However, to the participants, the expected benefits of moving towards more automation and autonomy for deep sea operations appeared to be less than clear. With the big boats – I do not see it. It is not worth it. There is no reward. So you can also remove accommodation. This is mostly appropriate for small ships. The big ships you do not have the savings, one participant offered, while another stated that "The business case is not there because you need crew for so many operations. We are not going to save any money", again a line of thinking that resonated with another participant – "Crew is cheap. Crew is so cheap. It does not pay to put all of that [redundant/autonomous technology] into the ship. It is better to have a guy with a hammer and a spanner".

Diving deeper into the conversation about the business potential of more automation and autonomy, many participants shared a concern over the cost of building new ships with these capabilities. "I think that maybe the ships will be more costly with this technology which costs more than people", one participant remarked, while another believed that with more advanced technology, "You would need to have people with a higher level of education and diagnostic skills, probably. And you would probably need more of them". Whether existing ships, rather than new buildings, could be upgraded to become more automated or autonomous was also touched upon by a number of participants. One concluded that "There is no point in taking a conventional ship and trying to make it autonomous. It will be much more expensive", while another thought, "you do just what you need to do to rebuild a vessel, let us say for four months, it will just kill the economy".

Potentially a consequence of the views about the business perspective, seen from the shipowner's perspective, some participants remarked that development seemed to be a technology push. "It is not the shipowners that have been driven or have driven the discussion about autonomous shipping. It is the people with the technology that have", was one remark to that effect, while another was "My experience is that it is more other environments that are the driving forces in this discussion, and not the shipping companies, which I guess is maybe a sign?"

Human involvement, capability, and contribution to the future industry was one aspect which the participants kept returning to. Considering the role of humans from the 2022 perspective, one participant stated:

> I do not really see that humans will be out of the loop for a very, very long time. Having a human in the loop does not really reflect on where that human would be, [or] what – function a human would have.

Pinpointing that roles could change, but that final responsibility would remain with a human. "[maritime operations] where humans are not involved at any stage – is so far in the future that we do not need to think about that right now", one participant thought, while another believed that "the humans will not disappear in the system anyway – they will still be in the system at some point", a thought which resonated with other participants: "what I am seeing at least the next 10 years – you will have a normally crewed ship and when you are at deep sea it will go on automatic just like 10 years ago", one participant offered, while another concluded: "I think you will always have people in the loop. I think you will always have people in the loop".

Perhaps because of expecting a continued key presence of humans, some fireside conversations addressed the continued supply of experienced personnel. Referring to a source, one participant noted:

> Optimization is very important, but at least 70% said that the maritime operative competence is crucial for the maritime industry to evolve … But if all of [the ships] are unmanned how will you get that competence because nobody will be out there and get that operative knowledge.

Other participants saw similar risks associated with reduced competence. One remark was that

> [t]he other thing that worries me is the competence ashore also in decision-making. I think that the industry is currently dominated by economists, lawyers and politicians. How can I put this nicely? They need more help in understanding what is going on.

Another participant described this dilemma by stating, "I would argue that the many times I got the feeling that the distance between – the gap between – operational seafarers and let me call it theoretical seafarers – that that gap is widening", potentially leading to "an autonomous world, if you look very far into the future, those people will lack a lot of the understanding that you get from actually being on board a vessel".

Conversations about competence often turned to future training and education of seafarers, where one participant thought that

> [students] will perhaps have more IT and more engineering. The engineers will know more about that. They will have a broader education in many ways and they will also have the skills to do some rectification [–] on board but then it will be more software work than manual work.

However, not all participants shared the view that maritime education would need to change. "My belief is that there will be no big revolution", one participant suggested, and continued, "we may have to change a simple course or something in training but the bulk of the ships for many years ahead will be traditional", also highlighting that over time, new technology has been introduced, and "seafarers have adapted and have had additional training – and there will be – guys coming out who are bright and adaptable. They will learn what is necessary". Counter to that, however, another participant stated that "these guys with their limited education are the best seafarers that we have got. They are really capable of operating the ship. So getting more technology into their world could be extremely dangerous".

A final topic often reverted to, when considering a more automatic and autonomous "tomorrow", was technological readiness, that is, the ability to design, implement, produce, and test the systems required in the future. Thinking about one of the ongoing demonstration projects (2022), one participant noted, "And also with [this demonstration project] it has been – yes, next year, next year, next year. And we see that, okay it maybe was not as easy as some thought it would be", while another, considering an electronic lookout function, stated: "When it comes to what we are seeing and what we should do about it we are so far ahead of any computer that exists". Some participants saw technical limitations yet to be overcome, as well as test demands potentially beyond current capability. "So there are a lot of restrictions on what it is able to do and it has to do with the size of memory and things like that", one participant noted, and, considering testing, thought that "[i] f you want to use it in critical operations then you have to find a way to test it to show confidence in what it is supposed to do. This is extremely challenging for complex operations".

The problem raised relates to the definition of scope and the "design envelope" – that is, the limitations on system capability. A participant stated:

> You cannot always define the envelope. That is the problem. – then you might be able to define an envelope to test against but if you want to define an envelope that allows you to differentiate between different types of ships and stuff like that, then you have a problem.

The participant continued, "If you can guarantee that you have trained it sufficiently to a set of patterns so you will never get anything outside of that and you tested against it then it is okay", thus highlighting the design challenge posed. Rounding off, another participant ventured:

> I think shipping has a lot to solve before autonomous shipping is a reality [–] shipping is influenced by a lot of other factors than just [–] professional shipping. That has also to be solved in order to get good autonomous systems or unmanned ships.

Philosophically, one participant could not help thinking about "How can we make sure that technology can [provide the same kind of implicit safety]?", while another participant shared the concern, however phrasing it differently:

> Do you think humans will be involved in designing a fully autonomous ship? Probably. But what we have done is we have taken the gatekeeper out who might stop the things that the designers have designed not quite right.

SUMMARY

In the foregoing section, we reported our participants' opinions and thoughts about the present, and the way they thought the current landscape would influence the future. They reflected on the implicit safety which seafarers currently provide, and they had considerations about present reliance on technology, and what they saw as the impact of today's system complexity and design practices. The participants shared their thought about potential near-term revisions of training schemes, most likely to be independent of the autonomous shipping agenda. Looking forward, the participants were firm about the future agenda being set primarily – entirely – by well-known business motives, with potential purchasers focusing on the financial benefits and return on investment. A similar firmness appeared to be in place when it comes to the involvement of humans in the future – our understanding is that the fireside participants believe that humans may be in different roles, or in different locations, but they will remain "in the loop", to take actions where systems are inadequate, and to make decisions where human judgement overrides or replaces technology. The participants also expressed some concern over the continued availability of the qualified, competent seafarers they saw as being needed, and they shared some questions relating to technological readiness, and the ability to deliver the solutions demanded in the future.

IMO DEGREE 1

INTRODUCTION

We suggest that this section should be read recalling the insights summed up above, considering that they underpin the participants' thinking also about IMO Degree 1. The advent of key technologies corresponding to IMO Degree 1 appears to be imminent, based on the views of the fireside conversation participants, and according to the data, IMO Degree 1 also turns out to be most likely and relevant to deep sea operations – the reason being, as later sections will reiterate, that the fireside participants suggest that domestic shipping is more likely to target a higher degree of autonomy, like IMO Degree 3 and 4. IMO defines Degree 1 as

> *Ship with automated processes and decision support:* Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control (IMO, 2021)

This we take to include the introduction of an Electronic Lookout Function (ELF) (Tervo & Lehtovaara, 2021) and concepts like "Periodically Unmanned Bridge" (also called "B0") (Lehtovaara & Tervo, 2018), where the officer of the watch is either on the bridge, not undertaking the navigation of the ship but concentrating on other tasks and not undertaking the navigation of the ship, or even off-bridge, to be summoned to the bridge by an alert system if need be.

First steps

The fireside conversation participants thought a development in these directions likely to be the initial steps towards more automated operations. Potentially slightly confusing the actual aspirations of ELF and Periodically Unmanned Bridge, one participant thought the ELF safety concept did not require large changes, and stated that “basically, the B0 means that the system becomes a digital crewmember in the current setup”, a perspective that was shared with another participant, who stated:

> What we are doing here now is putting electronics to take the function of the guy at the helm and the guy that runs the engine and telegraph and we are putting electronics in for the Lookout but otherwise the information is the same. The whole concept [is].

An understanding which was shared with another participant, who saw Periodically Unmanned Bridge as natural for deep sea operations: “What you can do with the big ships is of course to introduce the unmanned operation during night times”. Participants however agreed that the change would be gradual – cautious – which one participant described with the statement: “It needs to be a combination of legislation, training and experience of the systems that are going forward”. Other participants concurred. “We need to go through [incremental] steps in order to ever be able to have an autonomous unmanned operation at a larger scale – you take these steps, step-by-step”, one participant offered, while another stated: “In the deep sea we are going to go incrementally and we will put in more and more electronics and training courses and so on”, a view supplemented by yet another statement to the same effect: “So they gradually, on big ships, will see an electronic lookout function that will be an integrated feature into the integrated bridge”.

Barriers and challenges

The mode of operation described by the IMO Degree 1 definition resonated with the thinking and opinion of the fireside conversation participants. As such, one participant thought that “If the automation is not able to handle the ship reliably in that situation then you have to have an operator”, thus describing the human as the backstop for technical shortcomings. Elaborating on such a scenario where human presence plays an important role, one participant believed:

> [T]he human need to be where they can still govern the vessel somewhere, and if they are on board, they must be in the immediate vicinity or nearby. If they are absent on the bridge for a period of time they need some alarm system where they can call them on the bridge if there is something happening – of course they have collision avoidance and those kind of things but they must be manned. So then they can intervene and take some kind of action in that track. The functions will be handled differently but we are still where we are looking to the man in the loop somewhere.

The issue of a human operator stepping in to manage a situation however gave rise to considerations about human reaction time, and thus the prewarning time needed to safely deal with problems, but there was not total alignment between participants. Comparing to autonomous cars, one participant felt:

> [W]ith [autonomous cars, there is] an implicit thinking that if something goes wrong the operator is then immediately able to take the steering wheel. It is not possible. They cannot do that. In a ship you can actually do it. Most of these situations develop relatively slowly. Except in the English Channel perhaps.

Another participant saw the issue to be subject to evolvement and increased pressure on the operator, as well as, potentially, resulting in new requirements:

> [T]he time needed for the attention of the human can be set in various ways– When something is seen on the radar less than 10 miles away an alarm goes off so someone comes to the bridge and sees what is happening – but I think everybody understands that gradually this 10 mile limit will be – if nothing happens – brought closer. You need to be sure that whenever you reduce the time for the human, it puts a lot of pressure on the system and the human to be able to quickly establish what is going on here and what is the problem and what options there are.
>
> If we have this scenario where reaction times [get] shorter and system capabilities grow at the same time then the capability of the person stepping in has to be assumed and prescribed at the same time – as complexity grows you will simply need – or my assumption from what I am saying now is that – we will need more qualified people.

Staying with the suggestion that the conceptual development for the deep sea fleet potentially would move in the direction of ELF and Periodically Unmanned Bridge, the fireside conversations also included talks about other potential barriers and challenges than those of human performance.

Hence, the ins and outs relating to rules and regulations, safety, as well as technology and technology development were recurring subjects. With respect to the overall issue of rules and regulations, one participant suggested that this would be the primary barrier to development. "I think the biggest issue we have today is the legal issue. Because there are so many limitations to where we can do it", it was stated, and, directly relating to ELF and Periodically Unmanned Bridge, continued "One of the examples of this kind of conflict is the STCW and its watch keeping requirements. These require physical presence on the bridge and specifies physical presence in other places". Taking a step back, the lack of a specific legal framework is seen as problematic: "Currently there is nothing really to know. We are not at that stage yet", and not having a firm rules base was believed to be an issue which also affected future education: "we do not have any legal system for MASS. First we need to have a legal system for MASS and then it would be part of the normal education of MASS seafarers". Novel technology was also considered to have a potential impact on accountability, and one participant mentioned that "because the way we handle [responsibility] is we put someone in jail if they make a mistake and the problem is that we cannot put an AI system in jail".

From a more operational perspective, the topic of traffic separation was touched upon by the participants. One participant believed: "The whole concept is that we are going to have mixed traffic forever", while another thought that the current instruments relating to traffic separation could be put to use to manage the mixed traffic scenario: My feeling is that we will get a stricter regulation of traffic through a more extensive Vessel Traffic Services (VTS) and possible changes to the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) that will allow autonomous ships to somehow signal their intentions.

Safety relating to ELF, as well as other systems beyond the present state-of-the-art, was a subject often discussed in the fireside conversations. From this perspective, one participant would welcome "an electronic lookout function – because we do think that is going to enhance safety", while another participant felt unprepared for a future with more advanced technology, stating, "I just do not think we have actually thought through what we should do to deal with the hazards that you cannot deal with immediately". The mixed feelings were also reflected when the discussion turned to the level of safety needed, where two comparatively different views were present. One view was:

> What is very important to bear in mind is that you cannot make anything bullet-proof. It is never 100%. You will have accidents. In the future as we do today. There are precautions and safety measures that we need to have on the ground to make things safe – And, yes, errors will happen.

While another participant thought that an ELF solution should improve current safety standards and stated that "we need to also make it better, safer because that is one of the challenges that we see today" [i.e., the quality of lookouts]. However, when it came to approval, there appeared to be no hesitation, but a preference to err on the side of caution: "They are all going to use autonomous technology but whereas for the big ships, well, the legal system is not going to permit it in a risky case", one participant said, and – referring to the issue of defining the design envelope mentioned earlier – continued to firmly state that "The limitation that they cannot prove this situation to take care of this in a good, bad or safe manner then it will not be allowed either from our side".

Technology, technological capability, and the design practice relating to technology had the broad attention of the fireside participants, however they were not always agreeing: "we expect to have periodically unmanned bridges – the technology is there", one participant suggested, and another shared that view by stating, "we have all the principles and now we have the technology to do it on the bridge – technology is available". Other participants had less confidence in the readiness of technology, especially the less proven elements containing artificial intelligence (AI) and machine learning (ML). Carefully pointing out that AI is not one-size-fits-all by stating that "You have true AI that has a literal database and it makes decisions based on this and it is connected to the Internet. It can think anything and it has processing power through the moon", this participant then turned towards the solutions it was believed likely to be used on ships, and stated that "Machine learning and artificial intelligence – I am very sceptical to that. So machine learning is a very neat idea but it is not really magic. It is a statistical method to do something" and continued to highlight that "it cannot do anything that has not been programmed to do". Human–machine teaming, and the design methods to develop usable future systems supporting collaboration between technical systems and human operators, also gave rise to unanswered challenges.

> The issue is that you have to find a good way for humans to interact with automation and have a good system. We have a big challenge ahead of us because we do not quite know how to do it.
>
> [H]ow to transfer information from the machine to humans and from human to machines. What is an acceptable timeframe to do the transfer? How do we ensure that we have the proper level of expectation management on both sides so that the machine understands what the human is capable and not capable of and vice versa also?

Technology limitations being one thing, the fundamental knowledge base required to design suitable future technology was also being discussed, in terms of translating human activities into technical requirements, and subsequently into solutions. As an illustration, one participant asked the question:

> How far can we replace a human for instance in the navigation operations in observing? In having an officer on watch, how far can we go to replace the officer in terms of their senses? How should that technology see? How good should it see in different kinds of conditions? What are the acceptable ways we can accept technology to replace a person on the bridge in a navigational situation for example?

This expresses a concern that other participants shared through similar doubts:

> One of the biggest problems we have when talking about algorithms is [–] what is it when we speak of good seamanship? I think that the biggest struggle we have and to describe good seamanship and even worse – How do we rewrite that into an algorithm?
>
> [B]ut how and how much does it take for technology to adapt and include all of these functions that a human has today? And hopefully not include those bad aspects?
>
> One of the things that will have to be dealt with in the longer run if technology is to replace the human lookout is to somehow translate the human skills of observing seas into technical requirements. This has not been done before because we more or less know what a good eye looks like and the requirements of a medical eye test and all this. But to translate all of this into pixels and stuff or to have objective standards of what it needs to be – to be simple and observable – that has not been done.

Summary

Considering concepts aligned to IMO Degree 1, the fireside conversation participants in general agreed that the introduction of an ELF and the concept of Periodically Unmanned Bridge would be likely the first steps for the deep sea fleet, but they also saw a number of barriers and challenges. These spanned a wide gamut, ranging from basic knowledge, methods, and modelling required to design technology able to dependably and safely replace humans, via technological capability to potential legal and regulatory stumble blocks. The participants did not always see things identically, but none of the participants seemed to believe that an ELF or an implementation of a Periodically Unmanned Bridge would be immediately ready and available, and without requiring some degree of change in the maritime industry to become reality.

IMO DEGREE 2

From the perspective of seafarers and the HUMANE project, IMO Degree 2 (as defined below) is only marginally different from Degree 1: in case of technical problems, the humans on board remain to be the back-stops:

> Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
>
> IMO, 2021

Obviously, Degree 2 introduces a significant change in the distribution of work between shore and sea, since it does introduce remote control and (implicitly) communications technology as crucial core concepts, but in the understanding of the authors, this is only in the context of normal circumstances when considering communications between the ship and the shore. However, in Degree 2 the requirements and responsibilities of remote-control centres, the capability of their staff as well as the dependability and availability of communications, are seen as considerably higher and more clearly having an impact on sociotechnical solutions, an aspect which is even more pronounced in IMO Degree 3. For this reason, the following section concentrates on the thinking and concerns of the HUMANE fireside conversation participants to this more challenging and severe perspective.

IMO Degree 3

Introduction

Defined as "remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board" (IMO, 2021). We suggest that IMO Degree 3 marks a significant change of paradigm compared to Degree 1 and Degree 2, a position that is best expressed by a fireside conversation participant:

> The main point we are talking about is "should we allow people to be away from the control position"? There is a lot of talk about these levels of autonomy from full manual control to full automatic control. The point is whether there is or is not a person there.

The perspective of "is there a person there or not" was apparently shared by another participant, who also saw the lack of manning – humans – as being decisive, driving requirements:

> [B]ecause when you take away the people on board, to do that you need to complement or supplement something else. When it comes to safety,

> if the vessel is not made to do that itself, then maybe you need to have something outside the vessel that can complement what earlier has been done by the people on board.

Rationale

Reverting to the theme of implicit safety provided by crew members on board the ships, one of the participants put a question mark on the fundamental motivation of remotely controlled ships, hinting that remotely controlled ships could also suffer from faults and would need to include inherently safe mechanisms to recover:

> If you think in terms of having a remotely controlled ship, the first question is why? And the driver that is always put forward in all these automated, autonomous systems is that it gets rid of human error. And people are the problem. Now, nobody is looking at it the other way and say[ing] that actually people are the ones who solve a lot of the problems that the system is not going to be able to solve for itself. Because unless your designer has thought of every possible way for the system might fail.

Carrying forward the idea of autonomous and/or remotely operated ships, fireside conversation participants again saw the future through the lens of business objectives. One participant, thinking about the concepts in general, stated:

> I suspect that if you are going autonomous or remotely operated – where is the payback? Because it is going to be expensive. I do not think that has been factored in. When you read all the things that I have read – people seem to believe this is going to happen. I just think, why? Where is the case for is doing this?

However, turning thinking towards more specialized cases, the business cases appeared to be more attractive, and clearer. One participant shared:

> I see a business case, for instance, for – ferries on demand – a small boat that is fully automatic. You book about and you swipe your card and then you go across a piece of water and then go up on the other side – I think we are going to see that soon.

This was echoed by other participants. One participant stated that such solutions could

> make a totally better logistics chain. This is actually what is going on in the cases we have in Norway. It is not an autonomous ship. It is a

> unique type of logistics. And I think we have looked at similar cases here in Norway. For transport in the fjords. Sheltered waters, low traffic and are replacement for car transport.

Another participant, considering safety and the local nature of transport, saw opportunity relating to "Short distances – Easy to access if something fails et cetera. Maybe this is realistic and a lot of places do have a smaller project which can be realistic on a shorter time period". Yet another participant shared this line of thinking and stated:

> you can probably build that ferry so that it is more like an elevator. You make sure that people cannot follow that. You have enough response services to be there within 10 minutes. Then it is close to inherently safe.

In addition, it appeared that for such domestic solutions, training users would provide both additional safety and independence:

> One of the ideas of "ferries on demand" for instance on the small islands is that it is viable to train the adults on the islands and give them some safety training so they do not need to have a steward on board. They can take the ferry to go to the job or go to a hospital at two o'clock at night because they have four hours of training so they know how to do an emergency suit and where the life raft is, when to press the alarm button and wait for somebody to come and pick them up. You can train people. The islanders can do things.

Another participant appeared to think rather much in parallel:

> So in principle you could for instance train people on the island to operate the safety mechanisms. So then you would have trained people for any trip at any time and then you could set up an on-demand ferry service.

Remote control and remote operations centres

Interpreting the IMO definitions, unmanned ships conceptually come only in two flavours. Here, the IMO Degree 3 ones are ships which are supervised, monitored, managed, and operated from "another location", and IMO Degree 4 ships– to be discussed later – are by definition entirely autonomous. As the HUMANE fireside conversations showed, the key concept of remote control and its many facets were given a lot of attention by the participants, together with the associated requirements, performance, and qualities of the lifeline between the ship and the remote-control facility

– communications. Setting the stage, one participant described the working methodology of the remote operations centre (ROC), believing

> that the role of the control room will be more of supervision than of operation directly. Maybe it may be the case that some of the safety operations could put a vessel in a safe state. But there is a responsible person. There absolutely is – you will be operating just like airline pilots – sitting in the chair monitoring stuff and the ship will sail automatically until there is an unsolvable problem and then you take over.

Another participant referred to space missions to convey a similar vision of the ROC:

> You need a hub. There is a famous saying: "Houston, we have a problem" – you need a Houston unit somewhere and you need to know how to contact. They need to know how to rectify things and so on.

The layout of the ROC, and thus the instruments available to staff, was not a topic often raised, but one participant offered:

> I am very sceptical to the idea that you should make a virtual bridge – the interfaces you may work with might be completely different from the ones you work with today.

The participant indicated that user needs could be different when working ashore, and thus would require a renewed design effort.

Staffing of remote-control facilities was a frequently occurring conversation topic. Speaking about the human operators there, participants shared the understanding that key roles would be fulfilled by mariners. "You need to know the maritime field", one participant thought, agreeing with another participant who believed that "They will also all of them have a seaman background that gives them a platform". A third participant believed that "you would need people who can understand the significance of the things around them", and a fourth participant confirmed the notion of having mariners in command, and continued to muse about alternatives by asking the (rhetorical) question: "Is there any possibility of making ships captains out of nerds or even more complex to turn ship captains into nerds?" Finally, yet another participant offered a more elaborate explanation of expectations:

> You have still got to have a Mariner in there. Those basic skills of being able to work out what the hell is going on and understand the rules and regulations, and to be able to drive a ship matter what is – those are core skills that everyone has to have.

The organization of the ROC constituted another recurring theme in the conversations, often demonstrating the shared idea about having multiple competencies spread across a team of operators. One participant described the ROC as having

> a team of different types of knowledge. You will also have a need for a technician that knows the different levels of the system and can go in deeper and operate it if something fails. But you also have the necessity to understand the vessel and its interaction with the ocean.

Four other participants detailed the thinking, not only demonstrating that the ROC is a widely shared concept, but also stressing the need for diverse competencies among the remote staff:

> What we thought about is that we would have a first-line operator who is only responsible for supervising and checking any problems to see if it is an easy problem to solve but if it is more complex than a small amount of work then it would be to a specialist behind. Something like that. This requires of course that you have a fairly big staff. You have to have a number of specialists and probably be able to handle a couple of incidents at once – The second line has to be a Mariner if it is a navigational problem or an electronic engineer if it is electronic.
>
> [W]e may have one education system for the guys who are going to understand the system and the small bits in the system and then you have other experts who can see the big system and then you have maybe a third category which is the shipping operational people who are manning in earnest – manning the ships.
>
> Most likely it would be stipulated that there will be a team of different types of knowledge. You will also have a need for a technician that knows the different levels of the system and can go in deeper and operate it if something fails.
>
> I think you have to have specialists in the holistic as well. So they can [talk] with the specialists in [detail] – dealing with fragments of the holistic system – with another [kind] of personnel where you focus on the details. We know who the devil is.

In some cases, the conversation about – and around – ROC staffing turned towards the training and education of staff members, and whether the present educational system could meet the demands of future remote operations. Here, the understanding among the fireside participants was more spread. One participant thought:

> What level of competence does the control room operator have? – It is not fixed yet – [but] it is certain today that control room operators will be doing similar [–] training on a full-bridge scale and both need navigation as a navigator if it is a bridge situation. Also within technology

> because the person needs to understand – and they need very much insight into the technology and how it functions

Another participant however believed that ROC operators "need to have backgrounds in a certain field but whether they have the exact same certificates as an officer of the watch has today, that is a different question". Potentially being a bit of a paradox, considering the basic nature of remote operations, two participants turned the conversation back to the subject of sea-going experience, one stating that "the navigator – needs to have some knowledge. They need more qualifications, maybe. But then we are back to experience again and we need experience of some things. We are not at the end goal", while another outlined the belief that "You need to have quite a few years to be able to be on board and to operate the vessel".

Communications

The importance of stable communications between the remote-operated ship and the ROC was a topic that concerned some of the fireside conversation participants. For one participant, context was important for seeing this as deciding on the delay – latency – of communications:

> How long can you stay without [–] human intervention? That is the debate really. Like my communication system, it breaks down for a minute and then comes back again. That is annoying but it does not kill off everything. Same with a control system. Whether you can go for one minute or five minutes depends on the waters. In the middle of the Pacific you can go for a half-hour or an hour without any problems.

Another participant thought that the maritime industry yet could have some distance to go in this respect, and shared that

> [t]he next big issue is communication. – With the ship you could move [the control room] onshore provided that – and this I think is a big barrier – the communication system between the ship and the control room remains perfect. And not just available most of the time. I think we have a long way to go before we have that understanding of just how important that comms link becomes.
>
> Everybody just assumes that communication is there and will work. What we have identified across all of the projects that we have seen is that problems one, two and three will be communication.

Also communications between unmanned ships and traditional vessels – potentially being managed by remote staff – were being considered in the HUMANE fireside conversations, where one participant described the expectations by stating that

> as a third party, while the ship is remote-controlled and fully autonomous and whatever, you as the third party should not be able to tell the difference. If you call it, it should answer, and it may be a computer avatar that answers you. As long as it answers intelligently.

Reflecting on the notion that "if an emergency happens then you need to do an action", one participant concluded that "Redundancy is very important as well in that", arguably to ensure the continued control over the ship. Conversely, it was suggested that "I think we have to assume that that link will be broken every so often", for which reason "the debate we are going to have is what are we going to do when we lose communications and the ship has to do something intelligent until communication is restored?" Potentially providing an answer, a participant thought that "there needs to be a security level system by which the ship can operate by itself at least going into a safe mode of some sort", but also added that "I do not think we are anywhere near the level of sophistication that would do [remote operations] sufficiently reliably. Until you are, it is a sort of hobby".

Summary

The HUMANE fireside conversation participants continued to see business drivers and perspectives as decisive for the future development of increased automation and autonomy. Based on that line of thinking, the participants expressed agreement that the most likely ships to reach IMO Degree 3 would be small units constituting integral parts of a new, or changed, infrastructure, and being engaged in domestic services, one reason being the closeness to shore and the operational safety that was considered to provide. Such ships, the participants moreover agreed, would be supervised, or operated, from Remote Operation Centres (ROCs), which would be staffed by teams having diverse skills and competencies, seafaring prominent among these. In spite of the local nature of such operations, some participants also focused on the significant requirements of availability and dependability of remote operations put on the communications link between ship and shore and expressed uncertainty as to the present-day feasibility. This caused speculation towards alternatives to completely reliable communications and remote control, including remote-controlled ships necessarily having fail-safe mechanisms and systems to ensure safety in case of communications failure as well as other types of command failure.

IMO Degree 4

The IMO defines Degree 4 of MASS as follows: "*Fully autonomous ship:* The operating system of the ship is able to make decisions and determine actions by itself" (IMO, 2021). This we take – and took – as meaning that control and operation of such ships would happen without supervision from shore, in other words in a "fire-and-forget" manner, where ships would be given a mission and, irrespectively of mishaps, conditions, and circumstances, would turn up at the destination at the agreed time. Such a concept was not widely discussed by the HUMANE fireside conversation participants, but one conversation partner stated:

> I do not think that anybody really plans a ship that is so autonomous that it would not have any[body] even when things go wrong and alarm start ringing – that there will not be a human somewhere in the chain picking up the phone.

This statement resonates well with the participants' beliefs mentioned earlier, best summarized by one participant stating "I do not really see that humans will be out of the loop for a very, very long time", which, in a fashion, abandons thinking about IMO Degree 4 for commercial (SOLAS) ships until lesser degrees of automation and autonomy have been successfully realized in practice.

DISCUSSION

This chapter attempts to present the voices of the HUMANE fireside conversations in a distinct, yet structured and thematic manner, while refraining from interpretation and avoiding researcher bias. By basing the narrative around actual quotes from the participants, we hope we have been successful in that respect, or at least give the reader the opportunity to form their own opinion. However, certainly, such a reader's view is being constrained by the foregoing process of coding, selection, and presentation of quotes from the large pool of data collected, and apart from good scientific practice, there are few safeguards in that direction. One of these, we suggest, comes from our internal collaboration, with multiple researchers having developed the codes, while another reason is rooted in a strict internal review process, undertaken by other researchers than those involved in the actual writing; researchers who either participated in the HUMANE fireside conversations themselves or who have full and unrestricted access to the primary data sources, in the form of the conversation transcripts and the recordings of the talks.

The selection of participants in the HUMANE fireside conversations is of course another potential source of bias, and, admittedly, by having chosen primarily Norwegian, or North-west European participants, the view of future autonomous and more automatic shipping is clearly coloured by, and limited to, the thinking and discourse in this part of the world. We suggest that this chapter be seen as a snapshot of the leading edge of the maritime industry in this part of the world in 2021, also reiterating the flux of the subject, and the potentially rapid changes it may undergo.

Having been invented out of Covid-19 necessity, at the methodological level we find that the concept of online conversations worked surprisingly well. A bit to our happy surprise, it seemed it was indeed feasible to create an intimate atmosphere even remotely, and for that reason we found ourselves involved in highly engaging conversations with key stakeholders, who freely shared their personal views, opinions, and experiences with increased automation and autonomy in shipping. Going forward, we are now seeing this online interview format as powerful, providing valuable data in an effective and sustainable way, and providing researchers with a global outreach with little overhead in terms of time, cost, or other expenditure.

CONCLUSION

The overall purpose of the HUMANE project is to enable a future of increased automation and autonomy in shipping from a sociotechnical perspective. Throughout the project, our process has been to let the stakeholders speak loudly and clearly, and through our analysis of such input, to arrive at the barriers hindering the adoption of novel technologies, new ways of organizing the industry, and new regulatory initiatives. Our basic thinking has not changed, being that without knowing the barriers as they are seen by the stakeholders, it makes only little sense to discuss enablers.

The HUMANE fireside conversations have helped us along, letting us appreciate and discuss such barriers in a number of places across technology, both in terms of capability and maturity, organizational and regulatory matters, as well human performance, involvement and training and education. In this chapter, we have shared our data with readers, to support a continued conversation on the subject, highlighting that it is within the scope of the HUMANE project to discuss these matters, and to provide suggestions as to ways and means to overcome such barriers. However, that conversation is beyond the scope of this chapter, which strives to remain objective and to avoid imposing our own opinion and potentially subjective interpretation on the collected data.

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Chapter 8

Industrial and regulatory progress

Jonathan Earthy

INTRODUCTION

This chapter provides comments on a report "from the front line" of industrial and regulatory progress with MASS as of mid-2022. These comments were assembled from a wide range of sources, including events and interactions specific to maritime regulatory controls, and a broad set of events exploring AI and digital technology in both the maritime context and beyond. The evolving understanding of the use of and required controls on AI are summarised in the following areas: scope of application, terminology, the human element, risk, the business case, likely applications, regulation, infrastructure, intellectual property, and assurance.

SOURCES USED

The sources on which these comments are based are listed here to demonstrate both the degree of discussion on this topic and its breadth, not to facilitate deeper investigation of these sources. However, key publications are cited.

Regulatory and maritime standards sources: International Maritime Organisation (IMO) Maritime Safety Committee MSC MASS Maritime Autonomous Surface Ship (MASS) regulatory impact study and other regulatory input; biweekly regulator and manufacturer IMO MASS team discussions (2020–2022); IMO MSC RSE March 2021 plan; EU-OSH and AI Sept 2021; MSC 105 April 2022; MSC MASS Correspondence Group meetings; ISO TC8/WG10 Smart Shipping; Meetings with NGOs/NGO partner organisations from Japan, Finland, China, Republic of Korea, Germany, Denmark, etc.

Other sources/events related to maritime AI/Digital 2020–2022: IMEC Human Element in Maritime Automation 2019; NFAS HF SIG events 2020–2022; EU Bauhaus of the Seas events 2021 and 2022; Dyson School of Design Engineering, Distinguished speaker series 2021; IMarEST conferences 2020–2022; UK MoD/Industry Human Factors Integration Liaison

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Group 2021, 2022; IMarEST Digitalisation Webinar Sept 2021; ErgoShip 4 conference 2021; EU CHEK project 2021 Alternative energy – issues for/from RIA systems; Autonomous Ship Expo Sept 2021; Swansea University/AAIP (Assuring Autonomy International Programme) joint event on legal aspect of maritime autonomy, October 2021; IEA Human–Robot interaction (HRI) 15th December 2021; Digital Ship digitalisation event January 2022; IFIP TC13 Open Symposium on Human Computer Interaction and User Experience March 2022; Warsash MASS Research Group inaugural meeting March 2022 (and subsequent discussion with UK operator owners); Sherwood Jones (personal communication) on Goldenfein et al. (2020) and Gudela Grote (2005), IPOS 2022, York AAIP collaboration workshop, 2022.

SCOPE OF APPLICATION

Most people involved with MASS are only talking about self-navigation. There is not much movement of thinking off the bridge. At the same time, decarbonisation/"green shift" is taking the money. But this should be seen as an opportunity because the more complex ships and operational practices will require more complex control, situational analysis, and failure recognition and management as well as greater knowledge about the novel areas of science and engineering and environmental impacts to cope with the inevitable additional (constraining) regulation. This may well become the main area of application of autonomy in the maritime sector.

TERMINOLOGY

Consistent and agreed terminology is required to clarify current uncertainty. ISO/TS 23860:2022 *Ships and marine technology — Vocabulary related to autonomous ship systems* defines terminology related to autonomous ship systems, which includes ships that can be classified as a Maritime Autonomous Surface Ship (MASS) according to the preliminary definitions from the International Maritime Organisation (IMO). The feasible scope of the proposed IMO MASS Code is unclear (IMO, 2021). Is it only Autonomy degree 4 (completely uncrewed with no human monitoring is the only case that is outside current regulation) or an attempt to impose higher standards on all existing areas of application of Information and Communication Technology (ICT)? Is it about an autonomous ship or about one or more autonomous systems on an otherwise "normal" ship? Will the IMO degrees of autonomy be revised to align with real applications of the technology? Will the IMO MASS Code requirements be additions to existing Regulations or additional requirements on operational functions or specifications on ship systems? Command responsibility, especially regarding the Remote Control

Centre (RCC)*, and liability are unclear. Operation of the RCC – what regulation and law applies and how does this affect location? Characterisation of MASS – is it identical to a manned ship or immediately identifiable as a robot? What is the impact of the assumption that engineering crew and deckhands will be on board even on a degree 4 MASS?

HUMAN ELEMENT

The International Robotics Federation (International Federation of Robotics, 2020) predicts that in ten years, 50% of workers will have a robotic companion. This is not seen as a problem if we put human(s) at the centre of design (from both physical and cognitive perspectives) and understand the context of use to ensure that the design of the interaction between the human and the robot takes advantage of both human and robot strengths. To do this, having the human at the centre of design needs to be in the business case for the system. However, we see that the selling points for some so-called cobots are the same as for traditional robots. This suggests that some manufacturers do not know how to design the interaction and find it is easier to design for the robot to do everything itself. This may also be the reason for the maritime focus on human replacement.

The Warsash Maritime Autonomous Surface Ships Research Centre (WMRC) inaugural event in 2022 reminds us that the focus of training colleges is on people delivery. The stated expectation was that technology will replace human skilled jobs with a warning that parts of this will happen really fast, and the only purpose of the user interface is to allow users to cope with the technology. The training community are still expecting people to be able to be trained or selected to be able to use/maintain/train the technology. And to be responsible on the basis that all maritime incidents/events are anthropogenic, *ergo* all ships require a master. The expectation is that the need for officers to have the ability to process large amounts of information will get more extreme and the job will get worse. The main role characteristic will shift to knowledge worker. There is an underlying assumption that people will come from somewhere, whatever the job, and somehow will be able to work safely.

However, as of late 2021–2022 we see an informed "inner sanctum" of stakeholders working on MASS agreeing on Human Autonomy Teaming being the better way to go. This perspective holds that increased safety and performance can best be achieved by the augmentation of humans. Unfortunately, at the time of writing, there is no regulatory development in this area. Also, nothing sensible on the regulation of machine learning, explanation, or knowledge management. The defence community believes that what they call Human Machine Teaming is an approach, not a technique. Trust seems to be their fundamental research issue.

* Now called Remote Operation Centre (ROC).

The intent from a human-centred point of view will be described in Chapter 10. From a teaming perspective, MASS are a form of cobot. The work on cobots mentioned above lists the most important factors to consider in designing human–robot interaction as follows:

- Allocation of function, including determination of functions or (sub) tasks.
- Operation and supervision, including implementation, robot autonomy, and safety.
- Interaction design, including anthropomorphic robot design, following design principles from ISO 9241-110:2020 *Ergonomics of human–system interaction – Part 110: Interaction principles* and system transparency.
- Task design, including job control and human–technology coupling.

Cognitive workload assessment is a means of distinguishing the transition between autonomous operation and performance by the operator. Work is still required to investigate how to encode implicit factors (i.e. the more social aspects of interaction).

Periodically unattended bridge operation is seen as a genuine cost-saver and safety improvement, but the requirements of the IMO Standards of Training, Certification and Watch keeping for Seafarers (STCW) Code are a barrier. This application is (again) not looking further than watchkeeping/navigation. It raises interesting issues of generalised ship alerts and opportunities for radical change of duty/organisational chart away from watches. Necessary changes to STCW will not happen in the current round and the IMO MSC MASS Correspondence Group or the IMO MASS Joint Working Group will need to propose the changes.

Emergency response requires more, and separate, design: What does the ship/system do? What does the responder do? What do uninvolved parties do? What automation is required for emergency response? This is not different from the current manned situation, but presumably the scope of emergency will extend from machinery failure and protection of the plant to include the ship or function applying a "learned" response to bounded situations. There is no regulatory development in this area.

RISK

Are requirements to be phrased as goals, or is a risk-based approach to assurance expected? The main risk is not internal, it is with new connections. There needs to be an investigation of how Safety II approaches relate to Automation's control perspective. Hollnagel et al. (2015) discuss this issue, albeit for a different sector of industry. A whole-system approach is needed for modelling. The greatest risk mitigation for the industry would come from applying autonomous systems to the least safe shipping (both type and activity), rendering assistance, and also investigating the risks of operating and working with autonomy.

"Equivalence" is the universal touchstone for approval, but to what and how? The regulator is made responsible by codes and conventions, but criteria are set at a very high level. It is likely that assessment will be passed to other organisations or finessed by the regulator or paid lip service by all parties. The danger is that if one regulator does this, it will set a precedent. Creating loopholes or precedence is a dangerous situation. The EU approach to the regulation of AI (European Commission, 2021) is a much better strategy. Another source of error when addressing equivalence is a tendency to compare human performance to some infallible autonomous entity. Whereas, in reality, we will need to live with a wide range of failure and uncertainty.

We are sleepwalking into remote control as a precursor to autonomy rather than the fact of autonomy being the necessary enabler for remote operation. As we move further into studies, it is becoming clear that the complexity of remote operation is far greater than fully autonomous, not only from a technical perspective but also from a legal perspective. For example, what about safety functions and communications, are two independent connections required (as for Unmanned Aerial Vehicle (UAVs))? Or another example: will the remote operator be able to hit the "big red button" and shut the ship down, or only advise what is safe?

There is a range of proposals for the most suitable risk management framework, from use of systems engineering to redesign entire functions or even the whole ship with the combined goals of as low as reasonably practical (ALARP) and reduction of complexity. This approach has the benefit of supporting both cost reduction and legal defensibility. The alternative is the identification and mitigation of the additional (often operational) risk from automation (EMSA, 2023). This latter approach fits within, and hence relies upon, the existing maritime safety framework. However, it has been criticised as potentially allowing the hazard to occur and then attempting recovery and encouraging procedural mitigation rather than hazard removal.

BUSINESS CASE

The standard business case is cost-saving with a nod to equivalent safety. But often the real aim is not economy, it is some other benefit, for example, crew removal is seen as a way to make an easy life in the shore office. More positively, maybe it is about spreading the skills in the industry across the predicted increased number of ships and *not* about de-manning for cost-savings.

There are lots of partial solutions, like assistants (not aids to navigation) under development, but not much thought about integration, none about consistency or communication, and very little consideration of usability or fit into bridge resource management. Most stakeholders are now pretty sure that deep-sea unmanned operation will not happen, but periodically unattended bridge operation will eventually be allowed, once the IMO MASS correspondence group delivers revisions to STCW (in a future revision of STCW). In the meantime, (presumably) this will either be the focus of MASS trials or a new framework like the one-man-watch experiments in the 1990s. But because of commercial interests related to products, this will be fraught with, or may even be prevented by, problems over data sharing.

There is a continued self-deception about the required integration of ship systems. There is not enough money or interest to have sufficient dependability for unmanned ships to operate throughout an international voyage, so it will be necessary to keep engineers and crew for maintenance and technical emergencies. As a result, ships will also need to have crew for passenger safety and emergency response. However, for the autonomous functions, given the limits of control at the operational level, accountability may have to shift away from crew to operating organisations and system designers (*pace* Grote, 2005). There is no regulatory development in this area.

Another area is the chartering of vessels. Where we have a remotely controlled vessel or a fully autonomous one, would we expect "bare-boat" charters to be available if the authorisation to operate is based on an analysis of the competence of the organisation to operate the system safely? And new players may not be maritime – what about their liability given that they are not shipping companies?

LIKELY APPLICATIONS

There is already a rapid growth in the use of floating and submarine drones and there is a range of opinions on whether these will scale into SOLAS-size international applications or not. The concept of an autonomous feeder ship (in at least European waters) seems to be stable, useful, and possibly feasible.

The issue being called "autonomy" is enhanced control. The technical dimensions are as follows: consistency, change process, digitalisation, and technical ambition. Enhanced control/autonomy/high automation will be a significant contributor to and enabler of decarbonisation. It will probably be critical rather than significant. But there is no obvious health and safety benefit unless it is applied to fishing vessels. The question is whether it is possible to "AI" your way out of dirty, hard work.

The quoted example applications are electronic lookout function and enhancement of watchkeeping. The actual applications are performance optimisation, variants of spy-in-the-cab image analysis, forward-looking sonar, and camera-based alternatives to castle-stacking on container ships.

These have a varying degree of analysis up to and including warnings, and even course alterations, to the bridge team. In navigation, there is no backup at present if the human(s) fail(s) to do their job. A holistic approach is required to understand workload. It is not yet obvious whether workload is reduced, or just shifted somewhere else. It may be that reduction of administration is the only cost-effective application.

All projects reported are trials. ML is being applied for recognition but not yet control. There are issues of training on synthetic data sets, cybersecurity extraction of valuable data, compromised fusion if several sensors malfunction at the same time, etc. No one is saying that it is business as usual. All stakeholders want to learn from experience. Collaboratory research should be the next step. Safety case is the first focus and then once trust is established, it moves to collaboration. The level of independence hoped for is "a degree of freedom".

REGULATION

All regulation expects *people* to do things and to be on board. If this is not the case, an interpretation of the regulatory requirement is required. Can principles be applied to a system, not an individual? There is no scheduled IMO task to address autonomy. The current revision of the STCW convention will not make changes related to MASS. Member states now have to make the progress. Trials are a way of getting support. The legal framework will be different depending on whether we are automating what we have, or if we are innovating.

Would an RCC be regarded as a bridge? What is the team in the RCC (on watch, in charge, what else, how many ships, equivalent competence)? Under what agreement would this operate? The fundamental issue is finding some way of defining MASS as ships so that they have the protection of UNCLOS (United Nations, 1982). They will be too expensive to operate if they are manufactured goods (liability is insufficient). Bridge operation and the responsibility for ensuring that the technology works properly cannot be removed from the owner. But the owner is only responsible for employees, not contractors, and except for very large companies with 100% employed staff, the RCC is a subcontractor. Should legislation change to make the owner responsible for the RCC? What is in charge if the ship is operating autonomously – not the RCC "crew". A ruling is required on whether the carrier or owner is responsible for cargo damage on/by a MASS.

However, from the technologists' point of view, the overarching philosophy is (as said sarcastically by a Regulator) "*we can do it, it's just* [only] *illegal*" – suggesting that technology stakeholders are out of control. There also seems to be a mindset that monitoring is no different to any other sector. For example, the assumption that air drones (UAVs) are equivalent to sea applications is not true; the users and legal framework are different.

There is a fear that new Recognised Organisations will emerge outside the Class framework. We also see the use of the term "soft law" to describe relatively informal documents, that is, not international standards. Is this the same as the EU OHS "regulatory sandbox" for AI (European Parliament, 2022), or something more insidious? Early work, such as the UK code of practice (Maritime UK, 2022) and generally local/trial "regulation", are setting de facto standards that formal regulation will have to live by. The longer this goes on, the more problems it may cause.

There are two schools of thought in the IMO MASS correspondence group. One group wants to limit regulation of MASS to fully autonomous vessels and to focus on the issues of unattended operation (put simply what to do if there is no human on the ship to apply regulatory and legal requirements). To this group, all other applications of AI/ML to ship systems and operations are business as usual and can be addressed within the existing regulatory framework. The second group wants regulation to be introduced to apply a more rigorous framework of development and testing to computer systems that use AI/ML or are involved in decision-making. This could be seen as trying to "shut the stable door after the horse has bolted" in that complex computer-based systems are already in widespread use in the maritime sector, and these have not been developed with this level of rigour. However, if the approach proposed by the second group demonstrates a general concern about the quality of maritime software-intensive systems, Class will have to step up in either case and start to apply standards for dependable maritime systems (such as ISO 17894:2005 *Ships and marine technology — Computer applications — General principles for the development and use of programmable electronic systems in marine applications*) much more widely.

As of mid-2022, the management of flag states started getting concerned regarding approving/accepting responsibility for MASS that may be dangerous. It seems that they only just realised the consequences.

From a human element point of view, the purpose of automation was intended to be helping people. Regulation should be an enabler. If helping people is the way forward, the enabling regulation will have to go further. We are currently depending on the safety management system (IMO, 1993) which just has "general safety duties" for all people working with SOLAS vessels.

INFRASTRUCTURE

An exchange of data is what unlocks its value. This means reporting of trials and sharing of information. We see national trial areas and the operation of local applications under national regulation. IMO has specified trial requirements for both MASS (IMO, 2019) and Electronic Navigation (IMO, 2014) testbeds (of which MASS would be a good application), but are they being applied or not by Flags? Standardisation in processes, as well as technology, is needed (where processes mean how the industry does things, e.g., port operations, etc.). Ideally, a port has spatial location information and VTS. Making this available requires a data infrastructure. Having local sensors in each ship is not the optimal solution.

Marine solutions have to demonstrate efficiency to help with emissions. Electric ferries and cold ironing are useful precursors to MASS but are not necessary. This may well be the same for the specific "drop in" transport replacement projects that are being developed, such as short seas transport. The main benefit is demonstrating the use of waterways. These applications need more than international standards for autonomy. At present, they are not a reliable service – when you hear: "*The technology is ready to be piloted in public space*", it means that this is still a trial. For example, it is not certain that automatic mooring in locks can be done without people, it is a whole system; not a boat coming alongside and a couple of ropes.

Although currently available satellite coverage is not adequate for remote control, and in the short term only nearshore and inshore applications can be supported (by use of 5G cellular communications), the expectation is that low orbital satellite constellations will be sufficiently widespread and economical in time to support deep-sea communications.

At the start of 2022, "digitalisation" seemed to be taking over from autonomy as the context. Sector-wide digitalisation was identified as a requirement. The ship's master being responsible and owning the data comes from the time of single-person companies. Nowadays the shore has access and therefore can better make decisions. A digital twin is not one thing. Twins are built for a purpose. Unfortunately, as of August 2022, digitalisation seems to be a short-lived trend, it may be too diffuse and lacking in specific products. If it is failing, then this supports a belief that was stated in the MSTE study reported in Chapter 9, that the maritime sector only buys quick fixes to single problems and cannot cope with systemic situations. This is not a good thing since one of the topics addressed by digitalisation is information management.

INTELLECTUAL PROPERTY

A study by the intellectual property office of Singapore (IPOS, 2022) looked at the topic of MASS from the perspective of the patents that were being registered for MASS to identify trends. This gives a more practical and broad-based impression of the state of development of the technology in comparison to advertising claims or highly promoted individual trials. The study also gives an insight into the thinking of technically advanced maritime Asian nations:

> MASS and smart ships are in early stages of development, with over 85% of global innovation from Asia. Strong local expertise is poised to support further innovations in perception and AI. Monitoring and diagnostics are a highly competitive space. Autonomous navigation

> and operations may soon become a crowded space. Design, simulation and testing are promising areas for further research and development. Maritime cybersecurity presents strong research opportunities. Logistics is a technology niche area for Singapore.

ASSURANCE

The Assuring Autonomy International Programme, that investigates the assurance and regulatory challenges to safely realising the benefits of robotics and autonomous systems, has concluded that as of 2022, the maritime sector needs further investigation of the following:

- How to represent reality using ML/AI in a maritime context.
- Understanding good seamanship in the age of autonomy.
- Safety management systems for off-nominal situations for MASS.
- Benchmarking the evolution of safety management and assurance in maritime context.

There is a misconception that autonomous systems can be a complete, all-knowing substitute. Grote (2005) explains that a more practical approach is to accept that current and future automation technology will contain some zones of no control:

> Any system design should build on this assumption [zones of no control] and develop concepts for handling the lack of control in a way that does not delegate the responsibility to the human operator, but holds system developers, the organizations operating the systems, and societal actors accountable. This could happen much more effectively if uncertainties were made transparent and the human operator were relieved of his or her stop-gap and backup function.

Grote's approach is essential to prevent designation of the operator as the "moral crumple zone" of an autonomous system (Goldenfein et al., 2020).

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Chapter 9

Maritime smart technology ecosystem

Jonathan Earthy

INTRODUCTION

This chapter reports the findings of the maritime smart technologies ecosystem (MSTE) study, 2020. This study was carried out in support of the HUMANE project to explore the scope of roles for ergonomics in relation to high levels of ship automation. The study looked in a novel way at opportunities for maritime ergonomics in the impact and management of maritime digitalisation. It asked three questions: (i) Is there an ecosystem for smart technologies in the maritime sector? (ii) If there is such a system, how healthy is it? (iii) What does that mean for the maritime sector and for ergonomics in the maritime sector?

The MSTE study was carried out in June 2020 in three facilitated online sessions with about 15 participants from around the world. These people were selected from the participants in the series of knowledge-gathering workshops held as part of the HUMANE project to represent areas of professional and academic expertise across the maritime industry. Thanks to all of those who gave their time to participate. Much appreciated.

MANY SYSTEMS

Some definitions of system:[1]

System: combination of interacting elements organised to achieve one or more stated purposes.

System-of-interest: system (whose life cycle is) under consideration.

Interactive system: combination of hardware and/or software and/or services and/or people that users interact with in order to achieve specific goals.

Work system: system comprising one or more workers and work equipment acting together to perform the system function, in the workspace, in the work environment, under the conditions imposed by the work tasks.

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Enabling system: system that supports a system-of-interest during its life cycle stages but does not necessarily contribute directly to its function during operation. Each enabling system has a life cycle of its own.

Now *natural ecosystem*: this is a community of living and non-living entities and occurs freely in nature. Every component interacts together as a combined unit through physical, chemical, and biological processes. The discriminating factor of natural ecosystems from other ecosystems is that they are completely natural.

The first three definitions will be more or less familiar depending on whether you work in macro-ergonomics, design (especially of complex engineered systems) or operational performance and safety. An *ecosystem* is a specific type of system made up of the natural environment (geology, weather, etc), living things, and able to adapt to cope with a range of threats and opportunities.

AN ECOSYSTEM FOR MARITIME SMART TECHNOLOGIES

In the context of autonomous systems, the term "ecosystem" is being used to advertise AI providers in a geographical area (e.g. Gagne, 2018), the provision of maritime skills (see Chapter 6), and the system of systems required to realise maritime autonomy (Haikkola & Merenluoto, 2020).

We asked ourselves, why is this term being used? And let us assume that it is being used with meaning. If so, what other parts of ecological theory could be used to analyse these systems as if they were naturally occurring ecosystems?

This is an application of problem-solving using *reframing*, that is, generating an understanding of a problem or situation by exploring it using the language and concepts of a different domain of knowledge. In other words, smashing the introduction of advanced Information and Communication Technologies (ICT) together with environmental science to try to capture a picture of the future. Then asking *what's missing?* Because if we don't have the infrastructure to supply and sustain technology, there are multiple risks in using it.

WHAT DO ENTITIES DO OR CONTRIBUTE?

There will be many types of each entity in an ecosystem, individually and collectively performing a range of functions that contribute to the health of the system.

The first session of the project employed a range of individual and group techniques to list and describe as many of these entities as possible within a MSTE, and then to describe what they did with respect to new maritime digital technology.

This long list of entities was then analysed in terms of what each entity contributed. Different species/entities contribute different things to a smart technology ecosystem. For the maritime sector in general, we identified four species and their contribution as follows:

- *People* are *competent*.
- *Organisations* have *capability*.
- *Regulators* ensure *governance*.
- *Researchers* develop *knowledge*.

This is illustrated in Figure 9.1.

THE FUNCTIONS OF THE MARITIME SMART TECHNOLOGY ECOSYSTEM

These lists of entities, their generic roles, and their functional links were then assembled into a simple model of the *functions* and *cycles* in the maritime industry related to the acquisition and operation of digital technology. In other words, the functional part of a Maritime Smart Technology Ecosystem; how it should work as a system to acquire, employ, certify, operate, and evaluate the use of these technologies. This is shown in Figure 9.2.

In the second workshop, we reviewed this model and added the shading of the boxes and large arrows to reflect

- The degree to which functions of the system are performed at present,
- The degree of linking at present.

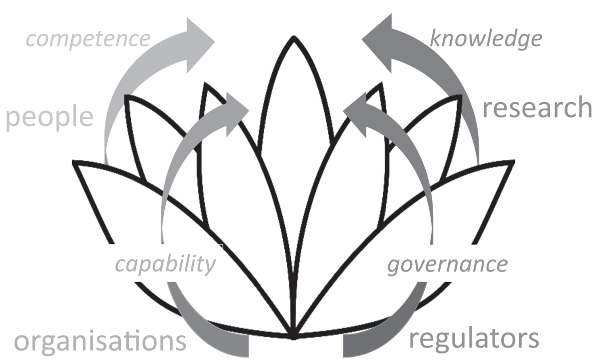

Figure 9.1 Contributions by each generic entity.

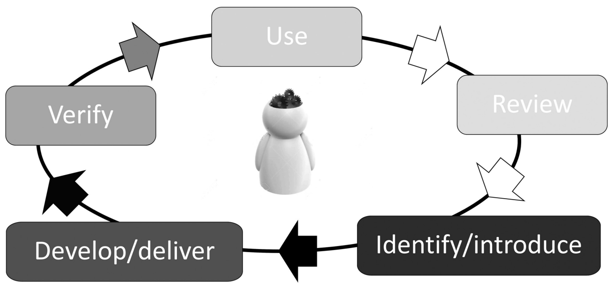

Figure 9.2 The MSTE functions performed by its entities.

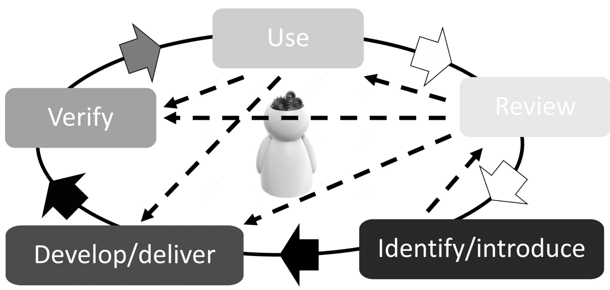

Figure 9.3 Feedback between functions.

What do we see? The density of shading represents the participants' agreement on the progressive reduction of achievement of each function and of feed-forward of information with a technology. Clearly, carrying out all functions before getting feedback is wasteful of time and resources and may be unsafe. Equally, not carrying out sufficient reviews is just as bad. The participants therefore identified additional feedback channels that should operate. These are shown in Figure 9.3.

Some of the progressive reduction in performance and linking of functions may be related to the length of time that the industry has been using advanced ICT (only 20–25 years), but it also relates to the degree of use of what has been introduced and the attention that is given to its success or failure.

ECOSYSTEMS HAVE MORE LINKS

The workshop participants agreed that the maritime sector and the organisations in it tend to acquire technology to fix a single problem without much thought about why they had that problem, whether there was a more systemic solution, or indeed whether the problem had been solved by the technology, and if and why the acquisition had failed to deliver. One participant summarised this behaviour as "*we believe in fairies*".

In a natural ecosystem, all entities are interlinked to some degree and in a wide range of ways. Between the functions of the MSTE, the primary exchange is of information. If there is no feed-forward of information, entities may not be getting any return on investment. If there is no feedback, decision-making is not informed to achieve a better fit of newly acquired technology and there is no guidance on what to do next in terms of the most useful acquisition.

The dashed arrows in Figure 9.3 reflect the links that the partners believed to be required for feedback in the system but are rare or not evident at present. When added, these links reveal an ecosystem that would be capable of a greater degree of control of the quality and value of smart technologies.

Ecosystems not only have links between entities, they also exist in and respond to their context. What is the context of the MSTE?

ENABLING SYSTEMS: THE CONTEXT OF THE ECOSYSTEM

The definition of a natural ecosystem includes contextual elements such as geology, weather, and risk. These arise from the operation of other, larger systems operating to different schedules and drivers.

In the second session, we also discussed and described these *enabling systems* to the functions of the maritime smart technologies ecosystem. Several of these systems may go beyond the maritime sector.

These enabling systems all exist and operate in the maritime industry, but the level to which they sustain the function of the smart technologies ecosystem is variable. We asked:

- How far and what is the impact?
- How will this change in the future?

AI/ML offers technologies from the software industry, it is and will remain largely separate from maritime.

The implementation and support of *Technology* is carried out by a range of companies with a range of sizes and with variable interest in and engagement with maritime.

Regulation in maritime is fragmented and unique in its structure.

Although buying, operating, and selling ships tends to be the focus of the *Operation* enabling system, this system also includes a wide range of shore and fixed assets and a complex, loosely coupled network of organisations.

Academia (comprising Education and Research) not only educates, it also generates feedback, particularly (from the ergonomics point of view) about the business, social, training, and cultural factors related to the successful adoption and use of smart technology.

What level of support does our ecosystem get from these enabling systems? What are their boundaries? Will they change as the use of, or even dependence on, smart technology increases? This will depend on communication between the enabling systems about smart technology in context. How it works, or does not, is essential if these enabling systems are to sustain the ecosystem.

So how is this communication achieved for MSTE? Yes, by the links across the centre of Figure 9.3. And perhaps this lack of integration of the enabling systems is another reason for the progressive lack of performance of the ecosystem's functions and, as a result, an increased risk of not achieving value from investment in smart technologies.

THREATS, OPPORTUNITIES, AND SPECIES

In the third session, the participants assessed the threats to, opportunities for, and entities in the ecosystem. Are there such things in this sort of system? What might they influence and how? Are there any key species for MSTE?

Threats and opportunities: Looking at the ecosystem as a whole and in context (MSTE and its enabling systems), what will harm it and what will help it? The imagination-enhancing natural ecosystem suggestions given to the participants included initiator/spark/trigger, nourishment/sustainment, host environment/context, and connections/interface.

Species: Looking at the ecosystem (MSTE), what elements do we see: introduced species (how are they fitting in), invasive species (are they taking over), key species (what is controlling)? The suggestions given to the participants included: are there such things in this sort of system? What might they influence and how?

Someone Else's Problem: The study also included looking for issues that were being ignored, but, if they are not addressed, will cause problems (Wikipedia, 2023). Looking at Figure 9.4, we asked the participants: Are there things that we are all assuming that someone else will do? What have we forgotten, or are making assumptions about? (This concern was the trigger for the study.)

The unfiltered, candid assertions and findings from this analysis are presented in the following sections. Because of the exploratory nature of the study, they are of the form of issues, questions, and observations rather than recommendations and conclusions.

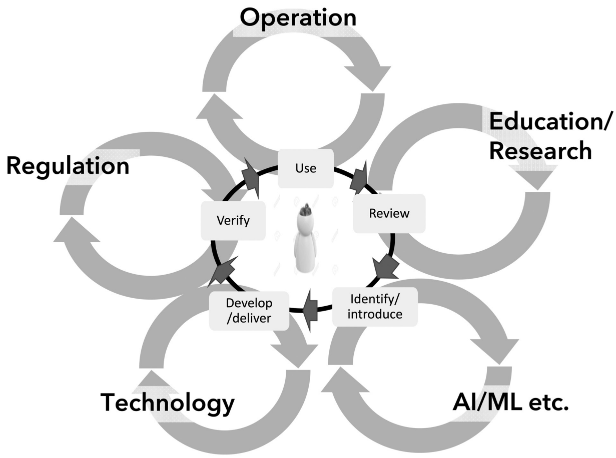

Figure 9.4 The enabling systems that support each function.

Autonomy so far

With regard to progress at the time of the study, one participant started the discussion with the assertion "*To be very frank; I do not see anything that might be defined as maritime AI*". The participants observed that most existing trials of autonomy are "small", in terms of either scale of application or size of the vessel. There was also agreement that there are opportunities for small, completely autonomous vessels; for example, port surveys, site scans, and hydrographic mapping. Some very small crafts (container/EuroCrate size) are already doing deliveries in Uber/Deliveroo style. The participants considered that this could be more of a change agent than the concept of Amazon running a shipping company. They noted that at this scale of service, there is not yet a need for port infrastructure.

Technology companies

The participants explored the effects of new technology companies engaging in maritime transport. They suspected that the real meaning of the Silicon Valley saying, *"move quickly and break things"* is just *"break it fast"*. They asked: If Amazon took over, would there be ship operators? Would the industry move to online 24/7? They pointed out that this is not completely in the future, already Google sells the most nautical charts (when all uses are considered), and the maritime industry already depends entirely on customised commercial technology from IT giants. But Silicon Valley organisations will only support a product for as long as it is interesting. This dynamic approach will change the marketing, support, and even the existence of the maritime sector.

AI and technology

The participants identified issues related to knowledge, interoperability, and independence. With regard to data, there are more issues than information, e.g. format, naming, meaning. There is no marine lexicon to facilitate communication and shared understanding. With regard to knowledge, who develops it, describes it, manages it? There is no standard for the elicitation, quality, or management of knowledge. Interoperability is not achieved, even in aviation (e.g. there are two communication systems). The participants raised concerns about how the maritime sector introduces new IT into old areas. Old IT systems were never intended to integrate. Another concern regarding independence is if a ship with full autonomy is cut off from the outside world it will need local support, how is this provided?

Trust

The participants identified issues related to data, integrity, and seafarer expectations. The industry is willing to use commercial technology, but is there sufficient system integrity to support this policy? Without sufficient trust in the integrity of equipment and systems, they may never be switched on or may not be used and the ship will carry two supernumerary engineers. With respect to trust and data sharing, trust is needed for information to be shared and decisions made. One participant reported a trial of digitalised supply chain data. This concluded that it can be done technically, but fundamentally trust was missing. The participants also discussed industry trust in seafarers. They concluded that it could be seen at best as schizoid (i.e., happy to delegate, then to blame).

Systems

The participants identified issues related to systems of systems, systems extending beyond the ship, including people in systems development and soft systems. The maritime industry is a complex system, not an anomalous blob. The participants advised that we need to think about ship systems with complex interlinking rather than whole, integrated, autonomous ships. Establishing feedback loops will be painful. Referring back to the definitions at the start of this chapter, is “system” more than a technical system? Is it a work system? Or a system of systems with some of the systems being procedural? Or are we looking at layers of systems with the higher and enabling systems being mostly soft systems? When we talk about technology, perhaps we should include the behavioural sciences as well as hardware sciences or quantitative sciences? And even to extend to management science in order to address governance and organisational effects?

Compliance

The participants identified issues related to the drivers for compliance and regionalisation. The belief is that regulation is so far behind the technology that it might as well not exist. This leads to the belief that there is nothing out there to say you can't do whatever you want to do with an autonomous vessel right now (at least in national waters or under bilateral agreements). Areas that will drive compliance start with pilotage, remote operation, and remote control. What are the drivers against compliance? The industry assumes that trade will be uninterrupted and international. What if every nation looks after itself? Such divergence has an impact on training; and it is possible that IMO (and marine lawyers) will lose the job.

Change

The participants identified issues related to where to start, areas of resistance, and barriers to change. Is resistance to change a belief rather than a fact? Operators buy technology to fix single issues (the believing in fairies mentioned earlier). We need to have a mature conversation about what didn't work before we roll out smart technology. Where is the best place for this to happen? There is more experience with new IT in offices than on ships. Adaptation to the technology is a bit slow. There will be a different pace and different drivers for each individual ship/owner and fleet/sector.

With regard to the aforementioned believing in fairies, this is not a joke. Hope is everywhere: hope that it integrates, hope that the product works as advertised, hope that it makes everything alright, hope that what you bought is compliant, hope that Class can be persuaded to approve, hope that the manufacturer keeps on supporting it.

Speed of change

The participants identified issues related to legacy, life cycle, and fast regulation. With regard to legacy and legacy hangover, ships are built for a long life of 30 years. This limits the rate of introduction of technology. With regard to obsolescence, a new version of an operating system or application may make a system unusable. "Introduction surprise" is a common problem for technology and its regulation, for example, Voyage Data Recorder (VDR), Automatic Identification System (AIS). The participants questioned whether the industry not getting real regulations for MASS before 2035 is a fact or a desire? Instead, we might see bad local regulation, "soft law", or another control (like P&I club premiums) really fast.

Education

The participants advised that education should be proactive based on future needs. If you are not giving people the skills and the knowledge they need, you are just as liable as they are for something going wrong. The gap between what seafarers do know and what they need to know is enormous; it gets to the point where people cannot keep up. Maritime colleges benefit from a fixed curriculum, ever-extending course length, and academic job titles, but do we actually need graduate seafarers? As STCW is currently configured, it is not serving us today, let alone in the future. How are we training (and assessing) our instructors?

Training

The participants identified issues related to investment and being competitive. Owners are extremely reluctant to invest in the "human capital". How will it be in the future? Encouraging smart technologies and then monopolising necessary education and training is a way that certain companies can control the industry. Operators may use the education of their crew from a marketing perspective (because there is no regulation) for two reasons:

1. To make it look good to their customers.
2. They want to push this in a regulatory framework so that it raises the barriers to entry for any other competitor.

Necessary skills

The participants identified issues related to where and when? In other words, knowledge management. The traditional model is that we have the competence available, and seafarers can manage. This study questions this belief. What is the impact of the technology ecosystem being leaky and connected to the rest of the world? Can the maritime industry acquire the necessary skills when needed from a general pool instead of putting everything that's needed in the head of an individual Mariner, trusting that they apply it the right way at the right time? This is more about knowledge management than about education. Maybe we need some more people in the system.

WHAT DOES IT MEAN FOR US?

The potentially significant changes to the maritime sector can be summarised as follows:

1. Industry-wide rethinking of where and when knowledge will be needed and how it is best provided.
2. Different rates of application between large, deep-sea and regional/national, small, and short-sea shipping.
3. The possibility of regional standards for information, or even for ship operation.

4. The potential for fast, industry-led regulation from flags that are advanced in applying a technology.
5. Establishing and sustaining a healthy MSTE requires the maritime sector to pay a lot more attention to closing the loop (i.e., collecting feedback, analysing it, and sharing the findings).
6. Doing this in a formal manner requires the maritime educational system to take a more proactive role and to increase the breadth and depth of its research.

Issues/actions for ergonomics are as follows:

1. *Ergonomics is a systems discipline*: As illustrated by the definitions at the beginning of the chapter, ergonomists are taught to think in terms of systems.
2. *A role in feedback on smart technologies*: Study participants repeatedly pointed out that the problems with smart technologies are and will be in relation to seafarers.
3. *Identifying and reporting human–system issues*: It is a key part of the research/education function.
4. *User needs for, or usability of (and trust in), new technology*: Eliciting user needs, assessing usability of (and nowadays ensuring trust in) solutions is the main job of many ergonomists.
5. *Knowledge acquisition and management*: The skills necessary for the elicitation of knowledge and meaning utilise the core skills of ergonomics.
6. *Change management*: This is much better if carried out with proper regard to sociotechnical issues.
7. The report of the IMO MASS regulatory impact study (IMO, 2021) emphasises the need to address the Human Element in the regulation of smart ships.
8. If there is to be a new relationship between seafarers and ship systems, what are the relevant skills, proactive education, and effective training?

Ergonomics should contribute to all aspects of the changes necessary to redefine the relationship between seafarers and the industry, that is, to identify the skills that humans can develop, to recommend the qualifications that contribute to society's requirements from the maritime sector, and effective continuing professional development.

NOTE

1. Source of definitions: system, system-of-interest, enabling system ISO/IEC 15288:2015; work system ISO 6385:2016; ecosystem National Geographic (2023). See also Wikipedia on digital ecosystem. In the work described here we explored the full affordances of the original concept of natural/biological ecosystem (Tansley, 1935).

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Chapter 10

Maritime autonomy fit for people

Jonathan Earthy

HOW WILL WE MAKE MARITIME AUTONOMY THAT IS FIT FOR PEOPLE?

So far, this book has reported an investigation of the potential for, barriers to, and timeline of complex computer-based systems that utilise artificial intelligence (AI) and machine learning (ML) to be safely left to work alone for extended periods. Consideration of the technical requirements revealed a need to understand the legal and regulatory requirements and this in turn revealed a need to consider the changes to jobs and competence within the maritime sector. This succession of considerations reveals the main finding. That, for many reasons, people will still be required even if these technologies are adopted. The reasons identified include legal and regulatory responsibility, flexibility, adaptability, situational awareness, resilience, emergency response, security, and the need to develop, retain, maintain, and apply knowledge about operating ships and the broader maritime and marine context. The study of the broader context (of the maritime smart technology ecosystem) added social, governance, and political factors, and the pandemic highlighted social well-being issues. These broader issues address aspects of shipping for which it is not easy to see autonomous technology as the solution.

This chapter changes the perspective and describes how AI and ML can be developed to facilitate the lives of people working in the maritime sector and how these technologies can assist them in meeting the demands of the present and future maritime working environment. In other words, how to make attractive, new, nice, well-designed job(s) for people working in the maritime domain.

A HUMAN PERSPECTIVE

Completing the picture: social and environmental drivers

Shipping moves most goods and services around the world and is the most flexible and adaptable means of transporting goods in bulk. As such it is

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intimately linked to and deeply affected by political, financial, social, and environmental changes in the world. Big problems for society are inevitably challenges for people in the maritime sector, but even more so for the application of AI and ML. These include the following:

1. *The "green shift"*: The need to reduce load on the world's environmental systems and to cope with any changes that have already happened by changing technology, energy source, and use and operational characteristics whilst at the same time operating in more extreme weather. This needs access to information in a form that supports decision-making and planning, monitoring, and visualisation of many changing parameters.
2. *Social well-being:* The maritime sector as a global employer, not only of crew on large ships but also in port, shipbuilding and manufacturing, fishing, and increasingly mining, energy, and farming. This needs community-building and integration and information-sharing using social media, risk awareness, sharing solutions, information routing, etc. to change the world view of the sea and work on it.
3. *Deskilling:* Ensuring a supply of motivated people with the required mental and physical abilities to allow the sector to function to the required level of capability and to be able to retain valued knowledge and experience. This needs work that is rewarding, demonstration of respect and value, positive user experiences, job design, knowledge management, feedback, and response.
4. *Managerialism:* Belief in and reliance on the use of management systems and objectives. This means that people other than the crew, for example, managers, programmers/developers, and new companies, will be the humans making the decisions. And they will usually be remote from the ship in both space and time. This will affect safety and regulatory systems. There is potential for disruptive application of processes that are effective in other sectors. When the real world is more variable than expected, it has been easier to report incorrect data than to revise the objectives. (Sampson, Turgo, Acejo, Ellis & Tang 2019)). As digitalisation increases, the sector needs to understand that "garbage in/garbage out" applies to machine learning. The use of AI and ML requires transparency and clarity, possibly to the benefit of seafarers.
5. *Needs-based transport:* If the trend of more extreme environmental and political activities continues, shipping will be required to respond to existential threats; for example, supplying food to avoid involuntary migration. Ships, ship systems, and their operation will need to be flexible and adaptable to meet these challenges. This needs flexibility and judgement in management beyond the limited ethical capabilities of AI. Less severe changes to maritime transport include onshoring and resulting potential trade (local trade, reduced import and export, change in trade patterns, impact on the type of ship, etc.), regulatory changes (potential shift to local), etc.

The ergonomics vision for maritime automation

The applications of AI/ML described in the previous chapters all relate (unsurprisingly) to control. Computer technology was introduced into defence, the process industries, and transport with the aim of enhancing human abilities to control. The following section on the human-centred perspective elaborates on the theory and philosophy. Unfortunately, the maritime sector rarely follows this approach. One visit to a ship control centre/bridge[1] (and to a greater extent the engine control room) is enough to identify inadequate consideration of how watchkeepers are expected to monitor or control the ship, let alone cope with the flood of information presented in an emergency. Now, in the promotion of autonomous technology, the first preference has been for replacing humans. However, the finding from the HUMANE workshops is that partnering humans with the technology, using each to augment the capabilities of the other, is seen as the best way forward. The brief review of the impending changes faced by the industry provided above suggests that this augmentation or teaming will also be needed at a pan-industry level. The question is how to do it.

Put simply, new, nice, well-designed computer-augmented jobs for people working in the maritime domain are essential to address the drivers and business needs. The rest of this chapter elaborates on how this can be achieved using a *human-centred approach*.

Enabling not driving

Thinking in this way (addressing societal and existential issues), we see that AI and ML are *enabling*, not driving, technologies, the same as communications, computers, etc. They allow the maritime industry to address the needs for responsible change described in the workshops and the drivers listed above by enhancing human and hence organisational capability. This perspective in turn has an effect on system design and the definition of success. The imperative shifts from single projects using technology wherever it might be possible (and hence needing a business case based on a specific demonstrable change like a manning reduction or the number of trucks taken off the road) to a tool for organisational knowledge management to enhance process quality, sustainability, agility, and, of course, safety.

THE HUMAN ELEMENT ISSUES TO ADDRESS

In relation to the application of AI/ML technology, or work systems developed using this technology, addressing human element issues is achieved and sustained by considering the social and technical issues associated with achieving the business goals. This is the responsibility of all stakeholders, it is not someone else's problem (principle a, IMO, 2004). There are two fundamental questions that designers need to ask. These questions are a summary of the good practice in job design and ergonomics (as described in the remainder of this chapter) as applied to ship operations:

What makes it a nice job?

1. Being provided with a working environment that is comfortable and safe and with user interaction that is effective, efficient, and satisfying, and gives a positive user experience (an example is the OpenBridge user interface (Nordby, Gernez & Mallam, 2019).
2. Feeling that your job has been designed to be achievable but challenging enough to be rewarding.
3. Feeling in control while doing all tasks.
4. Having the right information and equipment to complete tasks safely.
5. Not feeling undue time pressure but not being bored.
6. Opportunity to learn about new technologies on the job.
7. Chances to apply skills and learn new skills.
8. Knowing that skills that are occasionally required are available.
9. Knowing that your employer knows about and values these skills.
10. Knowing that sufficient competent people will be available to deal with all foreseeable circumstances and how long this can be sustained.
11. Procedures, systems, and working practices that check for and prevent errors and mitigate serious consequences if they do still occur.
12. A working location (or place to work) that you can get to even if your family or physical circumstances change (e.g., ship or shore).
13. Colleagues and technology (e.g., communications, cobot, or intelligent agent) that support you in your work and assist with situational awareness and decision-making.
14. Job and tasks that adapt to changes in workload.
15. Knowing that alternative designs or arrangements for providing information or executing commands are equivalently safe and usable.
16. Knowing that all ships with a high degree of autonomy will behave in an understandable and safe manner.
17. Being able to trust the computer systems that provide you with information and execute your commands.

How to make it a nice job?

1. Use technology to reduce or remove the need for watchkeeping when it is safe to do so.
2. Apply guidance on physical and cognitive ergonomics to the design of control centres, control stations, and user interfaces.
3. Design autonomous and highly automated systems in such a way that their behaviour can be understood and predicted by seafarers.

4. Design advisory and autonomous systems to provide on-demand explanations of their decisions or have behaviours that are understandable by seafarers and other stakeholders.
5. Identify and address the problems that seafarers may have in accessing, understanding, or using new technology. Permanent solutions such as redesign of systems or arrangements should be preferred to person-by-person solutions such as training.
6. Consider the job to be done. Do the tasks and responsibilities form a clear and meaningful set? Evaluate the job with representative seafarers.
7. Document and analyse the context of use of each system that will be used for user needs and implementation issues.
8. Analyse the tasks identified in the context of use for activities that will be repetitive, boring, or that will require long periods of attention and automate these activities.
9. Analyse the context of use for dangerous or unpleasant activities and discuss automating these tasks.
10. Analyse the critical and control tasks required of the user and design these to be carried out in the most efficient and effective manner. Set targets for the usability of the system whilst performing these tasks.
11. Evaluate prototypes and the complete system with representative users in the intended context of use.
12. Consider the user's experience of the system in the context of their job. Does it support meaningful work and demonstrate to seafarers that their contribution to performance and safety is valued?
13. Follow a human-centred approach to design.

ADDRESSING HUMAN ELEMENT ISSUES (THE ISO WAY)

The human-centred perspective

This section summarises the human-centred perspective that is taken by ISO TC159/SC4, the steering committee for human–system interaction. This was defined by its founder, Paul Branton, as described in (Oborne et al. 1993) and is adapted from Part 1 of that text.

Why do we need people in (control) systems/environments? The human-centred approach holds that one of the primary features that a person brings to the system is a sense of purpose and action. When the purpose (the goal) is understood, it is possible to begin to design a system to facilitate it. Only by understanding the person who is the operator will we begin to understand a man-made system (such as a ship or maritime transport), and when we understand the person's variabilities, we will be in a better position to adapt the system to accommodate and even to make best use of them. And when we can do this, we should be better placed to design the system for maximum efficiency, effectiveness, user satisfaction, and safety.

An effect of this human-centred concept is that humans in a system turn it from being a closed-loop to an open-loop system in which the deviation corrections are made by the operator based on their *mental model* of the system and its operation. Rather than concentrating on ways of improving the information flow between components within the system (at least the components which take account of the human operator), *human-centred ergonomics* takes as its central point the need to accommodate the human attributes which the person brings to the system. The emphasis is on accentuating the positive and reducing the negative effects of a person's interactions.

This perspective is important with respect to how ergonomics should be considered, especially the point at which an ergonomics intervention is made and how it is made. To take a simple example, the design of controls for safe and efficient operation. Traditional ergonomics argues that the control design should be made from the viewpoint of the machine's requirements as they impinge on the operator's wishes and abilities. The operator's abilities are recognised as important, but from the traditional viewpoint it is the system which defines the interaction and thus the design. The human-centred approach is one in which the operator and their abilities define the working system. From a *human-centred perspective*, design should be for the operator. They are the component which is designed to activate the system and to maintain its efficient running. The goal is to create supportive dynamic environments which enable people to work at their most safe and effective levels, not just to design the environment to "fit" the person in some static sense.[2]

The human-centred approach represents a major shift in the way in which ergonomists and hence designers view the role of the operator within the working situation. It supports people's ability to learn and compensate for their biological (and other) "weaknesses". The ergonomist's task is to design a supportive enough environment to facilitate such compensating behaviour. Designers therefore need to

1. consider the complete person as argued above (traditional ergonomics rarely does),
2. consider purposes rather than causes of actions (a purposive explanation of an event—in terms of anticipation and decision-making—is likely to be more illuminating than a deterministic, causal one—which will be couched in terms of events which have already occurred), and
3. understand the philosophical bases upon which a person's behaviour within the system rests; how they conceptualise the system and its functions.

In summary, "Design from the Human Out". The human being is at the centre of the working situation, and we must understand the abilities, responsibilities, and requirements which people bring to the situation (not just their shortcomings) in order to be able to deal adequately with the system:

1. Human-centred design (HCD) is from the viewpoint of the human being within the system rather than the system's requirements.
2. In doing so, the whole person must be considered. This includes a person's view of the system, its purpose and responsibility within the system, and the dynamic nature of the interaction. In particular, the thought processes of people need to be studied as well as the traditionally observable behaviours, and full cognizance must be taken of the values of people within the system.
3. The values that humans bring to a working system are that they are purposive, information-seeking, uncertainty-reducing, and responsible.

The human-centred approach for autonomous systems

There are standards on ergonomics and human factors which can be used in selecting, designing, and managing systems and equipment to ensure that they are effective, efficient, and satisfying to use. These are outlined below.

This section is adapted from ISO/TR 9241-810:2020 *Ergonomics of human–system interaction — Part 810: Robotic, intelligent and autonomous systems* explanations of how standards from SC4 implement the human-centred approach for autonomous systems.

Human-centred organisation

ISO 27500:2016 *The human-centred organization — Rationale and general principles* presents the rationale and general principles of human-centredness in a concise form for executive board members and policymakers. It explains the principles which characterise a human-centred organisation. These principles are as follows:

1. Capitalise on personal differences as an organisational strength.
2. Make usability and accessibility strategic business objectives.
3. Adopt a total system approach.
4. Ensure health, safety, and well-being are business priorities.
5. Value employees and create a meaningful work environment.
6. Be open and trustworthy.
7. Act in socially responsible ways.

They provide a framework for organisational behaviour when robotic, intelligent, autonomous (RIA) systems are considered or implemented.

ISO 27501:2019 *The human-centred organization — Guidance for managers* outlines the responsibilities of managers in supporting a human-centred organisation, in fulfilling each of the seven principles with reference to internal, external, and societal stakeholders.

Human-centred design

HCD is an approach to interactive systems development. By applying human factors/ergonomics, and usability knowledge and techniques, HCD aims to make systems usable and useful by focusing on the users' needs and requirements. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility, and sustainability; and counteracts possible adverse effects of use on human health, safety, and performance.

ISO 9241-210:2019 *Ergonomics of human–system interaction — Part 210: Human-centred design for interactive systems* provides requirements and recommendations for HCD principles and activities throughout the life cycle of computer-based interactive systems. It is intended to be used by those managing design processes. It is concerned with ways in which both hardware and software components of interactive systems can enhance human–system interaction. The approach described complements existing systems design approaches. It can be incorporated in approaches as diverse as object-oriented design, and waterfall, agile, and other rapid application development processes.

The principles and activities of a human-centred approach to design are elaborated in two HCD process models. ISO 9241-220:2019 *Ergonomics of human–system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organizations* describes the processes that ensure human-centred quality of interactive systems. ISO/TS 18152:2010 *Ergonomics of human–system interaction — Specification for the process assessment of human–system issues* describes the processes that address human–system issues in the engineering of systems. The processes in these standards go a lot further than the current norm in HCD practice (i.e., specifying processes to support HCD in governance and project management, saying that HCD people get involved early, defining the user requirements, and then driving the system/technical/platform-level requirements) and will apply to RIA systems as much as to other types of system and any set of human–system issues. ISO 9241-220:2019, Annex F, provides guidance on risk management and HCD.

Workspace and workload

ISO 6385:2016 *Ergonomics principles in the design of work systems*, ISO 9241-2:1992 *Ergonomic requirements for [office] work with visual display terminals (VDTs) — Part 2: Guidance on task requirements* and the ISO 10075 *Ergonomic principles related to mental workload* three-part series provide ergonomic principles for the design of tasks, work, and work systems. They encourage attention to human, social, and technical requirements in a balanced manner during the design process.

The systems approach in these standards assists in both existing and new situations, such as the introduction of an RIA system. Ergonomic evaluations of existing or new work systems will show the need for, and encourage attention to, tasks, goals, and responsibilities and the job and workload of the worker with/within those systems.

"Work system" covers a large variety of working and leisure situations, including permanent and flexible workplaces. Work systems involve combinations of people and equipment, within a given space and environment, and the interactions between these components within an organisation. Work systems vary in complexity and characteristics.

The principles specified in these standards support the design of optimal working conditions with regard to job performance, workload, human well-being, safety, and health. This includes the development of existing skills and the acquisition of new ones, while taking into account technological and economic effectiveness and efficiency.

Technological, economic, organisational, and human factors affect task performance, behaviour, and well-being of people as part of a work system. Applying ergonomic knowledge in the light of practical experience in the design of a work system is intended to satisfy human requirements consideration of workload and its measurement.

Context and environment

ISO 9241-11:2018 *Ergonomics of human–system interaction — Part 11: Usability: Definitions and concepts* provides a framework for understanding the concept of usability and applying it to situations where people experience or use interactive systems (including RIA systems), and other types of systems (including built environments), and products (including industrial and consumer products) and services (including technical and personal services). Usability is a scalable, task-based measure of the degree to which users are enabled to achieve goals effectively, efficiently, and with satisfaction, taking account of the context of use. ISO 9241-11 explains how usability can be interpreted in terms of human performance and satisfaction. It emphasises that usability is dependent on the context of use (the specific circumstances in which a system, product, or service is experienced or used).

Control and control centres present an early and widespread application of RIA systems. The overall strategy for dealing with user requirements in control centres is presented in ISO 11064-1:2000 *Ergonomic design of control centres — Part 1: Principles for the design of control centres*. ISO 11064-2:2000 *Ergonomic design of control centres — Part 2: Principles for the arrangement of control suites* provides guidance on the design and planning of the control room in relation to its supporting areas. Requirements for the layout of the control room are covered by ISO 11064-3:1999 *Ergonomic design of control centres — Part 3: Control room layout*. Ergonomic requirements, recommendations, and guidelines for the design of workplaces in control centres are established in ISO 11064-4:2013 *Ergonomic design of control centres — Part 4: Layout and dimensions of workstations*. Displays and controls, human–computer interaction, and the physical working environment are presented in ISO 11064-5:2008 *Ergonomic design of control centres — Part 5: Displays and controls* and ISO 11064-6:2005 *Ergonomic design of control centres — Part 6: Environmental requirements for control centres*. Evaluation principles are dealt with in ISO 11064-7:2006 *Ergonomic design of control centres — Part 7: Principles for the evaluation of control centres*.

ISO sets standards for modelling, measuring, and assessing the impact of properties of the physical and thermal environment. As RIA systems increase, their presence in environments, especially when controlling dynamic integrated environments, personal capability, comfort, and safety, will increasingly depend on machine application of these standards and correct interpretation of the integrated effect of environmental factors.

AND SAFETY

The safety set for a MASS

ISO TR 9241-810 asks

> *RIA systems can introduce new safety issues. For example, something that temporally is too fast for humans to address in real-time, or something that is otherwise not directly observable such as online activity. Latency, the time that humans have to take over from an RIA system that detects that it has lost control, is another factor. Or, at a societal level, there is the 'Frankenstein issue': the systemic consequences when the inventor (human or humanity as a whole) does not take timely responsibility for a created entity. Safeguards are necessary, but what form should they take and what part does ergonomics play?*

TR 9241-810 explains the concept of a safety set as a fundamental set of normal/expected human behaviours in context, for example, a robot at the edge state of physical engagement with a human body. These may be phrased as safety requirements (i.e., "*the system shall do this ... under these circumstances*") or as principles for the preparation of safety cases.

The safety set for a particular system or context relates to expectations, norms, ethics, and laws and regulations. The user–system relationship approach (as presented in Table 1 of 9241-810) is likely to influence both safe action and construction of safety/harm. Different safety sets can be required for different cultures. Consideration should be given to the broadest application of measurement of human-centred quality as a basis of assessment. This includes avoidance of harm, which is a human-centred treatment of safety and other types of harm (both to and from humans). ISO 9241-220, ISO/IEC 25063:2014 *Systems and software engineering — Systems and software product Quality Requirements and Evaluation (SQuaRE) — Common Industry Format (CIF) for usability: Context of use description* and ISO 25065:2019 *Systems and software engineering — Software product Quality Requirements and Evaluation (SQuaRE) — Common Industry Format (CIF) for Usability: User requirements specification* contain supporting material on human-centred quality, context, and user requirements, respectively. ISO 9241-220:2019, E.5, contains examples of harm from use.

Safety behaviours for a MASS

Based on existing maritime requirements, Schneiderman's framework Human Centred Artificial Intelligence (Shneiderman, 2020), and the HUMANE generalised handover model, we propose a set of safety behaviour principles for MASS (Maritime Autonomous Surface Ship or Maritime Autonomous Ship System):

For each of the following principles a MASS shall

- 1a Be identifiable as under the control of an artificial intelligence, or
- 1b be identifiable as under remote control.
- 2 Act in a manner that is understandable by seafarers on their own ship and seafarers on other ships and shore services (e.g., pilot, VTS, owner).
- 3 Communicate its status and capability to crew on their own ship and other ships and shore services.
- 4 Be able to explain its intention.
- 5 Be able to explain its course of action.
- 6 Recognise when it requires assistance.
- 7 Request assistance.
- 8 Place itself in a state in which it does not present a hazard to the environment, other shipping, fixed structures, or those rendering assistance.
- 9 Whilst in a safe state allow authorised personnel to operate the (systems/functions) necessary to restore, replace, or supplement lacking capability (defect, failure, events that are not reasonably foreseeable).

10 Render assistance to other ships and persons in distress.
11 Transfer control to authorised personnel on request.
12 Protect itself from unauthorised access.
13 Be sufficiently dependable to fulfil its intended purpose.

All behaviours are to be demonstrated under all circumstances. This means that in many cases or systems states (such as failure), the required behaviour will change to address the context and capability of the system in that case or state. Departures from specified behaviours are to be justified.

Each behaviour can be elaborated in terms of what it means, how it can be assessed, and the design required to meet it. This set of behaviours provides the Human Element approval criteria for evidence of risk-based design or an assurance case for an autonomous ship or system submitted to a regulatory authority.

NOTES

1. Despite the work in IMO and IEC to standardise navigation interfaces and alert management.
2. In human-centred design, the user is seen as self-controlled, necessarily possessing value standards and interests in social relations, perpetually seeking and evaluating information from the surroundings. The search varies in intensity, depending on level of motivation. Design considerations include the form of mental operations, their contents being material taken either immediately from the surrounding world, or from stored, primarily emotive, experiences. The explanation is purposive, rather than causal, as it is argued that the thoughts which determine behaviour are forecasts of future states of affairs and their consequences for the person, rather than past experiences that are in themselves of speculative origin.

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Chapter 11

An ethnographic perspective of autonomy

James M. Nyce

These project transcripts are essentially an extended discussion of some key issues and concepts like automation, autonomy, and professionalism (especially the interrelationship between the last two) as they play out in thinking about the maritime industry's future. Some attempts will be made here to unpack these discussions and pull out some issues that may not have received the attention they deserve.

A key value in the industry is autonomy which, along with a number of related terms, is often taken to be synonymous with flexibility and adaptability. Consequently, much of the transcript discussions centres on how to, whether participants speak directly to the issue or not, preserve, extend, and/or safeguard practitioner autonomy. This is because autonomy is what these professionals see as central to (and necessary for) their jobs on board ship. It is not clear, and this is a research question that needs to be taken up, how much of what practitioners understand as autonomous (machine) systems is derived from their notion of professional, human autonomy. The participants' attempt to defend, even extend, this autonomy in the face of "encroaching" technology is not some Luddite exercise but a response to ensure safe, efficient maritime operations as practitioners understand these terms. This is key to what professionalism means in this industry – the autonomy, freedom, and competence to choose the right course of action given the circumstances. It also needs to be mentioned that this sense of autonomy is inculcated in their training, education, and professional socialization and further confirmed by mariners every day in their daily work.

What complicates and at times conflicts with this notion of autonomy, especially in hierarchical workplaces like those onboard, is the question of who is in charge. In other words, there are many times at sea when autonomy and authority are not fixed and have to be decided and "worked out" minute by minute, context by context. As one informant said:

S.2.3 I think that is a really important point, there are many layers to that, [about] and who wants to be in charge and who should be in charge.

The resistance to crew reduction (their piece-by-piece replacement by various forms of automation) can be seen as representing the first step to chip away at what autonomy and professionalism exist onboard. The return

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again and again in the transcripts to the inevitability of crew reduction also masks some issues that have long underlay (and perplexed) automation debates. Perhaps the most central of these is related to power, and how and who will make these reductions? Related questions, which are also picked up on the transcripts, are as follows: How and who will make the decisions that define the qualifications for the “new” mariner? And what will all this have to do with the redefinition of professionalism that informants believe needs to accompany the next revolution in the maritime industry – unmanned (or less manned) shipping?

The issues of who will determine who is qualified and how, under the new unmanned regime, return us to the issue of power but at another level: Who will determine the rules of this (new) game and how will this new commitment to unmanned ships be played out? We do in short need to mine these transcripts and discussions of crew reduction to answer the question what’s really going on here?

One thing to consider here is whether this turn to unmanned ships is really a kind of zero-sum game. Or one in which someone holds all the cards? Or both? We ask this because it seems that these discussions of automation assume that the duties and competencies to be “automated” are fixed by today’s horizons and definitions. In other words, the scope and autonomy of human operations onboard will not expand regardless of how in the future automation onboard will play out. In short, if one “side” wins somehow, the other side necessarily loses: Are these losses of the kind one does not recover from in an industry on its way to the future? Analytically, the discussion participants seem to confuse (or vacillate) between seeing maritime automation as a zero-sum game and at times as the only game in town. Further, this obscures the role that those sitting around the table can have in determining what will happen next (and who defines the game itself). Nowhere is this clearer in the transcripts than when the idea is phrased in terms of parent–child responsibility.

S2.1 I have a thought about your discussion about who is the parent and who is the child. And that kind of discussion actually stems from a dualistic view about humans and technologies.

If we take this discussion apart, we find that these discussions about parent–child are not just about the optimal division of labour between man and machine. It also reflects a belief that these participants have little power to change the agenda (much like children everywhere) even when they are sitting there debating these issues. Nevertheless, the reality is that power and choice regarding these automation paths will be exercised by those who are not necessarily in the room (the adults, in other words). In fact, this acknowledged but still contested fact informs many of these discussions. One result of this is the future of maritime is often portrayed as more like a stacked deck than anything else. This in turn helps confirm the idea that many of the informants had that the future automation path is preordained by other persons and forces than these players themselves. This helps give the discussions a sense of being a kind of zero-sum game. This means that these future developments in the industry may still be decided in some less than democratic fashion no matter how much lip service is given to the ideas like participation, engagement, and dialogue in the industry's transition to the future. In short, while the rules of the game may change from time to time, these structural inequalities will persist.

One result is that it seems that we are left operating with a commonplace, rather naive, understanding of automation in which a direct replacement of (one?) man (behaviour/function) per machine or system must be planned for and is seen as almost inevitable. This led to many discussions in the transcripts about splitting off (and prioritizing) machine and human capabilities given the task at hand. Addressing the issue like this is however actually a variant on the zero-sum game already in play. In short, the end result in these discussions is to alternate between giving either the machine or the individual "too much" initiative, responsibility or autonomy. This led to some dystopian talk about machine (and often on shore) control. It also led to some discussions about enhancing human (biological) potential. Here we find the discussion centring on building some superman or girl, as one participant put it. Or as another said: "we all have to be [come] MacGyvers on board" (Humane WS1) in order to handle the qualitative and quantitative uptick of work on board that this picture of the future assumes. However, what underlies this discussion is more Faust than Frankenstein in that these human "upgrades" seem to be a kind of shorthand for preserving, even extending, human capability and autonomy in the face of forces (machine, economic) which threaten this autonomy. Even so, the issue of what future mariners should be like cannot be decided like this by discussions of what is necessary to be well-trained or multiskilled or both. It is as if we have put the cart before the horse when we start talking about training and skills without making any commitment about which (future) competencies are necessary and why. Here is an example from the transcripts:

M2 … If someone is appropriately trained, they have the necessary skills to adapt, to learn, new specifics. So if you understand the principles of navigation, anyone can hand you a navigation box of tricks and you can figure out how it works.

Now what is assumed here (a commonly held belief) is that it is reasonably safe to try to extrapolate tomorrow's work elements from today's and that there is some kind of fundamental logic to work which will remain the same over time (even if the nature of the work itself changes). Further, it is assumed the facts about this can be (1) easily retrieved and (2) taught successfully to novices. In a way, this is just one more variant on the cart before the horse problem sketched out above. But what it also does is minimize the discontinuities which often accompany all kinds of (future) organizational and labour change. In short, this reduces the need for any discussion of what in the future the endpoints regarding education and training might need to be. The transcripts do show some room is left to negotiate what constitutes man–machine work and responsibilities and especially which human functions can or should be replaced onboard. But before we go on, it is necessary, as a baseline, to spell out what in these discussions was the standard (and seldom challenged) definition of automation. Automation here is a belief that individuals (the sum of their parts, or individual by individual, or part(function) by part) can be reproduced *directly* by machine. However, while these discussions often revolve around this issue, there is a tendency to reduce the question to its lowest common denominator, that is: when can human competencies be directly and instrumentally translated into a machine? Still, everyone agreed that it came to such man–machine interactions the one thing almost impossible to translate was trust – one of the key markers of professionalism in this industry. Here's how this issue was talked about at one point in the discussion.

S1.5 How it will affect the trust from a human perspective that if I'm speaking to a machine in Urdu and the machine is replying in trans[lation]? But if it speaks the same language, then perhaps it's not in fact right.

First note (below) that this issue of trust is acknowledged by the participants, that it is problematic, and that it needs to be addressed directly. Second note that trust here is equated with linguistic or cultural competence.

S1. But I think that we're already seeing this occur though, because who uses call centres for whatever function? Do you know where your call centres are? Ours are in Mexico, of all places, so they tend to … so we've got all these Indian dudes sitting in Mexico speaking in English and Urdu and other languages to people all over the world. It's very confusing because they're sort of like multicultural. I think it's bizarre. Yeah, I agree in principle.

Note by the end this speaker acknowledges that the problem of trust may be more refractory than he first thought it to be. However, the idea that trust is not just related to performance but to professionalism appears very seldom directly in the transcripts. It is as if this is such a commonly held assumption that it does not need to be discussed further. When it is though … it is often only in reference to whether machine operations, no matter how advanced, can ever be fully trusted.

S2.4/M3 And how do they trust the system when they switch between these levels? So do you trust the systems? Because you need to trust the systems if you are handing it over to automation.

S3.5 Well today they mostly don't, today they mostly don't, they are … yeah.

S2.2 But they push the buttons anyway.

S3.5 They push the buttons but yeah, when they have an auto function, it is mostly off. The reason is mostly lack of training because we all talk about what skills they have.

To ascribe this scepticism about auto functions due to only a lack of (proper) training, as this participant does, seems to miss a more important point. The reason auto functions are not used (are mostly left off) has to do with this constellation of professionalism, autonomy (to act appropriately), and trust. In short, one simply cannot have one without the other two. As another discussion phrases this:

S3.1 But they [auto functions] haven't got the confidence because they are not (yet) competent.

There is much in the transcripts about deskilling and automation and the seemingly inevitable reallocation of resources to support this. Rather than discuss this in direct or instrumental terms (which would bring the issue of power to the fore), there is much discussion instead in the transcripts of how and where both machines and humans can function together or (semi) autonomously. This is because, like the term power, or what in the maritime industry constitutes professionalism and autonomy, as important as these issues are for determining the success (or failure) of industry-wide automation, they have not really been taken up in any straightforward fashion.

But given how professionalism is defined in the industry means that autonomy is also much valued. The tension between being a professional and a machine replacement is quite strong in the transcripts but so is the allure of today's (and future) technology. This in part makes it impossible for the industry to step back and consider the possibility of redefining man–machine relationships in other terms. However, replacement and substitution are not the only possible ways to describe for man–machine relations.

What makes man–machine replacement and substitution so problematic is the issue of trust. What often appears in the transcripts is the idea that trust (its lack of) divides human work and machine work. Trustworthiness is a key concept in the professions because it is something we all have to assess and rely upon to get work done every day. The issue of trust is heightened in the maritime community because of its work conditions. A key unresolved issue here is what is the relationship between human trust and (machine) reliability? Are these just different words for the same thing? Are they actually interchangeable? Perhaps what we need to break out of the transcripts is the relationship between these two terms and how all the players in the game define the two.

For example, if we use the example of when machines are thought to be (almost) always reliable, would we even then be willing to offload human tasks to that machine or system? In important ways, automation, autonomy, and trust are all interrelated at work. How each is defined throughout the day on the shipboard helps define the possible meaning(s) given to the other two. Through such negotiations, work gets done, professionalism is affirmed, and the need for individual autonomy is reconfirmed.

To put it another way, what challenges this debate is not so much the "practical", the implementation issues involved. It is the assumption that whenever or however we can resolve all these "backstage" issues, then everything will (almost inevitably) fall into place. Here's an example again from above regarding trust itself.

S1.5 How will it affect the trust from a human perspective that if I'm speaking to a machine in Urdu and the machine is replying in trans[lation]? But if it speaks the same language, then perhaps it's not in fact right.

Notice this time around, how the issue of trust "disappears" here. The successful completion of a machine task is taken here to be synonymous with trust and all it implies. In effect, the assumption is that if we solve the "simpler" problem, the more refractory ones will in the process be taken care of too.

In reality, it is (almost) the other way around. Unless we put the hard issues like trust on the table first, we run the risk of making decisions that turn out to be "short-sighted" or ones that could undo all the good work (and will) that these discussions have led to. There is a danger here that we see (accept) the status quo as something that extends directly without much change into the future. Extrapolations of this kind, which are seemingly sensible and the best way to think about the future, runs the risk of simply just perpetuating the past. In a way, we are suggesting that discussions about the future of maritime work and technology should put the hard issues first and put them on the table now. What we are not seeking here is unanimity but rather an increased understanding of the concepts and understandings we use every day but which can, often without us knowing it, get in our way. What we do not need to do is confuse unanimity with agreement and accept that these can be achieved by extending participatory processes already in place.

Ideas about (machine) augmentation and replacement often appear in the same sentences in these transcripts. This suggests that they are seen as very much the same kind of thing and reflect essentially the same kind of design goals. As Hynnekleiv, Lutzhoft, and Earthy (2019) have argued, augmentation should not be seen as a step towards replacement but rather as a design goal in its own right with its own benefits. This leaves humans to do the integration work (Lutzhoft, 2004) and to be the "glue" in the maritime sociotechnical system. Perhaps we have to put on the table the (heretical) idea that maritime technology in its present form, no matter how "advanced", is not sufficiently mature to deal with all the complex tasks and environments characteristic of shipboard work. Not acknowledging this may stop these discussions about automation from moving in more productive directions. At the very least, this will help us stop assuming that business case scenarios, for example, are a necessary place to begin thinking about the future.[1] If we always start with business models, initial planning and discussions about future technology can in fact lead us in unproductive directions.

> [T]he adaptability necessary for systems to handle potentially unforeseen variability is indeed provided by the human elements of the work

> systems, even when they make ample use of advanced technology. An important reason for this is the context-sensitivity issue. Unlike machines (which act literally according to rules), humans can reflect on the context of operations and identify potential gaps in procedures. Operators fill the gaps by adapting to the real conditions of operations and their dynamics.
>
> (Lay et al., 2015, p. 1)

But still, we have to be careful about what this idea of a stop-gap means, that is, such gaps (1) are the only place where human professionalism and competence are required and (2) that these gaps are just temporary ones – ones that can be "filled in" once the technology is sufficiently mature. These transcripts suggest that there are other ways to characterize and implement man–machine interactions – ones where there is some room left to negotiate what constitutes man–machine work and responsibilities. This opens a valuable discussion space (rather than set into play some unacknowledged or predetermined game?) between person and machine that can speak more directly to the question of which human functions can or should be replaced onboard.

For the sake of argument then, let's assume that augmentation, carefully defined, not substitution, is the best way to move forward regarding man–machine integration. This tack might even prove to be more cost-effective and effective than the ones (substitution) we tend to favour today. In other words, given the state of the art today, and perhaps for some time to come, we should instead focus on augmentation, not replacement, to achieve any legitimate form of human–machine integration in this industry. In other words, we should try to determine different task parameters than usual and so work on hand-offs to machines that would help us do everyday work more successfully and innovatively. This is not taking on principle some abstract philosophical or design position. It instead reflects how central the role of autonomy read professionalism is in the everyday life in the maritime community. This way expert work could be supported and embedded in the kinds of machines we can presently design and build. Let us leave it to the philosophers to discuss for now how and when computation will be ready to attack the problem of replacement or human-man substitution.

So where do we go from here? As usual, let's go back to the informants:

S1.2 The big thing I came up for the operator is picture management.

S1.4 What management, sorry?

S1.2 Picture management.

S1.4 Picture?

S1.2 Picture management. So to take an example, when I was in the Navy I worked with submarine operators who were very good at looking at a picture, or radiologists, for example.

[S1.4 agrees] Very good at looking at a picture.

Note how S1.4 is momentarily confused by S1.2's term – picture management.

S1.2 Yeah, exactly. I think at the moment when we look at officer's watch or a captain, you on the bridge …

S1.2 Perhaps the situation is developing over half an hour, so you've got a good situation awareness. I think the operator in the future is going to see a picture, interpret it very quickly, and act on that picture, especially if the system fails and they're going to have to look at it.

Now S1.2 does two things to help clarify what he is talking about. First, he defines what he has called picture management as an important, essential part of maritime work whether this means watch standing, being on the bridge, or anywhere else. Note too that S1.2 compares situation awareness to his idea of picture management and implies they are not exactly the same thing.

M1 So can you give an example? What kind of a picture would you show and what do you expect them to find?

S1.2 So let's take ECDIS for example, because we've got so many layers of information. Some people will look at it and just see a picture, they can't interpret it. But some people, their situational awareness, yeah, the information they could extract. And I saw it with submariners. That's how they navigate.

It is here with M1's example that S1.2 is able to clarify what he means. He makes a distinction, well known, for example, to radiologists between a heterogeneous variety or a set of information (layers), being able to make sense (a picture) out of this and so *know* immediately what needs to be done next. The line that separates interpretation/appropriate action in high-paced, professional work is a fine one. Further, he notes this competence is not something innate. Nor is it exactly the same thing as a mental image or construct, although that can be part of it. As he puts it, "Some people will look at it and just see a picture, they can't interpret it". To prove his point about pictures, he goes on to tell us how important picture management is for skilled work onboard. As S1.2 puts it, "I saw it with submariners" and then adds: "That's how they navigate". This argument (if this is how submariners navigate, then it must be an important element in all other kinds of maritime work) is one that would make much sense to the other participants here.

Further, it seems that for Sl.2 "navigate" means here a variety of things ranging from wayfinding (knowing what a vessel's course should be) to something more much expansive that encompasses a variety of sensory and intellectual operations (navigating in the world). Often the two are taken to be the same as (or fall under the rubric) of "sharing a common (or joint) perspective". It is not that the second slides into the other as much as it is not even analytically "recognized". How committed the industry is to this reduction can be seen below.

52.4 One of the primary drivers as to why (automation) happens today is to achieve shared perspectives.

This leads us to perhaps IT's most pervasive design category error. This one is as injurious to IT technology design and implementation as the other above. This is the belief that a group of workers has to hold *all* things in common (as in the many common definitions of situational awareness) in order for collaborative work to be effective and efficient. However, as contemporary social theory has shown us, one does not have to have *that* much in common to understand and cooperate with others. In fact, it may be that in the successful working out of what we don't have in common, or do not need to share in the normative sense of "what we *should* have in common", that collaborative work actually occurs. It is the normative with this idea of "should" that both power and the assignation of morality creep (often unnoticed) into the equation. This helps to drive design argument into abstraction and divert us away from how to capture and exploit the meaningful use of these "pictures" of information.

To strive for agreement may be a good thing say in a democracy, but it need not be the endpoint of every workplace technological agenda. This is because in the modern workplace hierarchy and equalitarianism (sharing in common) exist in equal measure but can impede or facilitate differently work task by work task.

For a moment, let us assume that S1.2 is right about how central pictures and picture management are to maritime work, the next question might be (after this is confirmed), what role should technology play in this process? Clearly, what S1.2 describes is neither just an internal nor individual nor social process but a kind of boundary object picture work that intersects both spheres (the internal and external). What S1.2 talks about as picture management, given its complexity and humanness, is something technology at present can support or augment better than it can substitute for.

Unpacking what S1.2 means by picture management (this integration work) gives some ways forward. But first, it has to be said that there is no universal, one size fits all solution for maritime automation. Having said this, let us sketch out how we might proceed. The first is to acknowledge that a wealth of valid design advice can actually be recovered, often in indirect ways, from seemingly naive operators. Second, taking this approach can help us arrive at some quite legitimate alternatives to conventional design agendas. Three, this shows that even a sample of one can help us to rethink what we should be doing when it becomes wicked problems like maritime automation. In other words, the kind of analytic work we need to carry out to help us understand the lives of others needs to be broad and eclectic if it is to help us implement any human and useful socio-technological agenda.

NOTE

1. At the time these interviews were done, the business case scenarios included the possibility of unmanned, fully autonomous vessels. Today for the most part, this is no longer the case.

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Chapter 12

MASS is everywhere – or is it?

Margareta Lützhöft and Jonathan Earthy

INTRODUCTION

As the HUMANE project was drawing to a close, we arranged a final event which took place on 23 June 2022, 09:00–13:00. The event was hybrid, with a few of the project participants meeting in Haugesund, and most of the participants online.

Concentrating on the role of *maritime humans* in a future with increasing automation, and perhaps even autonomous maritime systems, the HUMANE approach has from day one been to listen to a wide range of stakeholders in the maritime world. With the objective of providing a holistic set of recommendations intended to support a change towards a more high-tech maritime future the HUMANE project collected knowledge, views, and opinion from a wide range of stakeholders; including perspectives and insights on the perceived barriers and enablers relating to Maritime Autonomous Surface Ships (MASS). Data collection took place in two rounds (the most recent during 2021) and the results were available for presentation and discussion at the event.

In the HUMANE team, we wanted to keep listening to the maritime stakeholders and the HUMANE final event was therefore not a traditional event with only the HUMANE team speaking. Our clear aim was that the talking would be mostly done by the participants. We invited two experts to give a short presentation of the state of the art within their area of expertise – one technology-centred and one human-centred. We also invited a panel of six maritime professionals to receive and read the most up-to-date findings from HUMANE and prepare comments based on the following set of questions:

1. What is the most important or relevant finding?
2. Was there anything unexpected in the material?
3. Based on this material – what would be the most useful enabler?
4. Is there something missing?

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The event started with presentations from the project group based on the chapters that summarize the main results of HUMANE. Then the two experts presented, followed by a panel discussion with the professionals. This chapter includes summaries of the external presentations and the panel responses. We also received some ideas for how to make this book better, we listened and hope that it has worked.

EXTERNAL PRESENTATIONS

The first external presentation was given by an automation electronics engineer, with a technical perspective. He concluded:

> personally I think maritime autonomy has merit and will be much more useful than autonomy for cars – at least today. And, autonomy is enabled by automation, but it needs proper design and trustworthiness, verification and approval - it has to be designed correctly. Finally, we are also looking at a new concept for cooperation between humans and automation. It's really a cooperation where the human can trust automation to take the responsibility at certain situations.

The second presentation was given by a representative of a maritime union, with a human perspective. He concluded:

> the regulatory regime must fully take into consideration the safety and sustainable competence aspects for maritime workers and the practical viability for shipboard working and living ecosystems. Sustainable shipping requires a sustainable workforce to achieve the common Sustainable Development Goals. And I think this project will help us a lot to achieve our common goal, smart ships and intelligent humans, thank you so much to all of you!

The full text of the two presentations is included at the end of this chapter.

PANEL RESPONSES

The panel of professionals was composed of persons with teaching and pedagogy backgrounds, regulators, and representatives of seafarers' associations. They were asked to read through a few draft sections of this book before the meeting. They were encouraged to think of the four perspectives of the results listed above, what is important, unexpected, useful, and missing.

WHAT DID THE PANEL FIND TO BE IMPORTANT?

Whose business case?

The significance of the business case is the first mentioned issue, and the views range from believing it is not there for the shipping companies, and their primary goals of making profits and minimizing costs, to a more measured response that it may or may not come, but with the caveat that the use of technology is more worrying. The question of who drives it versus who benefits is raised.

> There appears to be significant scepticism out there about the financial viability of MASS, at least for general application. Yes, specialist applications, there's a lot of interest … but for general cargo coasters, coastal tankers, bigger bulk ships, dry and wet bulk, deep sea. I don't know … it's very interesting that it's been pointed out repeatedly that it's not the ship owners who are driving the discussion about MASS here, which I also think is interesting. And you know, maybe they don't see the economics of this either. And I think the scepticism the ship owners are showing here is healthy … they haven't had a great experience, I believe, in the roll-out of the first wave of IT at sea. I'm tempted to ask the question: is MASS an example of technology looking for an application here? And you know, MASS technology enabling, not driving. I'm really wondering who is really driving this. Is it the technology companies?
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> I am not the least bit worried about the business case, and it's not for me to make it. It will come – if it doesn't come, it [adoption of MASS] doesn't go. I believe that for MASS to happen there has to be a business case and we're seeing that evolve – where it makes sense, it will happen. If there's no business case for it, it's not going to happen. And you know, there's a lot of business case at the moment for it not to be happen[ing], which is fine. Nowadays, some technology is so ubiquitous that it's cheaper to build a ship with it than without it, even if there's not a need to use it. One example is DP where some new builds are including it "just in case" due to the relative low cost. Regulations focus on mandatory equipment, there are no regulations for what might be onboard that is not required. I'm not at all worried about the business case but of course, I'm worried about the use of technology.
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> The whole question of business case, what is driving this? Remember for the bulk of shipping the main business case is not from sailing cargo from A to B. Their main business case is they buy steel boxes with an engine on it. Crew is between 5 and 10% of the cost. And they earn their money when they sell again. They want standard, standard, standard, and they definitely don't want any maintenance and they don't want to need to think. And what we have learned from what you have

done, what many other people have done on MASS on this technology is it requires a ship owner to think – the ship owner is not thinking anymore because he's a financial guy. The ones running the ships, that's management companies, some of them may want to offer the ship owner: "we can manage a MASS ship for you at a cost". And then the ship owner, which is a Bank or financer or Bitcoin millionaire, will decide whether that's good business or not. So, I think we need to talk about management companies, and they will drive to some ship owners the benefit of this technology but to most ship owners they will just give the cheapest simple solutions and we're back to the Norwegian case where the driver has been the logistic companies. And then it will be the need of the logistics that may drive some of this and I think [I] fairly believe it's gonna grow from being something like the ASKO project. That will grow to greater, greater distances to greater and greater volume. Baltic, North Sea and so on. And the last thing that will be coming, that will be the big ocean ships, I think we're gonna have nuclear propulsion before we're gonna have MASS on the big container ships.

We've exactly the same challenges around maritime education and training, particularly placing cadets and stuff. Who do you talk to now? You used to talk to ship owners. They're not interested in anymore. You talk ship managers who are only basically about minimizing costs. We need to have a conversation about who we're talking to about all of this because we may not be talking to the right people some of the time and to understand who we should be talking to; I think we need to understand a little bit more about contemporary business models in the industry and so on.

People still needed

Humans will still be onboard in one way or another, and that will have a large effect on the development. They mention the human in the loop, meaning that humans will be involved in the operation of ships.

Seafarers and associated maritime professionals aren't going anywhere anytime soon. I think that's hugely important because it significantly impacts everything that happens from here on, you know, the human is going to still be in the loop, perhaps in different ways, but they're still going to be there and that needs to be […] very much put in.

The important and relevant finding is that the human will still be in the loop, recognizing that when we started all these discussions, we had several projects that were looking at autonomous vessels. We mixed that up with unmanned vessels. And I can now see slowly that we end up with vessels where there might be or probably will be future seafarers, where we still have people on board for money interests and for safety also. I don't say that there will not be unmanned vessels for instance the city ferries, or like Yara Birkeland and ASKO. But I still think there will be a human in the loop, and I think that's the most relevant and most important finding for me that we end up with that.

AI is not easy

Looking at it from the other perspective, artificial intelligence is considered very hard, maybe impossible, to make and to validate, especially as it is still not clear what the daily work consists of and how it can be "transferred" into any kind of machine.

> Automation AI – one of the challenges of implementing stuff is you have to make explicit so much context analysis, risk assessment, planning, decision-making that is currently largely implicit. You know, what does the officer of the Watch do on the bridge? What does the OOW do in the engine room? And those of us who've worked in software development, particularly working with AI and so on, you know, this is in fact incredibly hard to do. It's really, really hard. You know, and I'm always kind of amused by nonexperts who sort of just blindly brush over this: "And that's a detail. We will work it out". It's not. It's actually a fairly fundamental problem.
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> This was a concern that was raised very much in the finance side conversations. That complexity, we don't have the answer, but I think it was recognized that this is super complicated and it's basically because of what we came to call the design envelope that it's very hard to define. Where [do] system capabilities stop and what's going to happen when it stops? On the other hand, all of us realize that you cannot design without an envelope, there is a finite stop to capability somewhere. And you will never be able to validate something that supposedly goes beyond or doesn't have a limit somewhere, so it is a super interesting question. And I mean, we all know that the black Swans, they are unknown unknowns are the really dangerous ones. So, we need to come up with system[s] that really can explore the area of unknown unknown[s] so we can test and verify. But with the system as a whole that is even more difficult.
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> You cannot do this. Theoretically, you cannot do this. It's an open system. So, you cannot assume there is some Holy Grail where at some point we will be able to take a collision avoidance algorithm and demonstrate that it is going to work in every situation. It is theoretically impossible to do that. This is a massive challenge. It's a mind shift that the people have to make. These autonomous systems, while you may be able to prove the correctness of a part of a system, for example, maybe the conning, the steering – when you add that to another piece which is the collision avoidance piece and the engine control piece and whatever,

> you very quickly get to a point where the system is so large it effectively becomes what's known as open and it cannot theoretically be proved that it will work in all situations. So, there's a fundamental theoretical underpinning here people have to accept. You cannot prove that these systems will work all the time, and that's the reality […] from a technology perspective.

Automate the boring

On the topic of what work is performed and by whom, the discussion turned to what could be done to reduce the current workload, and it was suggested that automation could take over the paperwork and bureaucracy for the seafarers.

> We did a survey a couple of years ago of our members' attitude towards automation and it was surprisingly very positive. And they said yes, automate all the bureaucracy. Why do we have to fill out all this? Why do we have to do this? Automate the planned maintenance, the inventory control, all that sort of stuff, take away a lot of the bureaucracy that is stopping us from focusing on our job at hand. Give us tools that support our decision-making.

Who is the human?

It was pointed out that while we should support the human, designers should be careful to not fall into the trap of designing for one "type" of human – it was important to consider that all maritime humans are not alike.

> There's a whole range of different types of humans at sea and ashore, and they all make decisions a little bit differently. So, if you design something to support the human, is it going to be a very narrowly defined human, in which case we need to recruit that type of human in order to fit them into the system or is the system going to be that adaptive?
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> When we did the design of [product name deleted], we had exactly the same conversation. I mean, OK, so we want to do human-centred design. But who is the human? And we ended up by deciding that our humans are STCW humans, I mean we are designing professional systems for professional people. The point I want to make is I still think there is a tremendous difference between a system that is well designed for a sort of one size fits all human and systems that are just designed by engineers for engineers. I think there is room for improvement, even though we cannot design for individuals.

Update the training

It was also pointed out that the needed skills in the future could include, for example, more computer science and system science, while balancing the need for general and specialized knowledge needs.

> I saw a lot about what kind of skills we need. Do we need to up-skill? Do we need to down skill and do we need more IT skills? And where should those be placed onshore, offshore and so on? I think that future seafarers might need more computer science and system science knowledge. We already have some automated systems and I think that we need to update the maritime education and training with knowledge about the technology at hand. I think we all agree it's just finding the time and finding the scope of the learning. How much general knowledge do we need and how much specialized knowledge?

Disruption

The final topic of the "what is the most important, or relevant finding" session came back to the maritime system and the business case, using Norway as a case, and pointing out that development is driven by logistics.

> But it is interesting to look at the automation development because it was originally developed or driven by the technology. Norway is driven by the logistics supply chain owners, which see the possibility of building totally new logistics systems. And if you look at some of the big challenges we have in international shipping today, or national for that matter, the other big issue we are facing more recently is the resilience of the supply chains. It has been mentioned that the ship owner is here, but no ship owner is interested in including automated ships because it's contrary to the business model they are operating under. It's the supply chain owners that will look into this. There is a big potential there for complete disruption of shipping as we know it. If you look at shipping today, the business models are 200 years old. I don't think this is sustainable under the pressure we have now from the conversation and resilience in the supply chains. So, there is the potential for a Black Swan. Yeah, new types of ship concepts.

WHAT DID THE PANEL FIND TO BE UNEXPECTED?

Smell the elephants

The participants mentioned things they expected to see more of, the "elephants in the room". This included the performance of the technology we already have and the suitability of the STCW. The conclusion was that these topics were perhaps overshadowed by, and more important than, the development of MASS.

> We're collectively aware of a couple of really big problems that exist in our industry but for whatever reason we're nonetheless running ahead of ourselves a little bit and maybe we're off target a little bit from where we should be heading just now. I mean MASS is interesting and it's proving to be useful in certain niche areas. But to me, one of the things that's really come out of these conversations and this project is that I think we're at a point now where we need to talk about a couple of really big ongoing challenges which we need to work through before we can seriously get stuck into something like MASS. The performance of existing information and related technology on board ships; [there are] real issues with it. There are significant problems with human–computer interfacing and with information overload, that kind of stuff. We're just sort of going, yeah, we know those problems are there but regardless, we're going off now to talk about automated ships. That's a discontinuity for me … We should be making serious inroads to sorting out one set of issues before launching into another. Another area that I'm concerned about is the suitability and efficacy of STCW as a model for sea-going education and training. I've a leadership role in maritime education and training and it's well known that [there are] problems with it, yet we're not really talking about that. We're just kind of going, oh yeah, we'll tweak it around the edges and you know, make a few changes to it here and there and then we'll carry on and we'll introduce something as huge as MASS. What it's done is it's highlighted for me that over the last 20 years some real challenges have kind of piled up that I think we really need to talk about and make meaningful progress on sorting out before we take on more. And you know, that was not something I expected to see or expected to come out of this, but it hit me really strongly.

Human factors research

On the same line of thinking, a concern was voiced for the relative underrepresentation of research and publication on human factors in MASS.

> [M]y biggest thing was that human factors [were] so underrepresented in the research on MASS. And I had the impression that a lot is going on in Norway. I was kind of concerned that the other maritime human factors communities were not picking up on MASS in a big way. And I'm also thinking a bit about which kind[s] of problems can be interesting to the funding agencies. Of course, if you get funding for research. So, I'm thinking about barriers for, for human factors to get into MASS research, more hands-on. But I'm happy for your project and that seems

to be ongoing … because it's so important also to have the human factors and the learning sciences to start to look for how we can prepare the future seafaring students for a more autonomous future.

Not going back

A few comments related to the circularity of the development of new technologies and how the industry may be stuck in traditional thinking. Being open to new perspectives was suggested.

> I already mentioned that we actually start to understand the difference between unmanned vessels and the autonomous or automatic systems. And we still are going into the traditional traps like we focus on the economic impact and how we look at regulations and we think again and again and again in a traditional way. At the same time, we know that we are not going back. We are moving into a digital world. We are moving into a future that gives us opportunities and we will have more and more support from artificial intelligence and autonomous systems. So, it's a little bit unexpected that we go into this traditional way of thinking when we look into the future.
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> What you basically said was the traditional thinking is a barrier. And I agree [with] that. But maybe if you look in[to] the ship-owning side. I mean, people are evaluated on a quarterly basis. If your quarterly results are not good, then you will be looking for another job pretty soon. And the same goes for a lot of other positions in the industry and that is not really helpful if you want to be forward-looking forward thinking strategic. And so it becomes this Gordian knot. I agree that we need to be forward thinking. But I can't see how it's gonna happen in the business climate that that we have in the marine industry, and have you got any ideas?
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> It's a shift in perspective you're talking about. Yeah. Just look at it from a from a different angle.

THE TOPIC SHIFTED TO ASKING THE PANEL WHAT THEY FOUND TO BE USEFUL ENABLERS?

Focus on the human

The panel valued the focus on humans and their skills and appreciated a look into the future.

> I have noted the focus on the human skills. We know there will be human[s] in the loop and what will be the skills that they will need in the future. And also, this description of how we look into the future, this glimpse of the future, that's it's useful.

Good to talk (and to listen)

The method, the conversations, and the breadth of expertise and topics in the project were highly valued and provided a clear benefit for the participants, at the same time as it identified much future work.

> I considered this and what I came up with was I think the methodology that's been used, the approach that's been taken here. The conversation for me has been hugely valuable and as a project I've really enjoyed it and really found it very valuable. The breadth and scope of the subject matter experts that are involved here, the conversations that have gone on, I've found absolutely fascinating. This project I think has been very, very successful at getting people together to talk. And that doesn't happen in a lot of projects I've done, and this project is particularly successful. I think that is an enabler for where we go from here is very important because I think this project is speaking from a position of some authority in terms of the fact that it has had so many conversations with so many people.
>
> And it has demonstrated the breadth of this subject. It covers human factors. It covers technology, it covers legal, and I think it's a wonderful reflection of the richness of seafaring, the richness of working in the maritime professions, but also, I think, of the challenge we have. You start to talk about one specific thing, which is MASS, and very quickly, the conversation just goes this way. It just blows so wide because that's the world we live in and that's also a reflection of the challenges we have, tackling any one thing in the maritime sector quickly leads you into a conversation that just goes incredibly wide. So, while that's a challenge, I think this project has succeeded very well in highlighting that. But also, in laying out a very rich sort of crop here for us to basically enable further work.

Focus on humans

The focus on humans was mentioned again as a useful enabler and providing a useful reference tool for supporting the development and possibly "getting it right".

> To me the most useful enabler is this focus on the human in the loop and where in the loop they have to be and the definition that this technology should enable and not drive the operation. And I think by documenting that in this book that you're producing, that's gonna be an incredibly useful reference tool for all of us going forward because where some engineering-focused people might jump into autonomy thinking, you know: "that's it – we're getting rid of the humans". This will be a very useful tool in the industry. And if you continue this research, that'll be very good.

> Are a lot of people thinking that this MASS is being pushed on the maritime industry, that we're gonna be forced to go MASS? I don't see it at all that way. I see, particularly the work of the IMO is to enable a regulatory framework that where MASS is wanted, where there is a business case, it can evolve in a safe environment. But it's not being pushed. I remember back in 2005, 2006, going to our members and saying what do you want? And they said, well, wait a minute, get what we have right. And then come back and ask me what more I want, so we don't have a particularly good track record. But again, we're all gonna be forced to deal with MASS. I don't think that's an issue unless there's some sort of huge disruptor, which I don't disregard. But I think you know what's happening in MASS is [a] good development for very specific needs. And I think as an enabler, again the HUMANE documentation is going to be very useful for us all to have and to be able to refer to going into the future.

WHAT DID THE PANEL FIND TO BE MISSING?

Geopolitical context

The panel pointed out that the role of geopolitics was not clearly included and would have a large impact on the future.

> How geopolitics is going to play into the maritime sector over the next two decades and how the implications of that will play into changing ship operations. I think we are going to see very, very significant changes for shipping over the next two decades driven by the sustainability, the climate change challenge driven by the shortening of supply chains. I think certainly in Ireland where you know we were very, very open to the international economy we are seeing. A lot is actually happening, not just being talked about, but happening around this concept of onshoring. In other words, we're manufacturing, stuff is being brought closer to markets and so on that is going to have implications for shipping and obviously it will trickle down eventually to MASS as well. So, I know it will be a difficult paragraph to write, but I just think it's really important that at least you know there's an acknowledgement that look[s] all of this other stuff is going on out there as well, which is really going to impact in some way.

Focus on other humans

There was also a request for "calling out" the role of technology and focusing more on the humans. The need for considering the design of the team and more research on human…machine collaboration was highlighted.

The roll-out of technology at sea, the roll-out of MASS, whether it's a niche context or more generally, is really replacing functions currently performed by one group of humans. The crew on the ship, and indeed those [who] were monitoring and so on ashore with another group of humans who are, in effect delegating those functions to machinery and other words software engineers. And this is something that I've been calling out for a long time when you replace a function that's carried out by human being with a function that's now performed by a machine.

Yeah, the machine is doing the work, but effectively the machine was programmed by a human being, and that human being has all of the flaws that the crew have as well. And that gets lost along the way in. This goes to testing software and all the rest of it. And again, those software engineers make mistakes and those mistakes do lead to incidents and accidents. The 737 Max being the most recent example in the aviation sector. So just again to call that out that we're not removing human beings. We're just getting a different bunch of human beings to basically do something.

Perhaps we need more research. If we're looking at a team making collaborative decisions and that's collaborating amongst themselves on board collaborating with technology, collaborating with people ashore, etcetera. That's very new in the maritime sector, and there [have] to be trials. We need to determine what those teams will look like, how those teams will interact. If there is a disruptor, somebody may just pull this humane book off the shelf and say make it happen. So that solution should be as complete as possible. But if you have half a dozen people on board doing [a] collaborative effort, what does their environment look like? How will they keep active? And I don't know. If the system is running at 99% accurate, how do you keep the humans on board engaged? How do you keep them interested? How do you keep them prepared for contingency? And I think that the solution that we found 25 years ago was continuous on board drills and training, even if it's a simulation on board. So that you know they're prepared for these exercises and a wide scope of contingencies so that if it ever happens, they don't go from zero to 100. They've been trained to react. If you're looking at this core team for collaborative decisions that needs to be tested, it needs to be experimented with. It needs to be documented. So that we know what we're looking at and looking for.

Disseminate further

The consensus was that the HUMANE work was valuable and should be disseminated further, to, for example, the IMO and also find a way to keep the expert conversations going.

> It would be very important that the people that IMO who work with this hears about this project. And I think perhaps Norway would take the initiative and put you up for a presentation at MSC 106 in November. It would be really beneficial – that would be the first time since Corona that all the regulators on MASS will meet physically. We need you to come in and present your conclusions from the HUMANE project. To me there's nothing surprising really in it, it's so much in line with what I have learned [over] the last years, but we need to present this. We need to recognize what people have been talking about. Just getting everybody at IMO to think – they may go out of the traditional way of thinking – will be a huge step forward. My conclusion on this is we need you not just to have a book but go over to London and present what you have been doing. It's a good job you have done. We need to bring it to the decision-makers and not just to academia.
>
> I think what you're, what you're suggesting, if I may try to conclude on it and that is very forward-looking, I think you are suggesting a kind of a maritime think tank.

Humans digital regulation

In sum, we are pleased with the outcome of the event and pleased to have provided information for industry and regulation to take the next step, as illustrated by the quote below about progress on the IMO MASS code.

> Who actually drives this or drove that at the beginning. I have to say that the technology developer did and that was the case until just recently. As a representative to the IMO, I have to say that just recently I started to consider the human element more, but in reality there were many times that we actually pushed that to be to become a serious issue. It's not only about the safety it's about all the humans involved in the maritime industry and all of them need to have education and knowledge, yes, and training as well. However, what is the most important part, and I don't think it was mentioned, [there are] still the regulations, and the question [of] how the future will actually bring the liability. It's a legal question. It's a lot of things that are. I believe that we have to be more realistic about what the future will bring and that's just after three or four years of discussion on MASS.
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> We started just recently with the road map [for the IMO MASS Code]. And definitions, which are also an extremely important part of these discussions, because who are the masters? Who are the operators? Who are the people that definitions are the starting point for my view? And I believe that very soon we will have [a] much clearer picture about in which direction the MASS because it's not [an] autonomous ship. It's [an] automated ship and now we are talking about more about the digitalization than automation, which is also OK but still, I believe that the question will be very soon, much clearer than it is now.

FULL TEXT OF EXTERNAL PRESENTATIONS

This is the text of the presentations mentioned earlier in this chapter. It has been included in its entirety to provide full context. The first presentation was given by an automation electronics engineer, with a technical perspective.[1]

TECHNICAL PERSPECTIVE

It is interesting to compare autonomy in cars versus what you are seeing in the ship industry. A ship is all in the order of millions of dollars, whereas a car is in the thousands. This investment in the asset will obviously make the owner more eager to control whatever the ship is doing. The bigger crew is an argument that it can be cost-effective to use a remote control centre for a ship, but this is not generally the case for a single car. Ships require slower human responses from remote operators, in the sense that you have an obstacle detection range of nautical miles instead of meters, which translates to minutes in maximum response times rather than seconds for a car.

It is also, in my opinion, not feasible to go for full autonomy, neither in cars nor ships. In uncontrolled and mixed traffic where other ships or cars are controlled by humans, it is very difficult, if not impossible, to guarantee that a computer-controlled automation system will be able to understand any and all actions that the other ship or car takes, even less in more complex multi-ship or multi-car encounters, where rule-based reasoning is insufficient. A human in a remote control room (or a human passenger in the car) could assist in such situations, but this will require that the human has enough time to understand the problem and to take the correct corrective action. This is an obvious problem for today's semi-autonomous cars, but likely less so for ships, as required response times are much longer. That makes it feasible to use humans to assist the automation in semi-autonomous ships, much more than for cars, in my opinion.

The ability to use humans in a sensible way to assist automation from the remote control centre is really what makes ships much more interesting than cars for this type of what we call constrained autonomy. Automation is very good at handling deterministic and repetitive tasks. And although the main problem is that automation will not be able to in general predict what others will do, this is also the strength of the human being – that we can improvise. We can do things that automation not easily can reproduce.

Artificial intelligence normally translates to deep learning, and deep learning is basically a statistics-based method for trying to interpolate between a training set and what you encounter in real life. This means that you cannot really guarantee a 100% correct response for an AI system in an uncertain and complex environment. So, AI is best used for heuristic guidance where you can't really make deterministic rules. This means that there is an inherent probability that the AI provides the wrong answer and one needs to consider if these can have implications for the overall safety of the system.

Ordinary automation has a limited ability to handle indeterministic situations. However, in deterministic situations, it is generally better than humans in that it follows the rules all the time, and it's very fast. So automation can also complement the human in many cases.

If you consider the SAE levels of car driving automation three to five, you will see where we have problems now, on levels three and four. The way automation and humans are supposed to interact to make the whole driving experience safe is not well defined. You have this concept of fallback that the human has to do in a couple of seconds when the automation fails. The driving automation at SAE levels lower than five still has a limited operational design domain, but it is able to handle the cases it is designed to handle. But what about if you go outside the operational design domain? So, this is a major shortcoming in car automation as I see it today.

There's also a discussion about what is automatic and what is autonomy. The proposal we have put forward in ISO/TS 23860 is that automation is something that *can* function, within certain constraints, without human control, but that the human needs to continuously oversee it to make sure that it works as expected. Autonomy emerges when automation, possibly under the same constraints, is *designed and verified* to safely operate without human supervision. However, the human must still be able to safely take over control once the constraints are exceeded.

Also, as automation is expected to be able to safely control a ship for most of its voyage, for example, in open waters, one cannot expect the human to continuously monitor the system to wait for the moment when he or she needs to take control. Rather, the automation system should be able to alert the operator in a sufficient time before control is handed over, to let the operator get sufficient situation awareness to safely take over control of the ship.

This takes us to the issue of trust in automation. It captures the fact that the human must be able to understand what the automation can do and what it cannot do, and that the human can trust the automation to provide an alert in time for the human to safely take over control. We are talking about a new paradigm where automation and human cooperate to control the ship, rather than as today where automation is just an assistant to the human, and the human needs to always be vigilant. This is perhaps the essence of applied autonomy: trusting that automation will take full control as long as it is able to, and that it will safely hand over control to the human when it is no longer able.

When we are talking about maritime autonomous ship systems, there are a lot of components, both on the ship and off the ship, including the human operators. This may not have been fully acknowledged, so it's really a system perspective we need to have here. We introduced the concept of cooperation between automation and humans. The humans are no longer using automation to help them, they are relying on automation to do certain tasks. The concept of trusting automation is extremely important. When automation is in control, it has to be in control. It must be able to handle all the situations that it's supposed to handle, and it must be clear to the human when the human needs to take over control from the automation and vice versa. The issue of safe handover of control is extremely important, which in my opinion is the main problem for cars. We must put strong emphasis on this for ships, and that takes us to trusted automation.

A possible way forward is to look at the temporal aspect, which can be related to response times. The human, when not in control, has a maximum time before he or she is able to get sufficient situational awareness and is ready to give new commands. This can be called the maximum response time (MRT). Likewise, the automation system should be able to determine the minimum time it still can safely control the ship. This can be called the minimum deadline (MDL). Safe autonomy means that MRT is less than MDL at all times the automation is in control and that the automation alerts the humans to take control when MDL approached MRT.

I also want to mention a new vocabulary that we published in an ISO technical specification (ISO/TS 23860) where we have tried to define some of these concepts.

To conclude, personally I think maritime autonomy has merit and will be much more useful than autonomy for cars – at least today. And, autonomy is enabled by automation, but it needs proper design and trustworthiness, verification and approval … it has to be designed correctly. Finally, we are also looking at a new concept for cooperation between humans and automation. It's really a cooperation where the human can trust automation to take the responsibility at certain situations.

End of talk one

HUMAN PERSPECTIVE

The second presentation[2] was given by a representative of a maritime union, with a human perspective.

> Thank you very much for giving me the opportunity to participate in the HUMANE project as a representative of the workers – the seafarers – who are finally recognized as maritime humans – including the engineers!
>
> This project shows how crucial it is to collaborate across disciplines, as there is a big difference in political views, academic facts, fast profit, and the technical reality. When the world has forgotten seafarers as we

find in the UN and IMO's sustainability goals, who only have a policy of life below water (14), and life on land (15) – but no life on water, we had to introduce a new policy, a "14,5 lives on water" – the Sustainable manning!

We are especially grateful that the project "Human Centred Autonomy" is a success that has been noticed in the arena that works with regulatory development, to implement and close the safety – and competence gap, let's hope another sentence; Learning and learning-to-learn by doing – will give us the Safety and Security needed. Automated solutions on board ships have been, and will always be, an aid to human skills, competence, and human senses in a strictly regulated infrastructure – which the great ocean has command over – anyway!

To us – there is nothing new, SEAFARERS have dealt with automation since the 1960s, the challenge is the developers, shipowners and authority/flag state to accept the STCW Convention shall apply to designated and assigned STCW certificate holders PERSONNEL serving on board sea-going ships OR PERSONNEL OPERATING FUNCTIONS OF THE SHIP. What we need to concentrate on is STCW Basic Training – Vessel Specific Training and Familiarization, then the HUMANE can sail safe into the future!

As an engineer, I also want to highlight the technical fact that it's the engineers who are responsible for and deal with the MARPOL regulations and new types of energy sources for ship propulsion, manoeuvring and operation with innovative engine technologies to improve the protection of the marine environment.

Especially engine officers and engineering crew members who will face the greatest safety challenges as the same time competence-related challenges. Such safety challenges are originated with energy sources for propulsion that result in high temperature, high pressure, high voltage, toxicity, and corrosiveness of fuels. Furthermore, vessel manoeuvring, maintenance, explosion hazard and firefighting are also safety and competency-linked challenges. Energy source storage, fuel efficiency, bunkering, charging, vessel construction, evacuation design, firefighting, and Search and Rescue (SAR) must also be considered to close the safety and competence challenge gaps.

The regulatory regime must fully take into consideration the safety and sustainable competence aspects for maritime workers and the practical viability for shipboard working and living ecosystems. Sustainable shipping requires a sustainable workforce to achieve the common Sustainable Development Goals.

And I think this project will help us a lot to achieve our common goal, smart ships and intelligent humans, thank you so much to all of you!

And Margareta please don't forget this engineer next time you act, we need personnel like you!

End of talk two

NOTES

1. The text is from the script of the invited speaker. Only minor editorial edits have been made.
2. The text is from the script of the invited speaker. Only minor editorial edits have been made.

Chapter 13

Overview of recent research

Thomas Porathe

INTRODUCTION

This chapter briefly summarizes areas, topics, and origin of journal and conference papers about autonomous ships published during the period of the HUMANE project 2018 until July 2022. Altogether 111 research articles have been reviewed.

The method used for finding research papers has been "snowball sampling", an unstructured non-probability sampling technique where references in, or references to, existing articles are used based on a Google Scholar query using the key word "autonomous ship". Only articles published from January 2018 to July 2022 were included. Altogether 126 articles answering the search phrase were found. Fifteen articles were discarded for being outside the topic and the remaining 111 articles were reviewed.

The risk with an unstructured method is of course that what you look for is what you find and that the bias of the reviewer influences the result. It is also possible that the fact that the search was conducted from Norway might influence the search results. Nevertheless, the assumption is that the results give some indication of the research direction and where what research is conducted.[1]

AUTONOMOUS SHIP RESEARCH IS INCREASING

The scientific interest in autonomous ships has risen in the past decade since 2012, when the EU project MUNIN (Maritime unmanned shipping by intelligence in networks) set out to investigate the possibility of ships navigating unmanned and autonomously. During the study period, the number of published research articles increased. The corona pandemic effectively shot down much research during 2020 and resulted in less articles published in 2021. But in 2022 the numbers are back up with more articles published in the first half year than in the whole of 2020. Of the 111 papers reviewed, 8 were published in 2018, 19 in 2019, 30 in 2020, 21 in 2021, and 33 in the first half of 2022 (see Figure 13.1).

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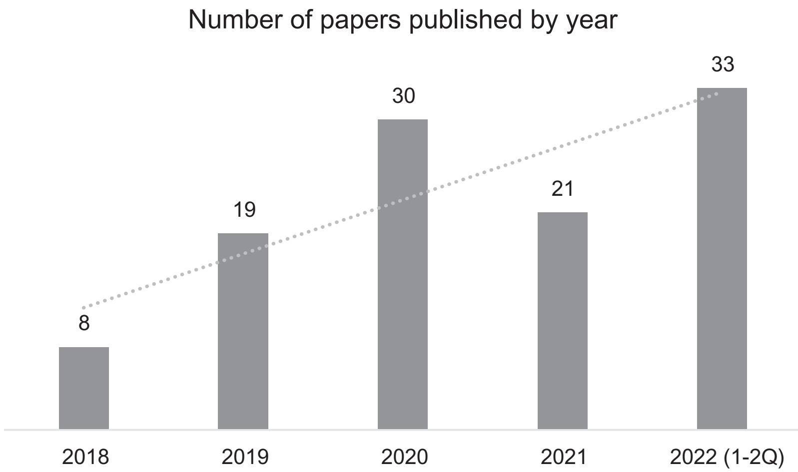

Figure 13.1 The distribution of the 111 papers found using the search phrase "autonomous ships" for the period 2018 to first half of 2022. The trend line shows a steady rise, although 2022 only contains findings from six months.

Most publications from Norway and China

The reviewed 111 papers were written by authors from institutions in 25 different nations. Most papers were written by a group of authors, often from the same institution, but sometimes from different institutions representing different countries. To assess where in the world research on autonomous ships was conducted, each co-author was designated a nationality based on his or her affiliation. This meant that some papers became designated to several countries depending on the nationality of the institution the authors had used as their affiliation in the author list. Viewed this way the 111 papers produced 141 national contributions.

Of these 141 national contributions, 34 came from Norway and 32 from China. Thereafter, nine contributions came from authors in the Netherlands and Poland, six from authors in Finland and in South Korea, and five from Japan and the UK, respectively. See the full list in Figure 13.2.

More technology than Human Factors research

The 111 papers were clustered based on the research domain using the most prominent topic of the study. Such classifications can obviously be tricky as papers could potentially belong in more than one category. However, most papers had a prominent focus. The classification resulted in nine research domains: collision avoidance, motion control, legal and regulatory, risk management, business and logistics, Human Factors,

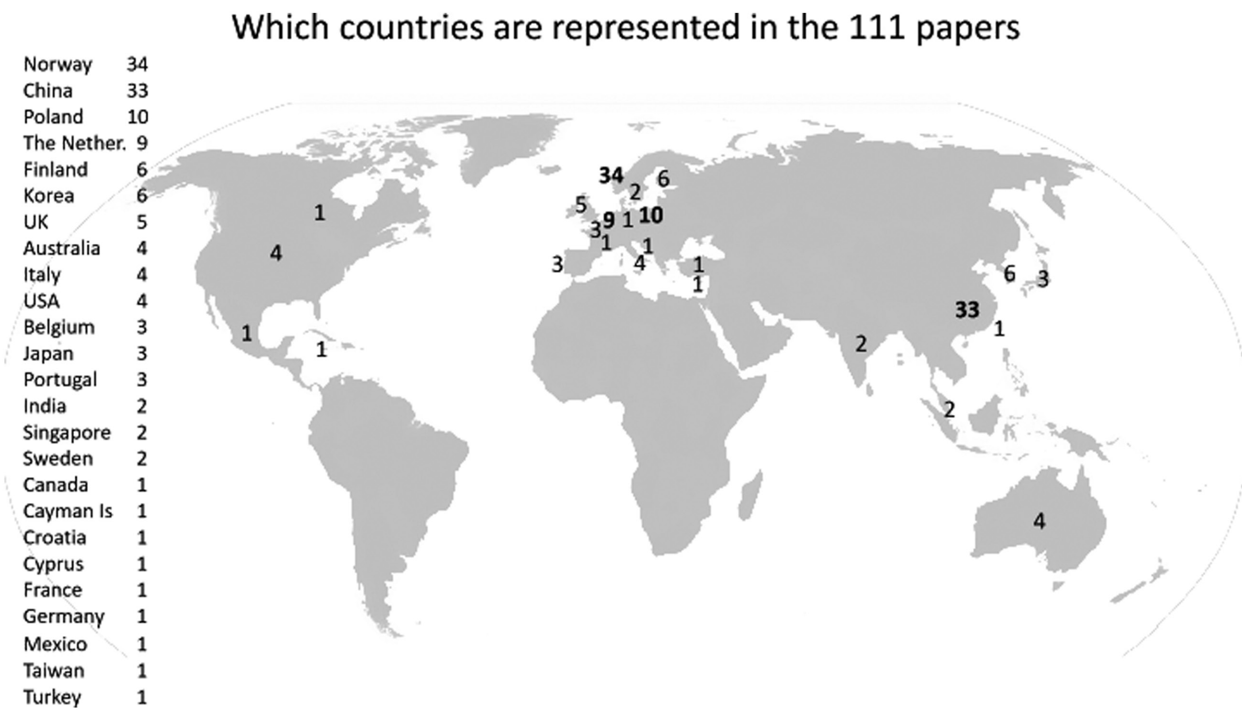

Figure 13.2 Which nations are involved in research on autonomous ships (as represented in the 111 reviewed articles)? Together the 111 papers produce 141 national contributions. Top nations were Norway with 34 contributions and China with 32 contributions.

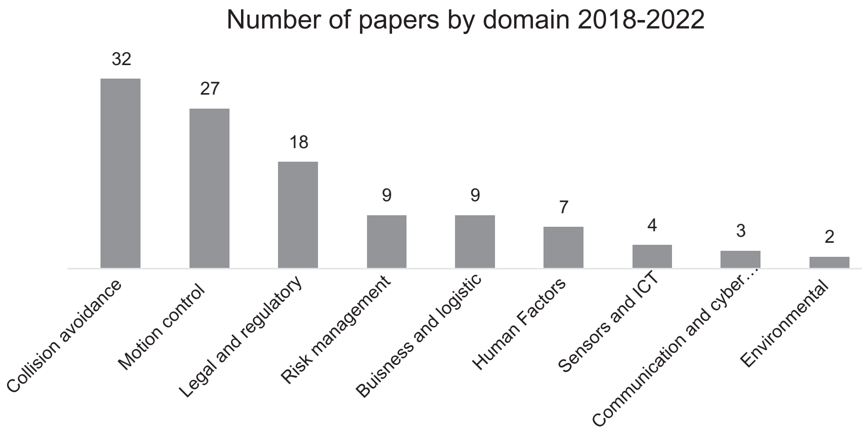

Figure 13.3 The 111 papers were reviewed and clustered into nine different domains depending on the subject of study. Collision avoidance and motion control were the two most published domains.

sensors and ICT, communication and cybersecurity, and finally, environmental (see Figure 13.3).

Furthermore, these nine domains are aggregated into three general areas: "Technical", containing motion control, collision avoidance, sensors and cybersecurity; "Organizational" with legal and regulatory, risk management, business and logistics, and environmental. The final area as well as the domains was the interest of the HUMANE project: Human Factors. Figure 13.4 shows the number of papers designated to each general research area.

RESULTS

In the following, the nine identified research domains and research themes in each domain are presented, starting with collision avoidance, followed by motion control, legal and regulatory, risk management, business and logistics, Human Factors, sensors and ICT, communication and cybersecurity, and environment.

Collision avoidance

Collision avoidance is the ability of an autonomous ship to automatically avoid colliding with known or unknown static or dynamic objects, for example, shore or other ships. During the period studied, 32 of the 111 articles found in some way dealt with collision avoidance. One article from

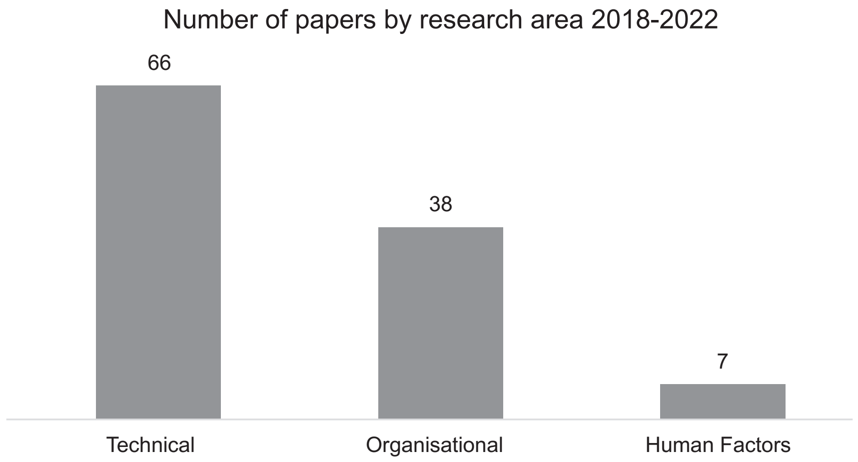

Figure 13.4 By merging the 111 papers into three general research areas we can get a glimpse of the overall focus of current research. Technical research is dominating the reviewed papers and Human Factors research is relatively small.

2018, 9 from 2019, 7 from 2020, 2 from 2021, and 12 from the first half of 2022 (see Figure 13.5).

We can see that the dip in published papers from the pandemic year 2021 is very pronounced. Possibly because research in simulators or on ships at sea was very limited. Instead, there are 13 papers published only during the first half of 2022, possibly because a number of studies were held up waiting for restrictions to ease.

In collision avoidance, China was the most productive research nation, followed by Norway. The 32 papers were written by 115 authors, representing

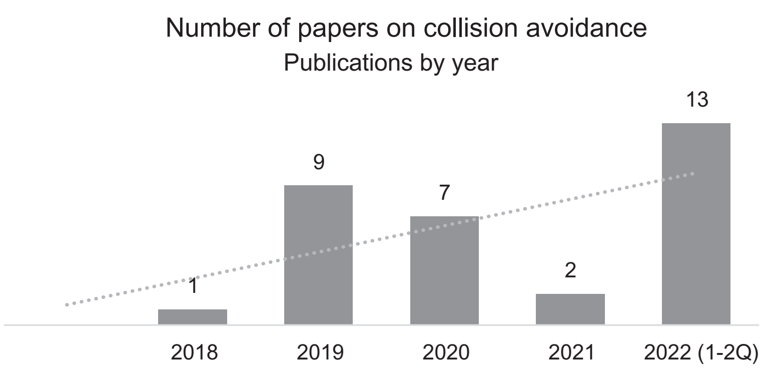

Figure 13.5 In total 32 papers were classified as dealing with collision avoidance of autonomous ships. Here sorted by publication year.

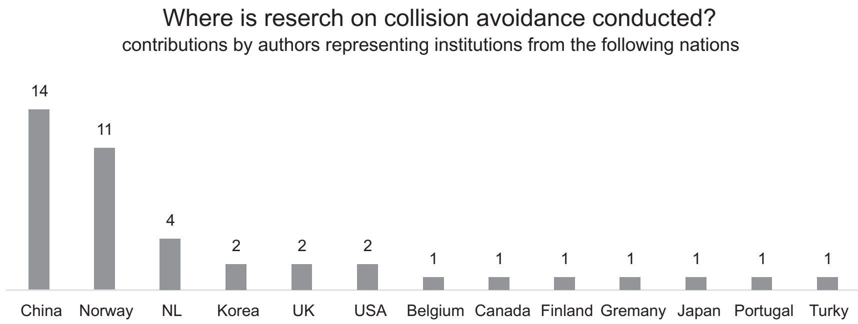

Figure 13.6 Researchers from 13 nations authored the 32 papers dealing with collision avoidance aspects of autonomous ships. The in total 42 national contributions are here divided by country.

41 national universities or institutions. Fourteen of these contributions were from institutions in China, 11 from institutions in Norway, 4 from institutions in the Netherlands, 2 each from institutions in South Korea, the UK, and the United States, and 1 each from institutions in Poland, Canada Belgium, Germany, Finland, and Turkey (see Figure 13.6).

Collision avoidance is the ability to automatically avoid colliding with known or unknown static or dynamic objects. Among various categorizations of collision prevention techniques, Huang et al. (2020a) presented the state of the art in collision avoidance, distinguishing between the following: route planning, which takes place on large-scale maps, for example, planning the route around the Cap of Good Hope (static) or weather routing (dynamic); path planning, which aims at finding a collision-free path on a local map considering static obstacles, for example, following the dredged channel into New Orleans; and reactive collision avoidance focusing on avoiding moving obstacles (ships) or obstacles unknown a priori. Two types of research can be distinguished: (1) the prevention techniques which support the operator in a remote operation centre ashore, for example, collision warnings and decision support for evasive actions and (2) methods applied automatically onboard the MASS, making the ship deviate from the predefined path for collision avoidance. The collision prevention problem in turn contains three sub-problems: motion prediction, conflict detection, and conflict resolution. Huang et al. (2020a) discuss these three methods for predicting the trajectory of other ships: (1) physics-based methods which predict the motion of the other ship based on the present course and speed and the laws of physics (extrapolating current course and speed); (2) manoeuvre-based methods that take the possible manoeuvres of the other ship into account, that is, navigational intentions, which are learned/estimated from historical traffic data or by the protocols for ship encounter situations, for example, COLREGs; and finally, (3) interaction-aware methods that consider the interactions between ships. Specifically, where communications between ships are included or planned trajectory information (intentions) is exchanged.

Woerner et al. (2019) point out that collision avoidance protocols such as COLREGs are written primarily for human operators resulting in a rule set that is open to some interpretation, difficult to quantify, and challenging to evaluate. Increasing use of autonomous control by vehicles emphasizes the need to more uniformly establish entry and exit criteria for collision avoidance rules, adopt means to quantitatively evaluate performance, and establish a "road test" for autonomous ship collision avoidance. Their paper suggests such means to quantify and subsequently evaluate the otherwise subjective nature of COLREGs, thus providing a path towards standardized evaluation and certification of protocol-constrained collision avoidance systems based on admiralty case law and at-sea experience. Theoretical algorithms are presented for evaluation of COLREGs collision avoidance rules, including overtaking, head-on, crossing, give-way, and stand-on rules as well as applicable entry criteria. These rules complement and enable an autonomous collision avoidance road test as a first iteration of algorithm certification prior to vessels operating in human-present environments. Additional COLREGs rules are discussed for future development.

Perera (2018) suggested that there are several milestones to be achieved to make autonomous ship navigation a reality. Remote-controlled ships are one of them. To achieve that, required maritime infrastructure that supports both remote-controlled and autonomous ship operations must be developed. Finally, success in ship intelligence is needed, that is, artificial intelligence to navigate and operate vessels and ship systems. Perera terms autonomous ships as "agent-based". An agent can be defined as a system located in a specific environment; therefore, it interacts with the environment through intelligent decisions and actions to satisfy its design objectives (Perera, 2018). Such intelligent agents should have the following basic properties:

- *Autonomy*: Each agent should operate by its own actions and/or internal states without the direct inference of humans or others.
- *Social ability*: Each agent should interact with other agents (including humans) by appropriate agent-communication language.
- *Reactivity*: Each agent should not only interact with the environment but also respond in a timely fashion to the respective environmental changes and challenges.
- *Pro-activeness*: Each agent should not only interact with the environment but also take appropriate initiatives to exhibit goal-oriented behaviour to satisfy its design objectives.

A considerable section of ship intelligence will consist of a deep-learning-based framework, that is, an artificial neural network. The same framework will create the respective agent behaviour within autonomous vessels (Perera, 2018).

Perera, in a subsequent article (2019), pointed to some “fuzzy regions” where Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) compliant behaviour can be challenging to find.

Kualofor et al. (2019) tested a model predictive control (MPC)-based collision avoidance system in practical sea trials in the North Sea. The sea trials focused on verifying COLREGs-compliant behaviour of an autonomous surface vessel (ASV) in different challenging scenarios using automatic identification system (AIS) data from other ships. The results from the verification exercise show that the MPC approach can find safe solutions in challenging situations, and in most cases demonstrates behaviours that are close to the expectations of an experienced mariner. Also, Lazarowska (2019) found in simulation experiments that an Ant Colony Optimization (ACO) algorithm and a Trajectory Base Algorithm (TBA) were capable of finding a ship’s safe trajectory in collision situations at sea. Perera and Murrey (2019) further studied autonomous ship navigation in a mixed environment, where remote-controlled, autonomous, and manned vessels are interacting, and the problem of predicting ship behaviour on a global and local scale.

Yang et al. (2019) proposed a Shipborne Autonomous Collision Avoidance System (SACAS) using a parallel trajectory planning architecture. Obstacle and ship manoeuvring constraints, COLREGs rules, trajectory optimality, and real-time requirements were satisfied simultaneously in both global and local planning to ensure collision-free optimal navigation in compliance with COLREG rules.

Marley et al. (2020) propose to distinguish between global and local collision avoidance methods. Global methods construct a nominal path which is free of obstacles known prior to the mission. Local methods detect and avoid obstacles encountered during the mission, deviating from the nominal path if necessary. They further proposed that local methods are separated into proactive and reactive methods.

Huang and van Gelder (2020) remarked that collision risk assessment is essential for supporting collision avoidance, which is the core of various collision alert and avoidance systems. One main task of the systems is setting off alarms for taking evasive actions. The alarms need to be triggered before the conflict has no collision-free solution. However, most of the existing collision risk measures are independent of conflict resolution. That means the collision alert does not indicate whether the collision is avoidable or not. They propose an improved time-varying collision risk (TCR) measure.

Zhang and Furusho (2020) claimed that for ships, combined rule-based and neural-based decision-making is the only option. They proposed to use a real AIS ship navigation environment with rule-based and neural-based decision processes with frame motion: further, to train the decision network using a Deep Reinforcement Learning (DLR) algorithm.

Huang et al. (2020b) pointed out that many collision avoidance systems (CAS) for autonomous ships usually presume that a ship's dynamics are completely known in advance. However, precise parameters for ships in different operating conditions are in fact uncertain and unknown. Thus, uncertainties in the ship dynamic model are unavoidable, which can lead to errors between real trajectories and predicted trajectories. These errors might result in an unexpected collision between ships. They proposed a way to incorporate the errors in CAS using a Velocity Obstacle (VO) algorithm to find collision-free velocities with estimated tracking errors.

Liu et al. (2019) claimed that most collision avoidance studies attach more importance to the collision risk between two vessels but failed to obtain the global collision risk in multi-vessel encounters. They proposed a model claimed to be able to assess the collision risk in a multiple vessels-based cooperative game. Simulation studies were carried out for two to five ship situations in the Dover Strait and the Yellow Sea.

Wang et al. (2020) proposed a novel scheme for the distributed multi-ship collision avoidance (CA) problem with consideration of the autonomous, dynamic nature of the real circumstances. All ships in the envisioned scenario cannot share their decisions or motivation, and they make decisions based on limited observable information. Each ship is assumed to have a high-layer intention to guide the CA decision, which is called the collision avoidance logic (CAL). Each ship has its own CAL that governs the CA decisions and actions; meanwhile, each ship tries to understand the CALs of other ships by continuous inference and observation according to their extrinsic behaviours, especially the difference between the observed information and the predicted behaviour. This iterative scheme features a four-phase, programmed decision-making procedure, namely the observatio n–inference–prediction–decision (OIPD) model.

Large ships typically have large inertia and long time delays when manoeuvring. In prevailing collision avoidance methods, their manoeuvrability is generally neglected wherefore there can be a dangerous situation if the system fails to control the ship course as ordered in a timely manner. Zhou, Zhang, and Wang (2021) proposed a coordination system which consists of two algorithms for avoiding risk and then returning to the scheduled waypoint. The collision avoidance algorithm is based on the VO (velocity obstacle) method, and the returning algorithm is derived from LOS (light of sight) guidance.

Han, Wang, and Wang (2022) proposed a global path-guided and local-reactive, COLREGs-compliant guidance strategy for underactuated (see the section on motion control) autonomous ships.

He et al. (2022) tested a dynamic adaptive intelligent navigation decision-making method for multi-object situations in open waters.

Heiberg et al. (2022) incorporated a subset of the COLREGs into a deep reinforcement learning (DRL)-based path following and obstacle avoidance system using collision risk theory. The resulting autonomous agent dynamically interpolated between path following and COLREG-compliant collision avoidance in training scenarios, isolated encounter situations, and AIS-based simulations of real-world scenarios.

Ozturk, Akdag, and Ayabakan (2022) reviewed path planning algorithms of autonomous maritime vehicles and their collision regulation relevance to reveal how the research community handles these issues. Findings pointed to that there are still many traffic rules to be dealt with by path planning algorithms. Algorithms that can be calibrated in terms of safe distance, safe speed, etc. may be deemed more compliant after regulation amendments.

Safety

Under autonomous ship operations, the COLREGs will need to be interpreted by both humans as well as systems during these ship encounters, making their own respective decisions in a mixed environment. Kim et al. (2022) discussed potential safety challenges related to autonomous ship operations in a mixed navigational environment as well as several possible ways to reduce the same issues related to the identified safety risks, while including a discussion for possible future practice and research interests in ship navigation.

Remote-control room operators

van de Merwe et al. (2022) conducted a study which explored navigator roles and tasks in supervisory control of autonomous collision avoidance systems. They compared two cases: one case where the navigator performs traditional collision avoidance from the bridge, and one case where collision avoidance is performed by a collision avoidance system and where the navigator acts as its supervisor. The study demonstrated that by performing a systematic analysis of tasks, with input from COLREGs, procedures, navigators, and observations of collision avoidance manoeuvres, performance requirements could be established.

e-Navigation

Porathe and Rodseth (2019) proposed simplifying collision avoidance using e-Navigation services like route exchange to make ship intentions more transparent. Paired with a simplification of the traffic environment using an extended network of Traffic Separation Schemes (the Route Network Topology model), they suggested that interaction between manned ships and ships in autonomous mode could be facilitated.

Akdag, Solnor, and Johansen (2022) highlighted the importance of collaboration between vessels involved in a collision avoidance situation. They identified gaps ranging from assumptions on communication capabilities and considerations related to non-cooperative actors to cybersecurity concerns and also suggested taking advantage of e-navigation concepts and technologies. In this paper, they provided a high-level outline of a collaborative collision avoidance protocol.

Test scenarios

Trust in collision avoidance systems depends to a large extent on them being tested in all possible scenarios. Bolbot et al. (2022) proposed a systematic and automatic process for the generation of hazardous traffic scenarios that can be employed for testing collision avoidance systems. The process was applied to a cargo ship operating in close proximity to shore, demonstrating a significant reduction in the identified number of scenarios that can be selected for testing either in a virtual environment or full-scale trials.

Anchoring

Autonomous anchoring operations were studied by Cao et al. (2022) and an intelligent detection algorithm for autonomous ships conducting anchor operations was proposed. The objective was to automatically detect and analyse suitable mooring areas at the departure port, the destination port, and in the vicinity of the route, for emergencies, loading and unloading, boarding, disembarking, and waiting for berth. Anchoring operation is affected by wind, wave and current, ship manoeuvrability, the accurate positioning of ships, the congestion of the anchorage, water depth, bottom material grip force, anchoring chain length, anchorage circle radius, and the safety distance between anchored ships. In everyday navigation, ships usually choose a larger anchorage circle radius to ensure anchor safety, which results in a waste of anchorage space.

Proposed controllers, methods, and models in the reviewed papers include the following:

- Ant Colony Optimization (ACO) algorithm, (Lazarowska, 2019).
- Control Barrier Functions (CBFs) based hybrid kinematic controller for obstacle avoidance (Marley et al., 2020).
- Collaborative collision avoidance for MASS (Akdag et al., 2022).
- Finite-time robust containment control (Ma et al., 2022).
- Improved Beetle Antennae Search (BAS) algorithm (Xie et al., 2019).

- Improved real-time "Hybrid A* multi-object-encountering" algorithm (Miao et al., 2022).
- Improved Time-varying Collision Risk (TCR) measure (Huang & van Gelder, 2020).
- Intelligent detection and control algorithm of the mooring area for single anchoring ship (Cao et al., 2022).
- Inverse Reinforcement Learning (IRL) method based on cross entropy and projection (Zheng et al., 2020).
- Model Predictive Control (MPC) (Kufolaor et al., 2019).
- Navigation Situation Clustering Model (Hwang & Youn, 2021).
- Observation–Inference–Prediction–Decision (OIPD) model (Wang et al., 2020).
- Obstacle Collision Avoidance Guidance (OCAG) using obstacle detection with a 2D LiDAR (Kim et al., 2022).
- Route Exchange (Porathe & Rodseth, 2019).
- Ship predictive collision avoidance method (Xie et al., 2019).
- SACAS parallel trajectory planning algorithm (Yang et al., 2019).
- Time dimension-added multiple obstacles avoidance algorithm (Yu & Wang, 2022).
- Trajectory Base Algorithm (TBA), (Lazarowska, 2019).
- Velocity Obstacle (VO) algorithm (Huang et al., 2020b).

MOTION CONTROL

The second largest research domain, with 27 of the 111 papers, was studies related to controlling the motion of autonomous vessels. Ship motion is basically controlled by rudder and propellers, and one would think that problems in this area would have been solved a long time ago given that autopilots have been around for almost a century. However, humans often have to intervene during bad weather conditions, and with no humans onboard, motion control still remains a problem.

The dip in published papers from the pandemic year 2021 is not visible in this domain. A possible reason might be that this kind of research can be made by mathematical simulations which were not affected by pandemic restrictions. The trend of increasing publications is however visible also in this domain.

In motion control, as in collision avoidance, China is the most productive research nation, followed by Poland and Italy.

A basic task in maritime navigation is path planning. Path planning is classified into three stages: route planning, trajectory planning, and motion planning. Route planning is a purely geometric issue, focusing on the characteristics of the path, for example, planning the shortest or safest path

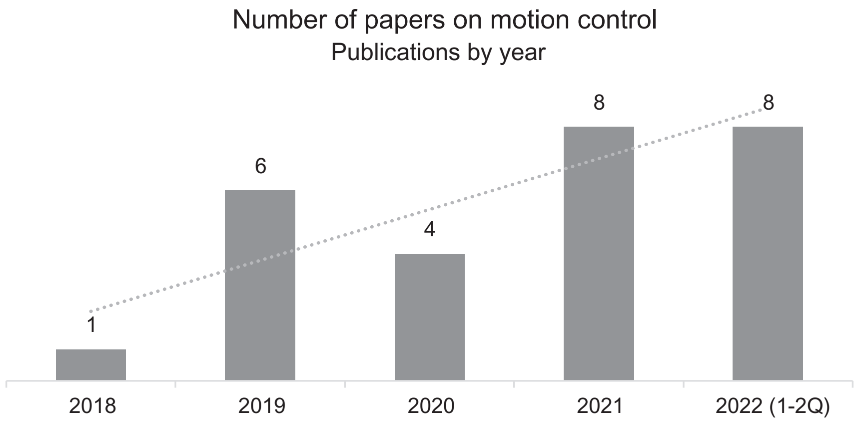

Figure 13.7 In total 27 papers were classified as dealing with motion control of autonomous ships. Here sorted by publication year.

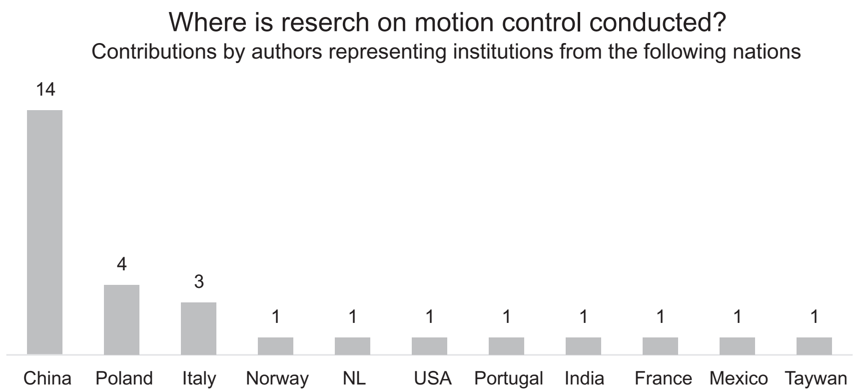

Figure 13.8 Researchers from 11 nations authored the 27 papers dealing with motion control aspects of autonomous ships. The in total 29 national contributions are here divided by country.

between a port of departure and a port of destination, or two waypoints (Du et al., 2019). Trajectory planning is an optimization issue. Besides the path, the kinematics constraints are considered, such as speed, heading, and curvature of a turn. Motion planning is a control issue. Unlike the first two stages, it focuses on whether the planned path can be achieved by the control system (rudders and thrusters).

The motion of large vessels needs to be controlled. Wang et al. (2019) exemplified the following performance characteristics of large ships, whether conventional or autonomous:

- *Large mass, large inertia, slow disappearance of remaining speed*: When a ship has just stopped its engine, the ship's speed drops rapidly due to the large resistance. However, as the speed decreases, the resistance decreases accordingly, and it is difficult to stop the ship completely. Generally, when the ship's speed is 3–4 knots, it has no rudder effect, so the performance of emergency stopping is poor.
- *Poor turning performance*: Because of its large size, the rudder control has a certain rudder turning rate, so course stability and responsiveness are poor.
- *Weak response of applied rudder:* A rudder angle smaller than 5 degrees has little effect and must be corrected with a larger angle.
- *Susceptible to external interference factors*: Ships might be very large, the ship area above the waterline is affected by wind and the area below the water line by current. When large ships suffer crosswinds, the drift velocity can reach 4–5% of the wind speed.
- *Ship–ship and ship–bank effects*: When docking, the pressure difference between the side of the ship, the water, and the shore wall causes the ship to be "dragged". Generally, when the distance between the ship and the shore reaches 1.7 times the width of the ship, the influence of the shore wall can be shown. This effect becomes larger with smaller channel width, shallower water depth, closer to shore, higher speed, and larger hull.

These characteristics lead to several motion control problems.

Tracking

Miller and Walczak (2020) stated that the problem of trajectory modelling and prediction is not trivial. During trajectory estimation, the physical constraints of an autonomous ship must be satisfied. One must determine the minimum turn circle radius, tangent acceleration, and all three velocities (longitudinal, transversal, and angular). Moreover, the generated trajectory needs to be smooth and the ship's velocities along all three axes need to be constant (Miller & Walczak, 2020). For navigators, using waypoint coordinates is the easiest and most natural way of trajectory definition. When plotted on a chart or the Electronic Chart Display and Information System (ECDIS), waypoints are connected with straight line segments. But, due to ship dynamics, the trajectory defined in this way is not feasible, according to Miller and Walczak. When applied to an autonomous ship it generates big errors in control signals on turns, which are undesirable. These errors may be minimized using model-based control strategies combined with reference generation optimization.

Furthermore, according to Rodriguez (2022), ships are subject to parametric uncertainties and external unknown disturbances such as wind, waves, and water currents. In conventional ships the helmsman (nowadays more often the autopilot) is responsible for the motion control, that is, speed and course keeping of a ship. With a technical term most ships are "under-actuated". This means that they have less control actuators than they have degrees of freedom. A ship actuator could be a propeller–rudder system, azimuth pods, thrusters, or water jets of some kind. An old-fashioned ship has only propellers at the stern and if the wind is pushing the bow sideways, the ship must make speed through the water to make up for that leeward movement. Today ships most often also have a bow thruster, but tunnel thrusters will only work at low speeds (typically <4 knots). Other configurations exist and some ships are fully actuated with a "dynamic positioning" (DP) system, allowing them to move at slow speed in any direction and hover in a precise spot. DP systems are an example of an autonomous system that automatically can keep, for example, an oil drilling platform still over a spot while drilling. The drawback of DP systems is that they need more actuators and sensors and thus become more expensive. They are also optimized for station keeping or low speeds, not transiting at standard speed. For autonomous ships, the challenge is to provide systems of motion control that are reliable without constant supervision from a watchkeeper.

A common feature in all levels of autonomy is that the diminished role of the human operator results in a larger role to play for the control systems (Esfahani et al., 2019). This includes control and tracking of a given trajectory with the best possible accuracy and minimum control efforts to decrease fuel consumption. If an autonomous ship cannot adjust the motion control strategy according to the external environment, it is difficult to realize accurate control, which will increase the navigation risk (Wang et al., 2019). Considering the inherent characteristics of large-scale ships such as signal delay and large inertia, accurate and stable motion control is always challenging. All in all, how to design a suitable motion controller is the key to realizing autonomous navigation.

However, the automation of ship steering is old. An autopilot based on a proportional–integral–derivative (PID) ship steering controller was proposed already in 1922. The downside is that the validity of such linear controllers is limited to the course-keeping, since only a small rudder angle action is involved. Once the ship manoeuvre calls for rapid and large course-changing movements, hydrodynamic nonlinearities need to be taken into consideration in the steering controller design (Guan et al., 2022).

Heading control of autonomous surface ships has been treated as a basic yet challenging control problem in marine applications. Precise heading control can be achieved by adjusting the rudder angle; however, ships are usually exposed to wave-induced disturbances, which inevitably leads to a heading angle deviation and frequent regulation of the rudder angle. To address this issue, Ruan et al. (2022) proposed a shared control framework that includes a ship autopilot and a human pilot. The human pilot is responsible for high-level decision-making such as anomaly estimation, anomaly correction, and monitoring analysis, and the ship autopilot is responsible for a low-level task of command following.

However, with the human pilot in a remote-control centre, several new problems arise.

Alessandrini et al. (2019) pointed out that a convenient control system should be able to command the several actuators installed on board during different conditions – for instance, during oceanic navigation, harbour approach, narrow channels, and congested areas. Such tasks are accomplished by different switching controllers for high- and low-speed motion, which must be orchestrated to ensure effective manoeuvring. Alessandrini et al., in their work, looked at a switched controller for switching between four tasks:

- Change position: low-speed path-following.
- Drift-free track: high-speed path-following able to compensate for drift.
- Dynamic positioning.
- Smart pilot: autopilot and speed pilot are simultaneously active.

In many methods, real-time measurements of the kinematic states of the autonomous vessel are required. These measurements depend on costly and delicate sensors. In case of the failure of sensors, these control schemes become unreliable. Deng and Zhang (2021) stated that, generally, the position and the attitudes of the autonomous ship can be easily measured by standard marine devices like GPS and compass. This inspired research on output-feedback control, which only employs the information of position and attitude (Deng & Zhang, 2021). Also, in most of the existing control schemes, the signals collected from the sensors were transmitted to the controller continuously, and the transmission channel was occupied all the time. This set-up leads to a waste of communication resources, which are usually limited in nautical practice. A solution to this question is event-triggered control (ETC). In this method, the signals are transmitted only when the triggering condition is violated.

Furthermore, Ma et al. (2021) proposed a neural-network-based backstepping controller for autonomous ships troubled by external disturbances and actuator dead-zone.

Some papers investigate the "leader–follower" formation problem of multiple underactuated autonomous surface vessels in the presence of model uncertainties and environmental disturbances (Lu et al., 2018; Park & Yoo, 2019; Peng et al., 2019). Leader–follower formations are typically used for bathymetrical surveys, search and rescue, and mine-sweeping operations where the path of a manned or remote-controlled leader vessel should be followed by several autonomous follow crafts.

Xu et al. (2021) suggested an integrated system where autonomous vessels are capable of following a predefined path, while avoiding obstacles automatically. It is different from the most common methods, which usually study path-following and obstacle collision avoidance, separately. This study considered the coupled path following and collision avoidance task. Meanwhile, the study also showed a heading control design method in the presence of static obstacles.

Peng et al. (2021) proposed a reduced- and full-order, data-driven adaptive disturbance observers' method (DADOs) for estimating unknown input gains, as well as the total disturbance composed of unknown internal dynamics and external disturbances.

Berthing

During the process of automatic berthing, an autonomous ship needs to sense its own status relative to the berth accurately in real-time to avoid collision with the infrastructure. Hu et al. (2022) proposed a berthing state perception method based on 3D LiDAR. Currently, most vessels mainly rely on global navigation satellite systems (GNSS) and compasses to obtain position and heading information when berthing. The GNSS positioning accuracy of the open water is metre level without differential calculations. In port, the multipath effect caused by the surrounding buildings may cause the positioning error to reach 50 m, which cannot meet the centimetre-level accuracy requirements of vessel berthing. Using the 3D LiDAR method proposed by Hu et al. will remedy that.

In order to study the influence of wind and wave coupling during berthing, Xiao et al. (2021) explored a berthing computational fluid dynamics (CFD) model with characteristics of speed field, pressure field, and vortex obtained under different wind speeds, wind directions, and quay wall distances. The results provide a control strategy for an unmanned ship's berthing safety and also provide a theoretical basis for unmanned ship route planning, obstacle avoidance, and safety design.

Dynamic positioning

Dynamic positioning is a well-tested function in, for example, the oil and gas industry, however, always supervised by a watchkeeper. An autonomous ship should be able to keep her station or heave-to in a much larger weather envelope. Qu and Cai (2022) developed a nonlinear station keeping controller for underactuated unmanned surface vehicles to resist environmental disturbances and accomplish specific tasks such as marine ecological surveys, maritime search and rescue, and firefighting.

Tomera and Podgorski (2021) studied a ship motion control system with a disturbance observer for the dynamic positioning of a fully actuated autonomous marine surface vessel in the presence of uncertain time-variant disturbances due to wind, waves, and ocean currents.

Dubey et al. (2021) offered a complete experimental study on a steering model identification and control design for autonomous ships.

Proposed control algorithms or methods in the reviewed papers include the following:

- 3D LiDAR berthing state perception method (Hu et al., 2022).
- ADP-based optimal adaptive gains-super-twisting sliding mode control (Esfahani et al., 2019).
- Adaptive Closed-loop Gain Shaping (CGS) control based on Extended Kalman Filter (EKF) Identification Method (Guan et al., 2022).
- Adaptive kinetic control law (Peng et al., 2019).
- Bézier Curve parametrization method (Miller & Walczak, 2020).
- Closed-form nonlinear optimal control law (Chen et al., 2020).
- Control-oriented modelling of a twin thruster hulls (Simetti & Indiveri, 2022).
- Data-Driven Adaptive Disturbance Observers for Model-Free Trajectory Tracking (Peng et al., 2021).
- Distributed guidance control law (Peng et al., 2019).
- Disturbance Observer (OBS) (Lu et al., 2018).
- Duelling deep Q networks prioritized replay reinforcement learning (Gao et al., 2022).
- Dynamic Positioning System with Disturbance Observer for MASS (Tomera & Podgorski, 2021).
- Event-Triggered Composite Adaptive Fuzzy Output-Feedback Control (Deng & Zhang, 2021).
- Finite-time control based on adaptive sliding mode strategy (Rodriguez et al., 2022).
- Lyapunov-based adaptive gains-super-twisting sliding mode control (Esfahani et al., 2019).
- Minimal Learning Parameter (MLP) (Lu et al., 2018).
- Modified Vector Field Path-Following Control System (Xu et al., 2021).
- Neural Network Adaptive Position Tracking Control (Zhang et al., 2020).
- Neural network-based tracking control for MASS with unknown actuator dead-zone (Ma et al., 2021).
- Nonlinear Station Keeping Control (Qu & Cai, 2022).
- Risk-Based Model Predictive Control for Autonomous Ship Emergency Management (Blindheim et al., 2020).
- "RRT*", Optimized Rapidly exploring Random Tree algorithm (Zaccone, 2021).
- Robust-adaptive dynamic programming-based time-delay control (Esfahani & Szlapczynski, 2021).
- Shared control of ship autopilots and human pilots for maritime autonomous surface ship in the presence of actuator anomalies (Ruan et al., 2022).

- Switched controllers (Alessandrini et al., 2019).
- Trajectory-cell model (Du et al., 2019).

Legal and regulatory

This section presents a brief review of papers analysing the issue of unmanned autonomous shipping from the perspective of international maritime law and regulations with a particular focus on crew-related conventions like COLREGs, SOLAS, Standards of Training, Certification, and Watchkeeping (STCW), and Maritime Labour Convention (MLC).

This domain was the third largest among the 111 papers reviewed with 18 papers distributed equally with 2–3 papers per year except for 2020 when 9 papers were published, making the trend line flat (see Figure 13.9). A possible explanation for the peak in scientific publishing in 2020 could be the IMO's regulatory scoping exercise which took place in 2017–2021 and which might have initiated the peak in 2020.

The 18 papers were written by 38 authors representing universities or institutions in 14 nations. Four of these contributions were from institutions in Norway, three from institutions in Australia, two from China, and one each from institutions in Belgium, the Caiman Islands, Croatia, India, South Korea, the Netherlands, Poland Singapore, Sweden, and the United States (see Figure 13.10).

Interesting to see here is that China is no longer the largest contributor when it comes to the publication of research regarding legal and regulatory matters. Instead, it is Norway, Australia, and Japan.

Operation of autonomous ships

Karlis (2018) aimed in his analysis to identify potential operational difficulties that could deter shipowners from investing in or adopting this new

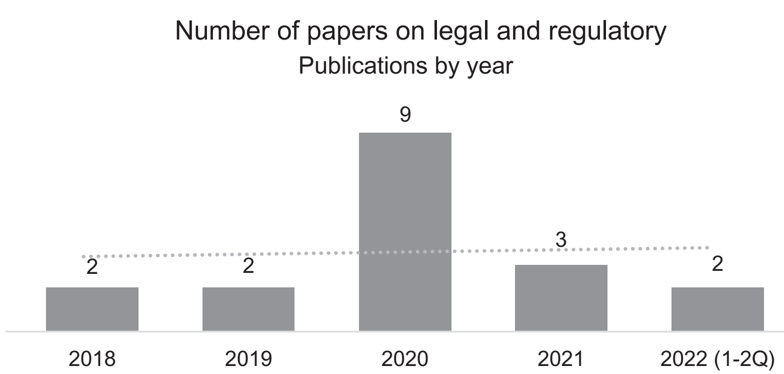

Figure 13.9 In total 18 papers were classified as dealing with legal or regulatory aspects of autonomous ships. Here sorted by publication year.

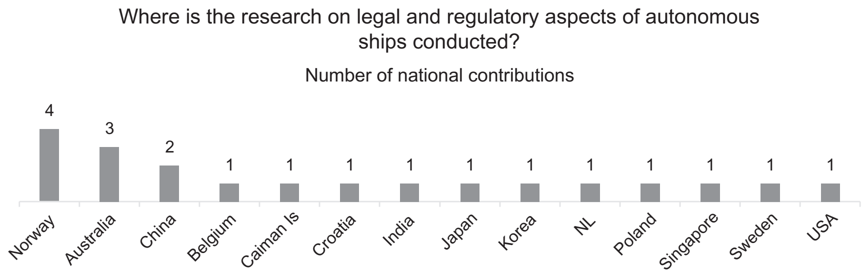

Figure 13.10 Researchers from 14 nations authored the 18 papers dealing with legal and regulatory aspects of autonomous ships. The in total 20 national contributions are here divided by country.

technology. The analysis indicated that there were several areas of ambiguity that could create impediments to a positive investment decision and deter shipowners from adopting the autonomous ship design. One of the problems to be solved in this context was to establish a party or parties responsible for undesired events that may hinder the execution of a transport task, and create safety risks to personnel, ship, cargo, and the environment. Further, Pietrzykowski and Malujda (2018) studied the stages of a transport task and identified areas calling for legislative measures addressing safety, security, and responsibility.

Ringbom (2019) elaborated on the distinction between the level of autonomy and the level of manning and highlighted the sliding scale which features in both. Certain building blocks that are needed for regulating autonomous ships were identified, followed by an assessment of how key existing IMO rules deal with the challenges and an analysis of available precedents. The conclusion was that the then ongoing IMO Scoping exercise was unique, almost without precedent, but that the work, so far in 2019, failed to address the most important – and complex – regulatory challenges.

Jordan (2020) suggested in his study that the legal challenges with autonomous unmanned ships are not insurmountable. The regulations at any level can always be amended to accommodate new developments. The bigger question, however, is whether there is a societal acceptance and preparedness in the maritime community and beyond to make changes to accommodate unmanned shipping. If that is positive, the legal challenge is reduced to identifying the key rules that need adjustments and making the amendments. The amendments could possibly even be in the form of a generic acceptance of certain key issues of principle, such as the possibility to perform on-board functions from a remote location and the relationship between crew responsibilities and automated functions.

The ongoing development of diverse maritime autonomous vehicles for varied ocean activities – ranging from scientific research, security surveillance, transportation of goods, military purposes and commission of crimes – is prompting greater consideration of how existing legal frameworks accommodate these vehicles. Klein et al. (2020) presented the core legal issues, as well as current developments in relation to commercial shipping, the law of naval warfare, and maritime security. The article captured how these issues are being addressed and what other legal questions will likely emerge as the newest technology impacts on one of the oldest bodies of international law.

The development of uncrewed maritime vehicles has the potential to increase the scale of military maritime surveillance in the exclusive economic zones of foreign coastal states. McKenzie (2021) considered the legal implications of the expanded use of autonomous ships for this purpose. He shows how features of the legal regime – namely how its application depends on determining the intent of a vessel's operation (to distinguish marine scientific research from military surveillance), as well as the obligation to have due regard – have a "dynamic" quality that will pose a challenge to uncrewed maritime vehicles operated by autonomous technology. The legal obligations will require equipping such vessels with the capacity to communicate something about their identity, the purpose of their mission, and to be able to have some capacity to be responsive to the economic and environmental interests of the coastal state.

Carriage of goods

When performing the carriage of goods by sea, each contracting party, shipowner, and charterer has a number of rights and obligations. In legal sources which regulate the carriage of goods by sea, international conventions and national laws, a standard clause is the shipowner's obligation to provide a seaworthy vessel. Such obligation implies that the vessel must be able to carry and keep the contracted cargo in good condition and also have the required number of qualified crew. Pijacar and Bulum (2021) compared problems related to the carriage of goods by sea between traditional and autonomous vessels, regarding the regulation of seaworthiness, safe port warranty, liability, the limitation of the shipowner's liability, and exclusion of liability. The results of this comparison lead to the conclusion that reconsideration of the content of the listed terms is needed when we are talking about the carriage of goods by sea by autonomous vessels.

Definitions

Suri (2020) discussed the conundrum of the lack of international definition of the concept of "ship". UNCLOS uses interchangeably the terms "ship" and "vessel". But the legal definition lands on national law which might differ from country to country. The question this paper tried to answer was whether the current regulatory framework allows for the admission of the autonomous vessel as a 'ship' in the private law domain. The discussion is interesting because generally the law governing what claims can be achieved by way of detaining a "ship" is known as "the Admiralty law" of the country, a specialization within the broader term "maritime law". A particular type of claim distinctive to admiralty laws is *in rem* claims which gives a claimant the right to arrest and auction the "ship" and satisfy its claim against the proceeds if the shipowner fails to provide alternate security in court. Conclusively, a vessel that fails to come within the definition of a "ship" under a country's admiralty laws would destroy the right to claim *in rem*.

Taxonomies provide a context for coining new names and applying existing ones. This is important for definitions and communication in a new developing domain. The concept of autonomous mobile robots (AMR) has gained much popularity in recent years, particularly in commercial settings where the name industrial autonomous mobile robot (IAMR) is proposed. In addition to automatic guided vehicles and automated mining trucks, IAMR also includes autonomous merchant ships. AMR is an old concept which was first introduced in the 1980s. Although the concept of AMRs is old and broadly used, there is still no common definition of autonomy where mobile robots are concerned. Rodseth and Vaga (2020) undertook to review some of the most known definitions and develop a taxonomy for autonomy in mobile autonomous robots. This is to be used to compare the different definitions of robotic autonomy. The paper mainly looked at IAMR, that is, systems that are designed to operate with a clear commercial objective in mind and which are normally supported by a remote control centre. This means that the robot is not fully autonomous but to varying degrees dependent on humans in some control and monitoring functions.

Flag states

Shipping is a highly regulated industry with a vessel's flag state having responsibility for ensuring that vessels registered under its flag comply with the numerous international regulations. The jurisdiction of vessels is determined by the United Nations Convention on the Law of the Seas (UNCLOS). Balls (2020), however, claimed that it is still possible to progress the introduction of new technology and IMO's interim guidelines for Maritime Autonomous Surface Ships (MASS) trials – MSC.1/Circ.1604 – making it clear that flag states have the primary responsibility for the safe operation of MASS.

Inland navigation

Backalov (2020) presented an analysis of technical regulations addressing the safety of inland cargo vessels in Europe, in light of the developments leading towards the introduction of autonomous ships in inland navigation. The regulations are scrutinized with respect to the role of human operators in attaining the appropriate level of safety on inland vessels, as well as in view of possibilities for the remote control and remote execution of safety functions on the vessels. The paper specified some of the technical requirements, contained in the regulations, which ought to be amended in order to improve the conditions for the introduction of autonomous inland vessels.

COLREGs

At present, there is much discussion in the maritime industry on, if, and how the COLREGs will need to be amended to be able to be applied to MASS.

Porathe (2019) discussed whether the present quantitative, collision regulations need to be updated to rules where expressions such as "early" and "substantial" are quantified, or if ships can sail autonomously under the present rules? Another question was if autonomous ships should be marked to signal that the ship is in autonomous mode or if it is enough that she follows COLREGs? The paper advocated *automation transparency*, meaning that the behaviour of an autonomous vessel must make sense and be understandable to human operators on other manned ships and craft.

Zhou et al. (2020) reviewed the literature on autonomous ships from the perspective of the obligation of good seamanship imposed by COLREGs. The authors concluded that to facilitate the introduction of autonomous ships, the application barriers presented by COLREGs need to be analysed. With this goal, this paper presented a perspective from navigational practice. Four nautical scientists and two deck officers were invited to give their opinions. The analysis indicates that COLREGs require further elaboration and amendments to eliminate the uncertainty of interpretation. In particular, the paper highlights the need to amend the look-out-rule (Rule 5) to permit look-out by computer vision alone while, at the same time, preserving the distinction between vessels navigating in restricted visibility and in sight of one another.

Hannaford et al. (2022) presented an exploratory study with insights from a sample of licensed deck officers regarding the potential future of the COLREGs with the implementation of unmanned autonomous ships. The results showed that many barriers exist when applying the COLREGs to autonomous ships, and minor amendments to certain terms and definitions are recommended. Moreover, the COLREGs should not be quantified, and autonomously navigating vessels should be identifiable from other ships. Deck officers with more experience with practising the COLREGs are found to be slightly more open to changing the rules versus deck officers with less experience. When compared to the results of the IMO's regulatory scoping exercise, the results of this study were found to be in congruence.

Miyoshi et al. (2022) presented answers to questionnaires received from 130 pilots, ship captains, and navigation officers concerning COLREGs for autonomous operation. They discussed the rules from the perspective of seafarers who need to interpret COLREGs when dealing with situations involving autonomous ships at sea. They also discussed possible required amendments to COLREGs. They concluded that in order to continue achieving the end-goal of COLREGs, which is to avoid collisions, the actions of autonomous ships must be predictable to seafarers on conventional vessels. For Look-out (Rule 5), a numerical standard for autonomous ships would be beneficial. When given a literal interpretation, autonomous ships are counted as power-driven vessels, and the presumption that all COLREG rules would be applied to them is strong. In the foreseeable future, conventional and autonomous ships will need to communicate well, trust each other, and perform give-way/stand-on vessel manoeuvres.

Remote operators

Choi and Lee (2021) discussed the legal status of a remote operator of MASS, and the possibility of granting them status as a ship employee or master. The authors argued that the status of seafarer or master should be required also for autonomous ships. The study presented an expanded notion of seafarers by extending the combination of ship and seafarers to remote operators of autonomous ship employees. Further, it suggested that remote operators should be regarded as seafarers and a master with perpetuated status as the final person responsible for the ship.

SOLAS

The absence of people on board an autonomous ship and the associated safety measures could result in a more efficient design, but amendments to the existing regulatory framework will be needed. In their article, de Vos et al. (2020) discussed potential changes in the Convention for Safety Of Life At Sea (SOLAS) and in particular in the Required Subdivision Index. The index gives a requirement for the allowed probability of sinking when a ship is damaged due to collision. The evaluation was performed by using the principle of equivalent safety, which will ensure that unmanned ships will be at least as safe as manned ships. If the crew is no longer present, the consequences of an incident will be less severe, since the probability of casualties is no longer present. Consequently, a lower subdivision index could be accepted for unmanned autonomous ships.

Insurance

Wilhelmsen and Bull (2020) suggested that insurance of autonomous ships does not raise many challenges for the parties to a hull insurance contract based on the Nordic Marine Insurance Plan. The insurance covers computers and programmes, but probably not data, which must be protected by an alternative cover. This is a natural consequence of hull insurance being a casualty insurance covering physical objects. However, in order to avoid uncertainty, this should be clarified. Further, the starting point is that system failure and cyberattacks that are not war-related are covered, and war risk cover is provided for cyberattacks by pirates, saboteurs, terrorists, or foreign states. The only immediate problem Wilhelmsen and Bull saw from the assured's perspective is the need for clarification on how the rules on identification apply to remote crew.

Risk management

This section presents nine papers classified as dealing with the risk management of autonomous ships. This domain was the fourth largest among the 111 papers in the sample and the publication year showed a rising trend with one paper published in 2018 and 4 in the first half of 2022 (see Figure 13.11).

The nine papers were written by authors representing universities or institutions in six nations. Six of the papers were written by, or had contributions from, institutions in Norway, three papers had contributions from institutions in Finland, and three from Poland, two from China, and one each from institutions in the Netherlands and the UK (see Figure 13.12).

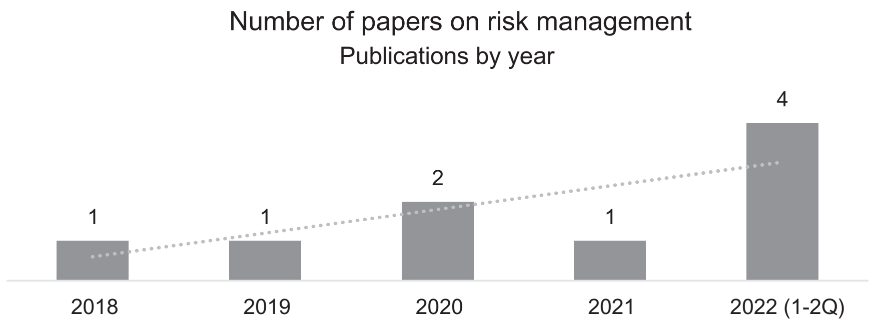

Figure 13.11 In total nine papers were classified as dealing with the risk management aspects of autonomous ships. Here sorted by publication year.

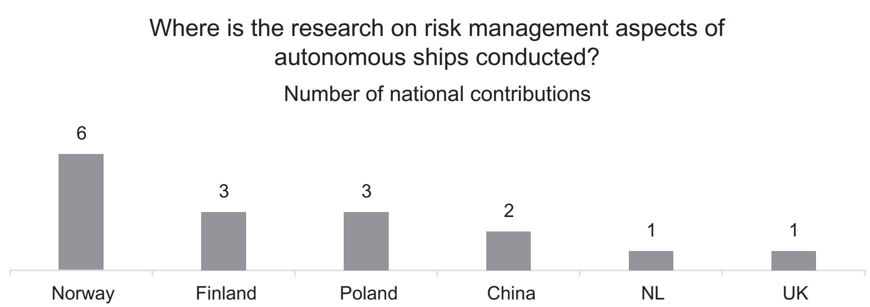

Figure 13.12 Researchers from six nations authored the nine papers dealing with risk management aspects of autonomous ships. The in total 16 national contributions are here divided by country.

Again, it is interesting to note that Chinese researchers, who greatly outnumbered other nations in the collision avoidance and motion control domains, here only are represented by one paper, while Norway is represented by six authors.

Marine Autonomous Surface Ships (MASS) are tested in public waters. A requirement for MASS to be operated is that they should be at least as safe as conventional ships. Thieme et al. (2018) investigated how far the current ship risk models for ship–ship collision, ship–structure collision, and groundings are applicable for risk assessment of MASS. Nine criteria derived from a systems engineering approach were used to assess relevant ship risk models. These criteria aimed at assessing relevant considerations for the operation of MASS, such as technical reliability, software performance, human–machine interfaces, operations, and several aspects of communication. From 64 assessed models, published since 2005, ten fulfilled six or more of these criteria. These models were investigated more closely. The authors' conclusion was that none of them were suitable to be directly used for risk assessment of MASS. However, they can be used as the basis for developing relevant risk models for MASS, which especially need to consider the aspects of software and control algorithms and human–machine interaction.

The Norwegian University of Science and Technology (NTNU) was designing a small autonomous passenger ferry for up to 12 passengers. The ferry bridges a harbour channel in Trondheim, Norway. Thieme et al. (2019) presented the results of the preliminary hazard analysis conducted in the early design phase of the ferry. The main hazards were associated with software failure, failure of communication system, both internal and external, traffic in the channel, especially kayaks, passenger handling and monitoring, and weather conditions. In addition, the paper summarized the practical challenges encountered in the ferry project. These challenges were related to available hazard and risk analysis methods and data, determining and establishing an equivalent safety level, and some of the prescriptive regulations currently in use by the Norwegian Maritime Authority. The presented analysis and identified challenges may assist other, similar projects designing and developing autonomous vessels.

Fan et al. (2020) proposed a framework for the identification of factors that influence the navigational risk of remotely controlled MASS without crew on board. In the framework, four operational phases were considered: voyage planning, berthing and unberthing, port approaching and departing, as well as open sea navigation. For each phase, four types of factors were assigned related to humans, ships, environment, and technology. To populate the framework, a literature review was conducted, which was further supported by the elicitation of expert knowledge. As a result, 23 human-related factors, 12 ship-related factors, 8 environment-related factors, and 12 technology-related factors were identified. The proposed framework can be employed for any risk and safety analysis related to remote-controlled MASS. This, in turn, may assist the processes of design and operational planning of maritime transportation systems accommodating MASS and its remote control centre.

Wrobel et al. (2020) attempted to identify research directions of a remotely controlled merchant ship by revisiting her system-theoretic safety control structure. The authors claim that despite the concept of MASS being in the limelight of research and development efforts within the shipping industry, there are still some existing research gaps. These relate not only to technical solutions to be implemented but also to the issue of the impact of new technology on maritime safety. To identify these gaps, they performed a literature review of the operational features of remotely controlled merchant vessels. The framework was based on a safety control structure developed in accordance with the principles of System-Theoretic Process Analysis (STPA). The results indicated that most scholars focus on the high-end components of the system, while organizational and human-oriented issues remain under-explored.

Despite the expected benefits of reducing human error and significantly increasing the overall safety level, the development of autonomous ships would undoubtedly introduce new risks. Chang et al. (2021) aimed to develop an approach to evaluate the risk level of major hazards associated with MASS. To that extent, a Failure Modes and Effects Analysis (FMEA) method was used in conjunction with Evidential Reasoning (ER) and a Rule-based Bayesian Network (RBN) to quantify the risk levels of the identified hazards. The results showed that interaction with manned vessels and detection of objects contributed the most to the overall risk of MASS operations, followed by cyberattacks, human error, and equipment failure. The findings provide useful insights on the major hazards and can aid the overall safety assurance of MASS.

Analysing the reliability of autonomous ships has recently attracted attention mainly due to epistemic uncertainty (lack of knowledge) integrated with automatic operations in the maritime sector. The advent of new random failures with unrecognized failure patterns in autonomous ship operations requires a comprehensive reliability assessment specifically aiming at estimating the time during which the ship can be trusted to be left unattended. While the reliability concept is touched upon well throughout the literature, the operational trustworthiness needs more elaboration to be established for system safety, especially within the maritime sector. BahooToroody et al. (2022) took a probabilistic approach to estimate the trusted operational time of the ship machinery system through different autonomy degrees. The uncertainty associated with ship operation was quantified using Markov Chain Monte-Carlo simulation from a likelihood function in a Bayesian inference. To verify the developed framework, a practical example of a machinery plant was used for a typical short sea merchant ship. The study can be used by asset managers to estimate the time in which the ship can be left unattended.

Autonomous ferries are providing new opportunities for urban transport mobility. With this change comes a new risk picture, which is characterized to a large extent by the safe transition from autonomous mode to manual model in critical situations. Hoem et al. (2022) presented a case study where the authors applied an adapted risk assessment method based on the Scenario Analysis in a Crisis Intervention and Operability (CRIOP) framework. The study focused on the applicability of the scenario analysis to address human–automation interaction. This was done using a prototype of a Human–Machine Interface (HMI) in the land-based control centre for an autonomous ferry. Hence, the paper presented findings on two levels: a method study and a case study. A concept of operations (CONOPS) and a preliminary hazard analysis provided the foundation for the scenario development, the analysis, and the discussion in a case study workshop. The case study analysed a handover situation where the autonomous system asked for assistance from the operator in the remote control centre. The results included a list of identified safety issues such as missing procedures, an alarm philosophy, an emergency preparedness plan, and a need for automation transparency. Findings from the study showed that the scenario analysis method can be a valuable tool to address the human element in risk assessment by focusing on the operators' ability to handle critical situations.

Johnsen et al. (2022) described the hazards and mitigation of risks for operating automated ferries in sheltered waters in Norway. Two cases were explored, one with 25 persons onboard close to shore, and another involving fjord crossing with 130 passengers onboard. The approach was based on the Formal Safety Assessment (FSA) framework specified by the IMO. The first step was Hazard Identification (HAZID) in collaboration with key stakeholders (manufacturers, maritime authorities, operators, and researchers), based on action research building on the experience and risk perception of the stakeholders. The HAZID was based on prior incidents, safety critical task analysis, and hazards that may impact personnel safety and security. They identified key areas of concern: fire, collision/grounding, man-overboard, evacuation, and the ferry capsizing. They suggested design approaches/measures to reduce probabilities of hazard occurrence and/or mitigate consequences. Challenges of non-failsafe situations must be handled through emergency response centres and mobilization of passengers.

Johansen and Utne (2022) developed online risk models that could be updated as conditions changed, using risk as one metric to control an autonomous ship in operation. The paper extended and integrated the System-Theoretic Process Analysis (STPA) and Bayesian Belief Networks (BBN) with control systems for autonomous ships to enable supervisory risk control. The risk metric was used in a Supervisory Risk Controller (SRC), which considered both risk and operational costs when making decisions. This enabled the control system to make better and more informed decisions than existing ship control systems. The novel control system was tested in a case study where the SRC could change depending on (1) which machinery system was active; (2) which control mode to run the ship in;

and (3) which speed reference to follow. The SRC was able to choose the optimum machinery, control mode, and speed reference to maintain safe control of the ship over a route in changing conditions.

Business and logistics

This section presents the nine papers classified as dealing with the business and logistical aspects of autonomous ships. This domain also showed a rising publication trend with no paper published in 2018, one in 2029, two in 2020, and four in 2021. Also, two papers were published in the first half of 2022 (see Figure 13.13).

The nine papers were written by authors representing universities or institutions in nine nations. Five of the papers were written by or had contributions from institutions in Norway, two papers had contributions from institutions in Finland, two from Korea, and one each from institutions in Australia, Belgium, China, the Netherlands, Poland, and the UK (see Figure 13.14).

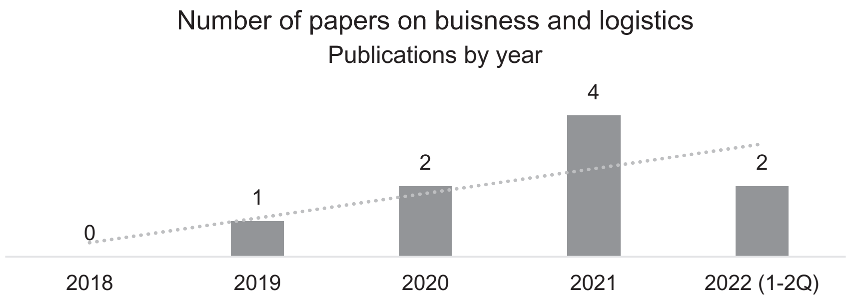

Figure 13.13 In total nine papers were classified as dealing with the business and logistics of autonomous ships. Here sorted by publication year.

Figure 13.14 Researchers from nine nations authored the nine papers dealing with the business and logistics aspects of autonomous ships. The in total 14 national contributions are here divided by country.

The maritime industry has continuously transformed the nature of its business and strived to embrace technology in many aspects. In this context, autonomous technologies have been receiving momentum with a potential to revolutionize the business landscape of the shipping industry. Ghaderi (2019) conducted a comprehensive literature review on the issues facing the short sea shipping industry and developed a model to explore the potential savings by removing crew and using autonomous technologies in a Continuously Unmanned Ship (CUS) that is operated by a Shore Control Centre. The analysis showed that autonomous technologies are workable given the challenges that the shipping industry is facing in terms of crew costs and skill shortages. To validate this statement, a case study was conducted and various scenarios were tested based on relevant operational and financial considerations, including crew arrangement, cargo utilization levels, and shore wage coefficients. The results suggested that savings occur in a demand-uncertain market where a network of vessels operates via a remote control centre. While autonomous technology use in shipping holds promises, there remain several limitations in terms of implementation, commercial attractiveness, risk profile, legislative, workforce planning, and port operations.

Chae et al. identified in a study published in 2020 the current development status of technologies for autonomous ships and discussed considerations and directions for improvements. They presented six major research fields that must be covered to realize MASS operations:

1. Roles: A clear identification of whether seafarers are onboard or not, depending on the degree of autonomy, and a clear classification of the personnel's responsibilities for tasks onboard or remotely. Further, new standards for the definition of seafarer and a clear division of the roles and responsibilities of remote operators and the captain.
2. Various types of decision-making systems were identified, and future directions were suggested.
3. Design changes for autonomous cargo ships and ship design and propulsion systems were investigated and potential impacts were considered.
4. Communication systems will need to be robust and supported by multiple systems to minimize potential risks from third-party infrastructures. Suitable protection of systems, networks, and data will be required as an integral part of the safety system for cybersecurity.
5. Issues of maintenance and repair were identified, with a maintenance strategy to be considered.
6. Hazard analysis of the autonomous ship was explored, and system-theoretic process analysis (STPA) and the functional resonance analysis method (FRAM) were identified as the most representative new methods that can be used for hazard analysis of autonomous ships.

Gu et al. (2021) presented a review of the literature on autonomous ships in general. Most of the published articles focused on navigation control and safety issues. Studies regarding other topics, such as transport and logistics, were very limited. Although their main interest was the literature on autonomous vessels, they compared its development with autonomous cars to have a better understanding of the future potentials in the research on autonomous vessels. The comparison showed that there are great opportunities for research on transportation and logistics for autonomous vessels. Finally, several potential research areas regarding logistics with autonomous vessels are proposed.

Kim et al. (2020) investigated the individual and combined impact of MASS on regulations, technologies, and industries in response to the new paradigm shift in the maritime sector. Additionally, other key issues including safety, security, jobs, training, and legal and ethics were addressed to find a solution for efficient, reliable, safe, and sustainable shipping in the near future. They suggested that holistic approaches for developing the technology and that a regulatory framework must be implemented.

While successful trials for autonomously navigating ships have been conducted, no commercial unmanned cargo ships are currently operating. However, there are solutions that would allow for low-manned ship concepts long before fully unmanned ships become possible. There are many drivers for low-manned and unmanned shipping, ranging from the availability of the workforce to increased safety and economy. Kooij et al. (2021) investigated the economic viability of several low-manned ship concepts as well as the unmanned ship concept for a short sea container vessel. The operating costs of these concepts were compared to those of a conventional vessel. That way, an assessment could be made of the economic viability. The results showed that the low-manned concepts investigated in the article are worthwhile for the ship owner as some savings can be achieved. Also, the economic viability of the unmanned concept is dependent on the chosen type of propulsion.

Introducing product–service–software systems (PSSS) to the market requires forming an enabling ecosystem, which can be largely based on current business ecosystems. Creating value through PSSS with autonomous capabilities will likely encounter numerous challenges related to the lock-ins in current ecosystem structures. Tsvetkova et al. (2021) used institutional theory as a lens and autonomous ships as the case to shed some light on the types and impacts of these barriers. They identified a set of institutional barriers related to regulatory, normative, and cultural cognitive pillars of institutions. They further analysed how institutional barriers affect creating, delivering, and capturing the value of autonomous ships, ultimately shaping the ecosystem formation around PSSS. The main contribution of the paper was the depiction of early ecosystem dynamics as the mutual adaptation of the PSSS value proposition and the structure of the current ecosystem.

The expected benefits of MASS include increased safety, reduced costs, and increased earning potential due to operational efficiencies and reduction in vessel manning. However, autonomous shipping bears greater potential than just replacing humans with machines. Rather, MASS can play a role in transforming supply and logistics chains. The value-creation potential of these ships depends on the degree to which they disrupt logistics. Tsvetkova and Hellstrom (2022) clarified how MASS can create value and for whom, as well as how different actors in the maritime logistics ecosystem are able to monetize or otherwise benefit from the innovation. Based on interviews with experts in maritime logistics and autonomous technology, and a desktop study of the opinions of the leaders in maritime innovation, Tsvetkova and Hellstrom analysed the different facets of value creation by MASS. They distinguished between the two key sources of value – on-board crew reduction and increased ship intelligence and their effects (cost reductions, earning potential, increased safety, and system value) – and clarified for which actors in the ecosystem the value is created. They identified the key changes in the maritime logistics ecosystem, which concern the changing roles of technology providers, shipowners, and operators, and highlighted the need for developing complementary infrastructure and activities in the ecosystem.

Arctic

Munim et al. (2022) investigated the competitiveness of various autonomous ship categories for container shipping on the Arctic routes. They proposed a multi-criteria decision-making (MCDM) framework using four ship categories as alternatives and eight criteria for competitiveness evaluation. They analysed collected data using the Best–Worst Method (BWM), one of the recently developed MCDM methods. Their findings revealed that operating expenses, navigation aspects, and environmental protection are the three most important criteria for deploying autonomous ships for the Arctic route. Among the three investigated autonomous ship alternatives, a semi-autonomous ship operated from a shore control centre (SCC) was prioritized for Arctic shipping in the foreseeable future, when benchmarked against the conventional ship. The SCC-controlled semi-autonomous ship alternative was competitive in the majority of the considered criteria, including operating expenses, capital expenses, navigation, ship–shore and ship–ship communication, search and rescue, and environmental protection.

Cost–Benefit Analysis

In-depth cost and benefit estimation of autonomous ship technology is in its infancy. Ziajka-Poznanska and Montewka (2021) presented a state-of-the-art analysis regarding the costs and benefits of the operation of prospective autonomous merchant ships with the objective of identifying contemporary research activities concerning an estimation of operating, voyage, and capital costs in prospective, autonomous shipping, and vessel platooning. Additionally, the paper outlined research gaps and claimed a need for more detailed business models for operating autonomous ships. Results revealed that valid financial models of autonomous shipping are lacking and there is significant uncertainty affecting the cost estimates, rendering only a reliable evaluation of specific case studies. Findings in this paper may be relevant not only for academia but also for organizations considering undertaking the challenge of implementing MASS in their operations.

Human Factors

This section presents the seven papers classified as dealing with Human Factors of autonomous ships. This number was surprisingly small considering that many papers in other domains pointed to problems and the need for Human Factors research. If one can talk about a trend with so few papers, the trend is rising with four papers published in the first half of 2022 (see Figure 13.15).

The seven papers were written by authors representing universities or institutions in five nations. Three of the papers were written by, or had contributions from, institutions in Norway, one paper each had contributions from institutions in Italy, Japan, the Netherlands, and Sweden (see Figure 13.16).

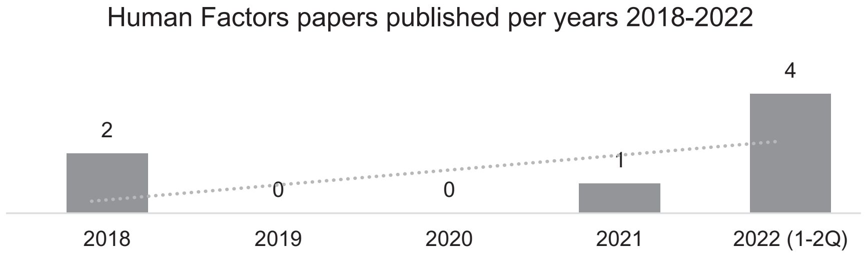

Figure 13.15 Number of papers classified as dealing with the Human Factors aspect of autonomous ships.

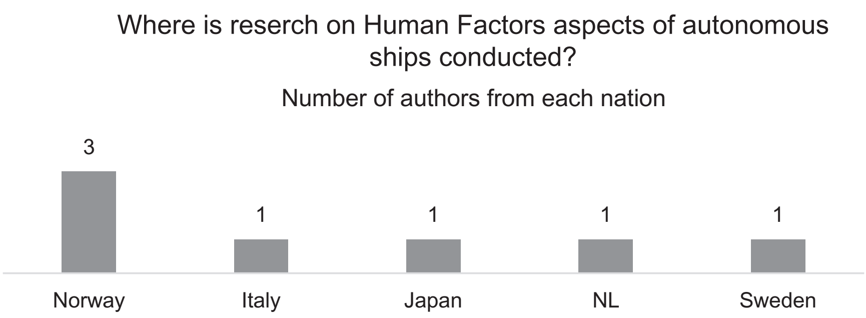

Figure 13.16 A total of seven researchers from five nations authored the seven papers dealing with Human Factors aspects.

It is again surprising that the large research community in China has made no contribution to this area.

Many researchers promise a shipping industry that is safer, greener, and more efficient with unmanned, autonomous vessels. Various studies claim that the number of maritime accidents involving what is called “human error” range between 70% and 90%. Could it be that if the human is replaced by automation, we then reduce the number of accidents? This question was discussed by Porathe et al. (2018). The author’s answer is that humans will remain in remote-control centres, maintenance, and as programmers of automation. Automation has also the potential of creating new accidents, for example, in the transition between automatic and manual control or when human operators, which are out of the loop, have to rapidly step in and make decisions.

Man et al. (2018) developed a remote supervisory control prototype on top of a fully-fledged ship bridge system to support the monitoring and controlling of remote-simulated unmanned cargo vessels. The results suggested that Human Factor issues could remain in systems assembled by assumed reliable technological components. Prominent challenges include psychophysical and perceptual limitations for the operators, decision-making latencies, and automation bias which is applicable to usability issues of interfaces, deprivation of ship sense, and lack of current regulatory oversight.

On any given ship, a large range of tasks is performed every day, each of which needs to be replaced in such a way that no human presence is required onboard. Kooij, Kana, and Hekkenberg (2021) discussed different possible combinations of tasks to be replaced. The findings were an overview of the most beneficial combinations of tasks to replace together and a logical sequence in which to replace them. This led to a plausible implementation path from low-manned ships towards fully unmanned autonomous ships.

Remote operators’ sources of information differ greatly from on-board sensors in terms of perspective, field of view, and available data type (qualitative or quantitative). Kato and Horiguchi (2022) studied the cognitive effects of first- (egocentric) and third-person (exocentric) perspectives on ship handling. The results revealed that (1) the cognitive characteristics of the egocentric (camera) perspective make it more effective in safely guiding ship manoeuvring than does the exocentric chart) perspective, and (2) the deviation in cognitive characteristics is prominent where collision can be easily avoided.

The question of Human-in-the-Loop (HITL) or Human-out-of-the-Loop (HOOTL) will come into focus in the development of automation for autonomous unmanned ships. Operators in remote operation centres (ROC) will be faced with the challenge of quickly getting into the loop when autonomous ships they monitor, after long periods of perfectly working automation, suddenly need assistance. Porathe (2022) proposed a Quickly Getting into the Loop Display (QGILD) to facilitate emergency handover from automation to human control.

Veitch and Alsos (2022) made a systematic review of human–AI interaction in autonomous ship systems. They included 42 studies about human supervision and control of autonomous ships addressing three research questions: (a) How is human control currently being adopted in autonomous ship systems? (b) What methods, approaches, and theories are being used to address safety concerns and design challenges? (c) What research gaps, regulatory obstacles, and technical shortcomings represent the most significant barriers to their implementation? They found that (1) human operators have an active role in ensuring autonomous ship safety above and beyond a backup role, (2) system-theoretic process analysis and Bayesian networks are the most common risk assessment tools in risk-based design, and (3) the new role of shore control centre operators will require new competencies and training.

Trust in automation and autonomy is an important and complex mental construct. With the goal of increasing the understanding of future operational maritime tasks, de Rosa and Strode (2022) designed the Maritime Unmanned Systems Trust (MUST) Game. The MUST Game is an analytical game which captures the beliefs, attitudes, and perspectives of the participants with respect to the employment of autonomous maritime applications.

Sensors and ICT

This section presents the four papers classified as dealing with sensors and ICT on autonomous ships. This number was surprisingly small considering the many technical challenges in this domain. If one can talk about a trend with so few papers, the trend is falling with no found papers published in the first half of 2022 (see Figure 13.17).

Of the four authors of the four papers, two came from Norwegian universities or research facilities and one each from Polish and South Korean universities (see Figure 13.18).

The four papers were written by authors representing universities or institutions in three nations. Two of the papers were written by or had contributions from institutions in Norway, and one paper each had contributions from institutions in the Republic of Korea and Poland (see Figure 13.18).

With the development of information and communications technologies (ICT) in recent years, various digital technologies and automation technologies are also used in the shipbuilding/shipping industry, and the existing closed structure is changing to an ICT-based open structure. If the various systems (navigation communication, engines, etc.) installed and operated on ships previously have been stand-alone units, they have now become integrated into widespread ship-operating systems which integrate data and share mutual information through networking. Moreover,

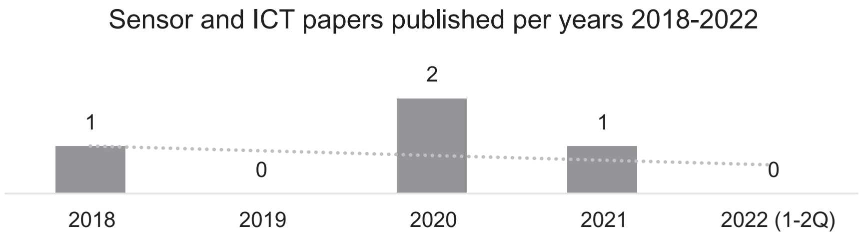

Figure 13.17 Number of papers classified as dealing with the sensor and ICT aspects of autonomous ships.

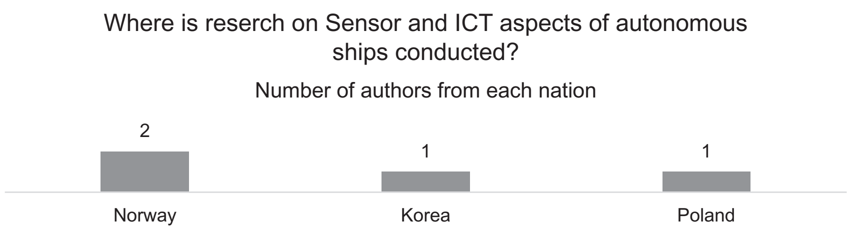

Figure 13.18 Researchers from three nations authored the four papers dealing with sensor and ICT aspects of autonomous ships. The in total four national contributions are here divided by country.

the development of the hyper-connectivity and super-intelligence technology of the Fourth Industrial Revolution has a rapid and widespread influence on the shipbuilding and shipping industry. Im, Shin, and Jeong (2018) designed a smart autonomous ship architecture for unmanned ships by using Intelligence Information Technology (IoT, Cloud, Bigdata, Mobile, Security + AI) and a remote ship operation and management system that can operate it safely, economically, and efficiently. In their paper, they derived the technology through the analysis from various angles such as the components of the ship, characteristics of shipping logistics, duties and roles of the crew, applications of intelligent information technology and a proposed Smart Autonomous Ship and Shore Architecture in which the information between the Smart Autonomous Ship and the Data Centre is converged and is organically integrated and operated by applying these technologies to a Smart Autonomous Ship and a Shore Data Centre.

Sensor fusion plays a key part in autonomous surface vehicles. However, the cost of sensors makes the barrier of entry in this research field quite high. Helgesen et al. (2022) presented a complete system for sensor fusion on the Norwegian milliAmpere autonomous ferry research platform as well as an open sensor fusion dataset for maritime tracking across two environments. Individual sensors and their detection pipelines were evaluated across various detection metrics. They also evaluated the tracking performance of the sensors both individually and in fusion using a multi-sensor extension of the Joint Integrated Probabilistic Data Association (JIPDA) multi-target tracker. They found that the different environments have distinct challenges precluding the use of only a single sensor. Utilizing multiple sensors, either individually or in fusion, could mitigate these issues increasing the safety margins of the situational awareness system.

Testing that ships are compliant with specified safety requirements has traditionally relied on real-world data, which is not scalable and limited to testable scenarios due to financial and ethical reasons. Low-fidelity simulations have been used to counteract some of these problems, which is sufficient for emulating simpler systems such as radar detectors, but not for testing complex systems such as those found in computer vision. In the automotive industry, the use of game engines has shown to be a valuable testing platform due to their customizability, and combination of real-time physics with computer graphics to create large volumes of high-fidelity images. Vasstein et al. (2020) developed an open-source maritime platform named Autoferry Gemini, where a Unity game engine was used to simulate sensors in real time. Utilizing simulated optics and general-purpose GPU programmes, the render pipeline is capable of modelling LIDAR, radar, visible light and infrared camera sensors simultaneously. The study demonstrated that game engines can simulate multiple electromagnetic resonance sensors of maritime interest, running concurrently in real time given the proper hardware. From these results, the authors claim that Autoferry Gemini is the first known simulator that combines visual light, IR, LIDAR, and radar simulations for autonomous ships.

The issues of existing requirements, performance standards, and future concepts of integrity monitoring for maritime position sensors were discussed and analysed in a paper by Zalewski (2020). The primary means for electronic position fixing currently in use in the majority of contemporary merchant ships are shipborne GPS (Global Positioning System) receivers or DGPS (Differential GPS) and IALA (International Association of Lighthouse Authorities) radio beacon receivers. More advanced GNSS (Global Navigation Satellite System) receivers able to process signals from GPS, Russian GLONASS, Chinese Beidou, European Galileo, Indian IRNSS, Japanese QZSS, and satellite-based augmentation systems (SBAS) are still relatively rare in the maritime domain. However, it is expected that such combined or multi-system receivers will soon become more common in maritime transport and integrated with gyro, inertial, radar, laser, and optical sensors, and they will become indispensable onboard autonomous ships. The authors concluded that to be prepared for a malfunction of any position sensors, their state-of-the-art integrity monitoring should be developed and standardized, taking into account the specificity of MASS and e-navigation safety.

Communication and cybersecurity

The sample contained only four papers classified as dealing with the communication and cybersecurity of autonomous ships. They all derived from 2020 with no papers before or after (see Figure 13.19).

The four papers were written by authors representing universities or institutions in three nations. Two of the papers were written by or had contributions from institutions in Norway and one each from institutions in Cyprus and the UK (see Figure 13.20).

This number of papers was surprisingly small in the sample considering that other studies, in other domains, pointed to problems and the need for research within communication and cybersecurity.

Recent advances in the maritime industry include research and development of new sophisticated ships with several smart functionalities and enhanced autonomy. However, the new functions and autonomy levels come at the cost of increased connectivity. This results in increased ship vulnerability to cyberattacks, which may lead to financial loss, environmental pollution, and accidents. Bolbot et al. (2020) proposed a novel method for cybersecurity

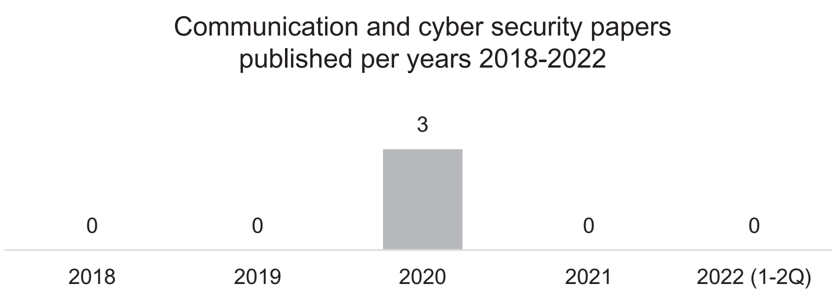

Figure 13.19 Number of papers classified as dealing with the communication and cybersecurity aspects of autonomous ships.

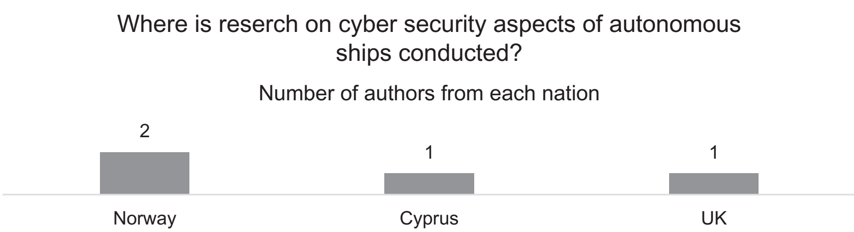

Figure 13.20 Researchers from three nations authored the four papers dealing with communication and cybersecurity aspects of autonomous ships. The in total four national contributions are here divided by country.

risk assessment of ship systems. In this novel method, the Cyber-Preliminary Hazard Analysis method, assessments were enriched with new steps supporting the identification of cyberattack scenarios and the risk assessment implementation. The proposed method was applied for the cyber-risk assessment and design enhancement of the navigation and propulsion systems of an inland waterways autonomous vessel. The results demonstrated that several critical scenarios could arise on the investigated autonomous vessel due to known vulnerabilities. However, these could be sufficiently controlled by introducing appropriate modifications to the system's design. The method was based on the identification of potential attack groups, the system components' vulnerabilities, attack scenarios, and a ranking based on specific guidelines. The method was applied for identifying and ranking cyberattack scenarios which can be implemented by terrorists in the case of the navigation and propulsion control systems of a fully autonomous inland ship.

Amro et al. (2020) discussed the autonomous passenger ships context and its stakeholders, regulations, standards, and functions to identify communication and cybersecurity requirements towards designing a secure communication architecture suitable for autonomous passenger ships.

Shipping undergoes rapid digitization, covering safety and security reporting, mandatory ship documentation, electronic port clearance, as well as commercial and operational information exchanges. Increasing automation of information processing, including the specific needs for autonomous ships, requires increased "digital trust" to allow humans to remove themselves from the information-processing loops. This requires better safeguards against cyberthreats such as counterfeiting contents or the originator of critical messages. Rodseth et al. (2020) described 13 use cases for maritime services and analysed how a Public Key Infrastructure (PKI) system could provide security barriers to mitigate relevant cyberthreats and possible consequences of unwanted events. Such a PKI needs to be designed with the special maritime business constraints in mind; the most important being the international nature of shipping, the lack of connectivity for ships that are far from shore, the network constraints associated with existing communication technologies and regulatory considerations. The authors claimed that cyberthreats are emerging as a risk in the maritime industry. If the navigational systems on board a ship somehow fail to function because of a cyber incident, the navigator is an important asset who is expected to handle the problem and provide a solution to maintain the safety of the crew, the vessel, and the environment. IMO urges the shipping industry to be resilient towards cyberthreats. To facilitate enhanced operational maritime cyber resilience, there is a need to understand how navigators interpret cyberthreats, which can be essential to safely conduct nautical operations. Rodseth et al. presented a qualitative study of navigators' understanding of cyberthreats based on interviews with ten navigators, and further provided recommendations for how the use of this knowledge can contribute to enhanced maritime cyber resilience.

Environment

This section presents the two papers classified as dealing with environmental issues of autonomous ships. This number is again surprisingly small considering the importance of research within this field (see Figure 13.21).

The two papers in this section were written by authors representing universities or institutions in Portugal and Singapore (see Figure 13.22).

Zanella (2020) discussed the environmental impact of MASS. The author states that the advantages of using autonomous ships, concerning the protection and preservation of the marine environment, are concentrated in two main areas: the reduction of pollution by vessels, and the reduction of human error. Pollution by dumping, which represents approximately 10% of the pollution of the marine environment, is a significant visible source of pollution, which causes sensitive damage to the environment. With no crew on board, there is no need to talk about pollution by dumping debris in the marine environment, particularly the elimination of plastics dumped from ships, which corresponds to 20% of the total plastics in the maritime environment. Also, the reduction of pollution by vessels is related to the advancement of the technologies used. The author points out that modern vessels tend to use less energy and emit fewer pollutants, and by using batteries, the unmanned vessel could be free from any emission and reduce air pollution to the environment. Regarding oil pollution from ships, it is important to note that this pollution occurs in two main ways: first, as a result of maritime accidents that cause the spillage of large amounts of oil

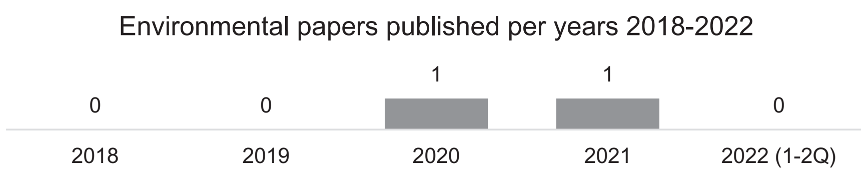

Figure 13.21 Publication years of the papers classified as dealing with environmental aspects of autonomous ships.

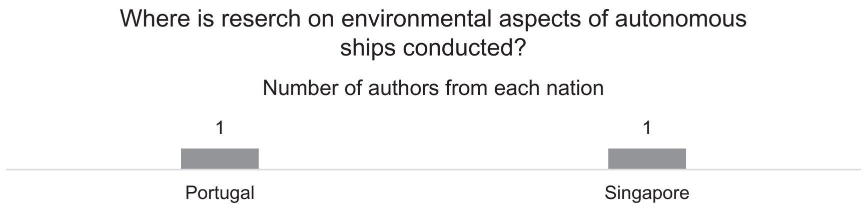

Figure 13.22 Two researchers from two nations authored the two papers dealing with environmental aspects of autonomous ships.

into the sea; and second, through operational discharges of the waste generated by the vessels, which involve the insertion of pollutants in smaller, but cumulatively significant quantities. Although oil tanker accidents are a more visible and dramatic cause of marine pollution, they account for less than 10% of all oil spilt at sea. The greatest threat still comes from deliberate discharges, such as tank cleaning operations. It is estimated that more than 80% of ship accidents occur due to human error. These errors can happen due to several factors, such as a decrease in performance (due to fatigue, stress, or health problems), insufficient technical and cognitive abilities, precarious interpersonal skills (communication difficulties, difficulties in mastering a situation, language), and organizational aspects (safety training, team management, safety culture). With the automation of ships, the trend is a reduction in accidents at sea, which often cause severe pollution with spills of oil and other substances. The author concludes that as Human Factors are the primary source of risk of accidents at sea, it seems interesting to develop technology that will make it possible to resolve these errors. Thus, logically, the autonomy of a ship results in the reduction of human error.

The projected escalation in global sea trade, to near tripling from 2020 to 2050, evokes the serious concern that atmospheric pollutant emissions will increase correspondingly along the sea routes in the future if the maritime energy strategy is not modernized in time. Meanwhile, the IMO has set a firm target to halve the total greenhouse gas emission from international shipping by the mid-century. Liu et al. (2021) examined in a study the potential reduction of environmental pollutant emissions with the adoption of autonomous vessels in future maritime transportation using a Bayesian probabilistic forecasting algorithm. The authors claimed that the emission reductions can be attributed to the related technological advancement, including particularly the improvements in navigational performance, and berthing in port, which can achieve better efficiencies and lower fluctuations in sailing speeds. In their study, a scenario-modelling approach was first established based on the foreseeable development of energy policies and usage as well as ship operations. Subsequently, assessments were performed for five major ports worldwide, namely Shanghai, Singapore, Long Beach, Hamburg, and Tokyo, from 2020 to 2050. The results were compared to the corresponding projections with manned shipping to determine the probabilistic emission reductions with the gradual adoption of autonomous ships into the fleet. The result showed that future emissions can decrease rapidly from 2020 to 2050 in all the study ports with autonomous adoption. At a 50% autonomous ship phase-in rate, the Port of Hamburg will achieve a maximum cut of 52%, followed by Long Beach (50%), Shanghai (42%), Singapore (40%), and Tokyo (32%). Further reductions are projected in the 100% autonomous traffic scenario, whereby all ports can cut emissions by more than 45% compared to 2020.

DISCUSSION

As mentioned above, the risk with an unstructured method is that you find what you are looking for and that the bias of the reviewer influences the result. The samples in this case were 111 research papers collected during a few days at the beginning of July 2022. The validity of the study rests on the assumption that these 111 papers are representative of the whole (and unknown) population of research articles on autonomous ships – and that we cannot know. The only search string used initially was "autonomous ship", which also might lead to unwanted exclusions.

As mentioned in the beginning, it is possible that the fact that the search was conducted from Norway might influence the result from the search engine used as the algorithms behind the engine are undisclosed. Nevertheless, it is possible that the results give some indication of the direction and number of studies that have been undertaken and where, and this is the assumption the following reflections rest upon. (However, see footnote 1 at the beginning of this chapter.)

It is maybe not so surprising with which force Chinese universities and institutions have entered this research area given the technological investments made in the recent decade. The author of this review has himself been a guest professor at one of the Chinese universities involved. What is more surprising is that a small Scandinavian country like Norway has an equal amount of published research articles. It is also surprising that a research giant like the United States has relatively little activity within this area, at least visible through public publications.

The material has been classified into three areas and nine domains. The classification has been relatively straightforward even if some papers could also have been classified for another domain, for instance, "regulations" are something that to some extent also have been discussed in papers now classified outside of the "laws and regulations" domain.

When we look at the distribution of research efforts it may be natural that more than half (66) of the 111 articles deal with technology, after all developing autonomous unmanned ships demands a huge technological advancement. And at first sight, it might not be surprising that so few publications deal with Human Factors, given that the effort is to develop autonomous unmanned ships. However, as is mentioned also in several of the technology papers, human operators in a remote control centre will be the very end of an automatic chain where final decisions are made and need to deal with unavoidable shortcomings in the technique.

However, it is surprising that so few communications and cybersecurity studies turned up in the search, given that the whole effort rests on safe and secure connectivity.

Another surprise was that the 111 articles found did not include any study into artificial intelligence. AI is often mentioned as an enabler for the "autonomy" part of autonomous unmanned shipping.

This review was done in the context of the HUMANE project, which has set out to study the Human Factors aspects of autonomous shipping. From this point of view, it is of course troublesome to note that so few (7) papers discuss Human Factors issues. However, some of the technology papers mention the human operator (e.g., Porathe & Rodseth, 2019, Huang et al., 2020a, Huang & van Gelder, 2020, Choi & Lee, 2021 and van de Merwe et al., 2022).

CONCLUSIONS

This chapter has presented a brief look at areas and topics included in published research about autonomous ships during the period of the HUMANE project, 2018 to July 2022. The method used for finding research papers was a Google Scholar query using the search string “autonomous ships”. These findings were augmented with “snowball sampling”, an unstructured non-probability sampling technique where references in, or references to, existing articles were used. Altogether 111 articles were reviewed.

The review looked at trends regarding the topic of research, publishing year, and nationality of the contributing institutions. A brief review of the content was also made. The research question was: where and when is what kind of autonomous ship research made?

Not surprisingly, the finding was that the number of papers published on the topic has greatly increased during the period (albeit the Covid-19 pandemic is clearly visible). It is also no surprise that technical papers constitute the majority and Human Factors papers a minority. More surprising was the finding that Norway and China came side by side as the main contributors to published research for the period in question.

NOTE

1. As this chapter was about to be printed in May 2023, a new Chinese bibliometric review of autonomous ship papers from 2015 to 2022 were published in *The Journal of Accident Analysis and Prevention*. The chapter comes to the same general conclusions for national contributions: Li, Z., Zhang, D., Han, B., & Wan, C. (2023). Risk and Reliability Analysis for MASS: A Bibliometric Review of literature from 2015 to 2022. J. of Accident Analysis and Preventions, (in press).

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Epilogue

Margareta Lützhöft and Jonathan Earthy

We end this project and this book with an epilogue – stating that it does not end here. We remember the beginning, describe the present, look forward and discuss what still needs work.

WHY DIDN'T WE WRITE A HANDBOOK?

Our initial goal was to write a book on the results, including barriers that needed removing, and a set of enabling methods and tools for anyone in the maritime sector. We didn't end up there. Instead, we almost ended up where we started but without the hype and with a healthy dose of realism. We thought that it would be a human-centred design handbook, but that was not the only problem. We thought it would be a managerial handbook, but that was not the only problem. We thought many things … but our informants, participants, experts, and professionals showed us differently. There is no handbook because the maritime sector does not understand the application yet, they do not have a concept of operations, nor an operational concept. Yes, they are two different things.

Briefly summarising our impressions of these years, we have found the following:

- An early assumption (by proponents of the technology) was that with fewer humans on board, ships would be safe because there will be less human error. Human senses would be enhanced, and human failings removed. Humans would also be subject to less injury. However, we find that at least some people will be needed as backup since technology apparently cannot be made fail-safe. Industry risk models need work to accommodate this change.
- Whilst there is a hope that people ashore will save the day, our findings indicate that the crew will still be onboard or "in the loop" for a long time. Considering a remote-control centre implies a belief that all the knowledge about a ship is currently in the ship and can be transplanted ashore as a unit.

- Other research into MASS does not cover the issues connected to humans. There is no description of the problem nor the solution, and seafaring has been reduced to directional control and anti-collision. There is no safety case. The fundamental goal is to be to maintain or improve the present safety level. But, how do we measure safety?
- The job of control when using complex, advanced technology where performance is facilitated with high levels of automation is different. Manual control is not possible. There will always be a layer of IT between the operator and the equipment under control. This supports the MUNIN project conclusion that "the technology must always be in control" (Porathe, 2021).
- In reality, which systems are made autonomous, when, and on what ship types will depend on cost-benefit and ease of implementation as well as operational factors. This may leave the remaining humans with worse problems.
- The business case for ocean traffic and SOLAS size ships is still not there, and aspects of the business case of the maritime smart technology ecosystem are not being researched academically. For example, we may need different business models for low manning or shore control, or the manning cost of shore control may be underestimated.
- The legal issues are unsolved – although work is underway. Our regulatory frameworks are not adapted to a "smart ship" domain. The allocation of responsibility and liability is not ready. For example:
    - The master is responsible for the cargo – charterers wouldn't give their cargo to a robot.
    - The duty to render assistance – supporting other ships is still unsolved.

In sum, there are so many areas unsolved that Human Factors is not (yet) an issue. We could give input if someone decided what they wanted to do – there is a set of methods and techniques that *could* be applied. The enablers are beyond our reach but there may be socio-technical issues we can raise – but not fix. At least not here and now.

Given the operational life and rate of replacement of the world commercial fleet, it is existing ships that will need to be modified to achieve business benefits from autonomy in the short and medium term. What needs to be done to make an operational traditional ship autonomous? To apply a human-centred perspective to this question, we adapted Moravec's paradox (Moravec, 1988). The paradox is summarised in Wikipedia as the observation by artificial intelligence and robotics researchers that, contrary to traditional assumptions, [logical] reasoning requires very little computation, but sensorimotor and perception skills require enormous computational resources. Inspired by this, we reviewed the operational practice and estimated the status of, and work to be done, to replace humans in current/traditional ship systems with systems that can be left alone to work by themselves for long periods (to paraphrase the robotics definition of autonomy).

In Figure 14.1, each ship system (physical, procedural, and technical) is rated against the degree of innate human skill required for that system to meet its purpose (the size of the person symbol), the degree of computational resources required for an autonomous replacement (the size of the screen symbol), and the degree of development of the replacement (the greyscale density of the screen symbol). Taken together, these give a very simple review of the existing fleet in terms of where each system is on the Moravec scale and hence the effort required to replace crew for that system. As identified in previous chapters, taking a function ashore will still require an autonomous backup in the event of immediate response, limitations on latency or bandwidth, and loss of communication.

This perspective gives us a different view of the job to be done in making a ship autonomous. The systems for which the computer symbol is large and grey are those that have a high "mandraulic" component (to use a colloquial term for needing to be done by people). These relate to understanding and working the ship, to maintaining and repairing the ship and its systems, and to keeping it safe and dealing with emergencies.

We observe that (from this perspective) concentrating on the bridge systems (Comms & Info, Nav and Handling) omits the many systems that depend on innate human skills (like maintenance, physical use/manipulation, estimating, dynamic planning, trade-offs, etc.). Is this a blind spot for those proposing autonomy, or a deliberate strategy by the proponents of autonomous ship technology to start with the easy tasks?

Another observation is that although a significant number of individual technical systems are highly automated, the use of control systems to keep the ship working effectively and efficiently requires innate human skills that are not yet fully automated. "What magical trick makes us intelligent? The trick is that there is no trick. The power of intelligence stems from our vast diversity, not from any single, perfect principle" (Minsky, 1986, p. 308).

WHAT STILL NEEDS WORK

The drivers at the beginning of the autonomy era were presented as more safety and no people onboard (i.e. more safety), and people would be out of harm's way in shore centres. The types of ships imagined at the time (unmanned, large, autonomous, deep sea) do not seem to be appearing any time soon, and the necessary infrastructure may take even longer to develop. Furthermore, the cost-effective use of drones and small ships may not be as simple as we currently assume.

We entered this work assuming that seafarers fit into the category of being "normal", that is, not having any mental issues, such as depression. We now know that as a result of modern industry and management practice, this is

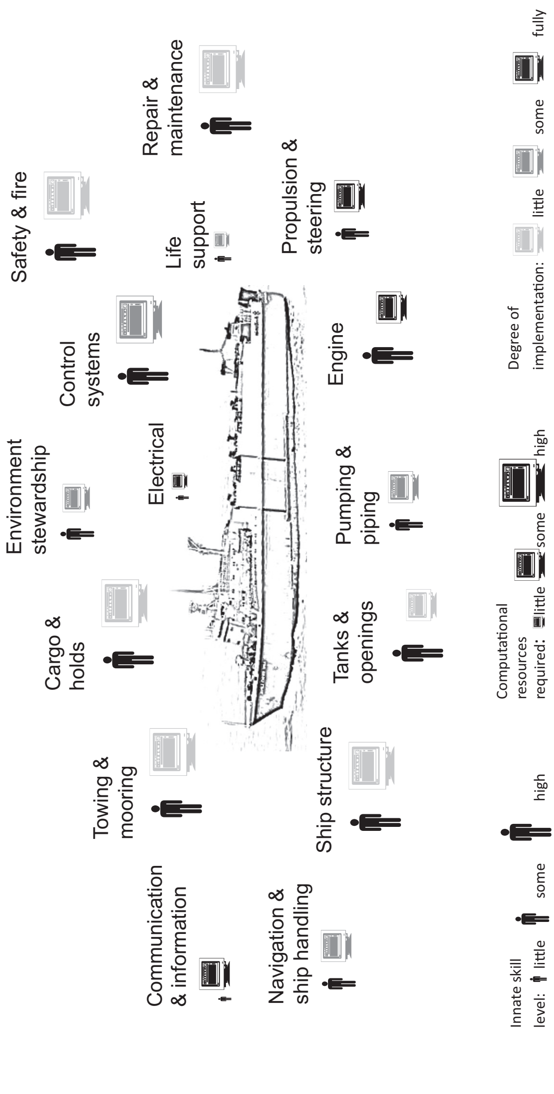

Figure 14.1 Effort required to make a ship autonomous.

not the case, and we suspect that improving seafarer well-being will be the next area of research. How to support this is a bigger issue, but the work we did is a part of this in identifying the need to study the new relationships between advanced technology and seafarers. We (the industry) must make sure that the people (who we find that we need after all) can function to do the work we require them to do: to act as responsible professionals within the technical system and to apply their unique human contribution to the maritime system. The technology must be designed to support that, not to make life more difficult.

The law applies to people. The law makes people responsible – because unless you can identify the responsible person, you never had anyone responsible (Rickover, 1961). Therefore, in designing and adopting autonomous technology, the industry has to make sure that this technology is designed and supported to allow responsible humans to fulfil this duty. Furthermore, at the time of writing, the IMO has recognised that UNCLOS is not going to change just to allow autonomous technology to be sold.

We believe that we have contributed to the facilitation of this area of study. One major reason this happened is that we brought a large group of maritime people together and started them talking. The benefits of that were clear, and this book aims to make the findings available to as wide a range of readers as possible. That is why we have included so many details and so many quotes – so as to not summarise the industry's views into a brief manifesto. This is also why we didn't write a handbook.

SAILING TOGETHER

The interpretation of the project acronym has developed; to achieve autonomous shipping, people need usable equipment, achievable jobs, and a humane living environment. We reaffirm our earlier sentiment that it is all about the humans:

> Even if such ships are entirely unmanned during a part of their voyage, or indeed their entire voyage, they will have regular interaction with human beings. In more concrete terms, they will be owned by humans, they will be designed, built, tested, and validated by humans, their operations will be decided upon by humans, they will be maintained and serviced by humans. Someday, humans will decide that they are obsolete, and they will be dismantled – most likely by humans. Throughout their lifetime, they will "meet" humans manning more conventional ships and working ashore.

A final thought, given the trend to redefine the term "human element" as another way to refer to "seafarers", and (perhaps the most important) the current opinion of DG IMO: Responsibility for Ergonomics and human-centred design is part of safe design and is therefore a Class issue. In case Classification Societies and ship designers find that addressing human–system issues is outside their comfort zone, this may present an opportunity for a code of practice on the human-centred approach.

The authors

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