Doctoral theses at NTNU, 2023:182

Brit-Eli Danielsen

Usability in Ship Bridge Design - A Mission Impossible?

A Qualitative Study of Maritime Stakeholders' Perspectives on Usability in Ship Bridge Design

Doctoral thesis

NTNU
Norwegian University of Science and Technology
Thesis for the Degree of Philosophiae Doctor
Faculty of Architecture and Design
Department of Design

NTNU
Norwegian University of Science and Technology

Brit-Eli Danielsen

Usability in Ship Bridge Design - A Mission Impossible?

A Qualitative Study of Maritime Stakeholders' Perspectives on Usability in Ship Bridge Design

Thesis for the Degree of Philosophiae Doctor

Trondheim, June 2023

Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of Science and Technology

Thesis for the Degree of Philosophiae Doctor

Faculty of Architecture and Design
Department of Design

ISBN 978-82-326-7068-0 (printed ver.)
ISBN 978-82-326-7067-3 (electronic ver.)
ISSN 1503-8181 (printed ver.)
ISSN 2703-8084 (online ver.)

Doctoral theses at NTNU, 2023:182

Printed by NTNU Grafisk senter

“We don’t want design on the bridge, it should be functional!” (Captain)

Preface

This thesis is prepared for the degree of Doctor of Philosophy at the Faculty of Architecture and Design at the Norwegian University of Science and Technology (NTNU). The doctoral work was undertaken at the Department of Design, NTNU, with Professor Thomas Porathe as the main supervisor.

The study was done as part of the Sensemaking in safety-critical situations (SMACS) project, which was funded by the Norwegian Research Council (grant number 267509) and led by Stig Ole Johnsen at SINTEF Digital, Trondheim.

The first part of the thesis provides a synthesis of the study's aim, background, research design, main contributions and discussions of overarching themes. The second part consists of five scientific publications, which include the main results of the conducted work.

Acknowledgements

“No man is an island”, a famous line by the English poet John Donne, illustrates the importance of the people we have around us. Well, no woman is an island either. There are several people that in different ways have contributed to the fulfilment of this thesis.

First, I would like to thank the informants, both at sea and on shore, for their hospitality and willingness to share their insights and perspectives. This thesis would of course not have been possible without them.

I am truly grateful for the continuous support, insights, advice, push and pull provided by my main supervisor Professor Thomas Porathe. I am really going to miss our weekly supervision meetings. During the first years, these meetings included coffee and cinnamon buns made by Thomas’ wife. Unfortunately, the covid pandemic put an end to that. I would also like to thank Professor Margareta Lützhöft, who joined as a co-supervisor mid-way in the project, offering encouragement and guidance through a difficult phase of the PhD endeavour. Also, a big thank you to co-supervisor Research professor Torgeir Kolstø Haavik for being especially helpful during the writing process, and more generally for being such a great colleague. I am also grateful for the helpful discussions with the late Karin Laumann at the outset of this study.

The basis for this PhD scholarship was the SMACS research project, funded by the Norwegian Research Council. I am grateful for the opportunity to be part of this project and I would especially like to thank the project leader Stig Ole Johnsen for his enthusiastic and continuous support. A big thank you also to project member Gunnar Lamvik for the great experience of doing field work together and for eagerly introducing me to the concept of seamanship.

Frøy Birte Bjørneseth rendered possible the field trips on board the offshore supply vessels, a very central part of my familiarisation with work on the ships bridge, which I am very grateful for.

Thank you to Erik Styhr Petersen for co-authoring one of my papers. It turned out to be a very enjoyable and highly educational writing process.

Being an employee at the Department of Design at NTNU has been a great experience. The department has not only provided the necessary resources, but a friendly atmosphere to work in. Thank you to all my fellow PhD students and especially to Åsa Snilstveit Hoem. As our projects have run more or less in parallel, it has been invaluable to discuss ups and downs with you.

I am also thankful to my employer NTNU Samfunnsforskning for giving me part-time off to pursue this goal. For more than a decade, the CIRiS department has been an inspiring place for me to work, and the opportunity to pursue my own research interests has been central for the path towards pursuing a PhD. A sincere thank you to all my colleagues for your friendship and support. Especially our morning coffee on Teams during the covid-pandemic was a life saver.

During the last months of writing, I also received tremendous help from Vilde Steiro Amundsen. Thank you for the outstanding work on proofreading and for the included supervision and moral support.

My friends that have ensured some contact with society outside the PhD bubble also deserve a big thank you. Especially the weekly 'walk and talk' with Ingvild has been important on many levels. Thank you for listening and for having an unbelievable belief in me.

My whole extended family has always been an important part of my life, also during the years of pursuing a PhD. I am especially thankful for the many ways my dad has helped me out and backed me up through academic and personal hardship over the last years.

Finally, to the most important people in my life, my daughters Silje and Maja, thank you for keeping me firmly grounded and for filling my life with laughter and love.

Summary

Navigating a ship requires close cooperation between the seafarers and the technology available on the ship's bridge. The *ship bridge design*, which in this thesis includes the design of equipment, systems and overall layout of the bridge, strongly influences the interaction and cooperation between the seafarers and the technology. Suboptimal usability in ship bridge design is one of the factors that contribute to navigational accidents, which in turn may lead to major financial loss and potentially have catastrophic consequences for human lives and the marine environment. The importance of usability in ship bridge design has received some attention. The International Maritime Organization (IMO), responsible for international maritime regulations, requires human factors considerations in ship bridge design through the SOLAS regulation V/15. In addition, decades of research have provided knowledge about the work on the bridge, maritime design processes and methods, and developed new technology and innovative solutions. Nevertheless, suboptimal usability in ship bridge design seems to be a persistent challenge in the maritime industry. Theoretically based within the human factors, design and safety literature, the overall aim of this thesis is to contribute to improved safety at sea by increasing knowledge on factors that may influence the advancement of usability in ship bridge design in the maritime industry. The research is guided by the main research question: *Why is usability in ship bridge design a persistent problem in the maritime industry?* The main research question is detailed through the following sub-questions:

RQ1: How can the human work in collaboration with technology on the ship's bridge be understood and described?
RQ2: How do different actors in the maritime industry understand and describe the human-technology interaction on the bridge?
RQ3: How do different actors in the maritime industry perceive their responsibility for usability in ship bridge design?

These questions are explored through a qualitative study comprising interviews, observations and document analysis, incorporating data from a variety of stakeholder groups: seafarers, shipowners, equipment manufacturers, a shipyard, a Flag State, classification societies, maritime insurers as well as accident investigation reports. The research has resulted in five scientific publications.

The study found that the seafarers, the end-users with the highest interest in ship bridge design, have low influence on ship bridge design processes. Seafarers take responsibility for bridging the usability gap by applying creative adaptive work strategies. Core stakeholders on shore also place the responsibility for the human-technology interaction on the ship's bridge on the seafarers, with the result that seafarers are expected to adapt to the available technology regardless of usability. Another factor that may play part in the limited improvement of usability in ship bridge design, is that for many stakeholders there does not seem to be any incentive for paying attention to usability, as the study found that the SOLAS regulation V/15 is not actively enforced and the economic benefits from investing in usable bridge equipment is not apparent to them. A noteworthy finding is that the responsibility for usability in ship bridge design seems to pulverise between the maritime stakeholders, as all stakeholders in this study believe the responsibility for usability sits with one or several of the other stakeholders – it is somebody else's problem.

Implementing human-centred design processes in the maritime sector requires human factors knowledge, interest and cooperation between several stakeholders. Currently, however, there seems to be limited attention in the maritime industry to how usability influences safety. The findings in this study show that there is a need for transferring existing human factors knowledge to actors in the maritime industry, but also that more research is needed to develop knowledge that will enable maritime actors to make informed decisions and prioritisations concerning ship bridge design. This study demonstrates that to bring about human-centred design processes in the maritime industry, it is imperative that the seafarers have a voice in ship design and procurement processes, and this can be made possible through the engagement of a broad set of maritime stakeholders.

List of publications

I Danielsen, B.-E. (2021). Making sense of sensemaking in high-risk organizations. In S. O. Johnsen & T. Porathe (eds.), *Sensemaking in safety-critical and complex situations: Human Factors and Design*. CRC Press.

II Danielsen, B.-E., Lützhöft, M., & Porathe, T. (2021). Still unresolved after all these years: Human-technology interaction in the maritime domain. In: Stanton, N. (eds), *Advances in Human Aspects of Transportation*. AHFE 2021. 270, 463-470. Springer.

III Danielsen, B.-E. (2022). The contribution of ship bridge design to maritime accidents. In: Katie Plant and Gesa Praetorius (eds.), *Human Factors in Transportation*. AHFE 2022. 60, 714–722. Springer.

IV Danielsen, B.-E., Lützhöft, M., Haavik, T., Johnsen, S.O. & Porathe, T. (2022). "Seafarers should be navigating by the stars": Barriers to usability in ship bridge design. *Cognition, Technology & Work,* 24, 675–691.

V Danielsen, B.-E. & Petersen, E.S. (2022). Somebody else's problem? Usability in ship bridge design seen from the perspective of different maritime actors. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation,* 16 (4), 685-700.

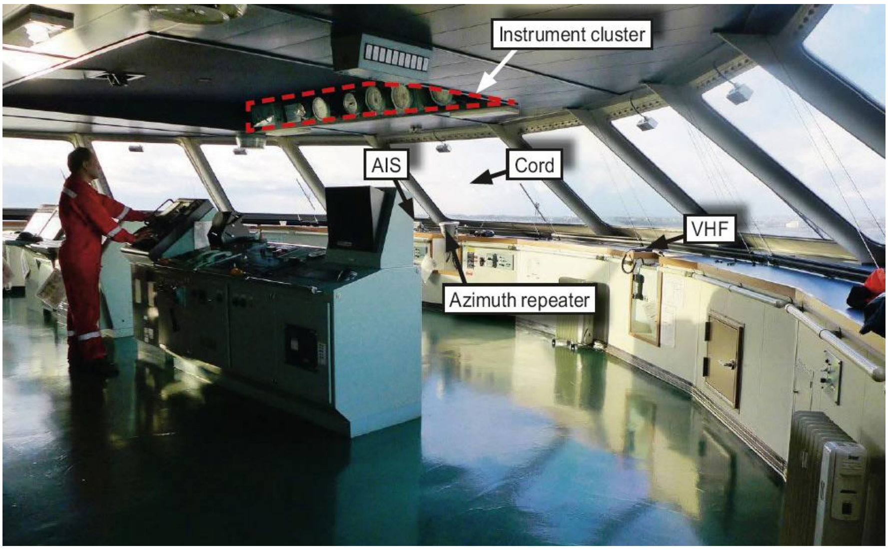
Vignette

In the evening on December 3rd, 2015, the pure car carrier *City of Rotterdam* departed from Immingham Dock and sailed outbound in the river Humber, on the east coast of northern England (Marine Accident Investigation Branch, 2017). The *City of Rotterdam* had an unconventional design with a hemispherical shape of the bow, intended to reduce wind resistance and provide better fuel economy (Picture 1). The shape of the bow affected the interior design of the vessel’s bridge; with the windows tilted inwards at the top and only the front window on the centreline facing straight ahead, all the other windows framed a view off the centreline axis. Also, the vessel’s bow was not visible from the bridge. On the bridge this evening were the master, the third officer, the helmsman and the pilot. Before departure, the master advised the pilot to mainly position himself where he could look out the front window, either by the conning position or the navigation workstation. The master also notified the pilot about a length of black cord that the crew had positioned down the middle of the centre window to provide a visual reference of the vessel’s centreline and thus its heading.

Picture 1. The City of Rotterdam (Photo: Tomas Østberg-Jacobsen/MAIB, reprinted with permission).

At 7:59PM, the attending tugs were released, and the ship was steered manually down the main navigation channel. The pilot monitored the vessel’s position by eye, the Electronic Chart Display (ECS) and the radar display. It was dark outside, but with clear skies and good visibility. The *City of Rotterdam* was high-sided and in ballast, and thus subjected to drift due to the tidal stream and the wind gusting up to 40 knots. Consequently, at 8:32PM, *City of Rotterdam* was on the port side of her intended track. The pilot was aware of this and informed the master that he intended to manoeuvre the ship further to starboard. By this time, the ro-ro freight ferry *Primula Seaways*, sailing inbound in the river, was in clear sight and the pilot informed that he planned to pass her port to port.

The very high frequency (VHF) radio was located below a window on the starboard side, which was off the vessel's centreline axis (Picture 2).



Picture 2. The bridge on City of Rotterdam seen from starboard side (Photo: MAIB, reprinted with permission).

At 8:35PM, the pilot was using the VHF radio to communicate his planned route to the Humber Vessel Traffic Service (VTS). The crew on board *Primula Seaways* were at this point concerned that the oncoming *City of Rotterdam* did not appear to be altering course. At 8:37PM, *Primula Seaways* called *City of Rotterdam* on VHF and the pilot was again looking out the off-axis window while responding to the VHF call. During this conversation, the pilot asked, "Is that you on my port bow?" (Marine Accident Investigation Branch, 2017). *Primula Seaways* was now on the starboard bow, but from the perspective of the pilot, the ferry seemed to be on the port bow. The pilot was now experiencing a *relative motion illusion* in which the vessel appeared to be heading in the direction he was looking. In the dark, the inward slope of the windows meant no objects could be seen in the periphery and there was no other ship structure visible that could have suggested otherwise. During this VHF call, the crew on *Primula Seaways* for unknown reasons erroneously confirmed that they were on the port side, which also strengthened the pilot's illusion.

At 8:38PM, the VTS called *City of Rotterdam* to inform them that they were concerned about the vessel's position in the channel and the approaching ferry. The conversations over VHF kept the pilot positioned by the off-axis window. At this point, the pilot had made several course corrections and believed that the vessel was heading southwards, towards the direction he was looking. However, in reality the heading was not altered significantly. At 8:39PM, the bridge team on *Primula Seaways* realised that the *City of Rotterdam* remained in their path, and steered full starboard and set the engine to full astern. A few seconds before the collision, the *City of Rotterdam*'s master also realised the severity of the situation and shouted out manoeuvring orders. However, it was too late and at 8:40PM *Primula Seaways* and *City of Rotterdam* collided, port bow to port bow.

Fortunately, the accident did not lead to pollution or serious injuries, and both vessels were able to return to Immingham without assistance. The cost for repairing *Primula Seaways* amounted to 3 million US dollars. The cost for repairing *City of Rotterdam* is not known, but from the damage described in the investigation report, the cost was probably no less. The *City of Rotterdam* was out of service for two months, which was an additional financial loss for the owner.

This accident illustrates and introduces some of the key issues in this thesis:

Design issues persist despite of regulations and guidelines

The accident investigation report states that the relative motion illusion experienced by the pilot on board the *City of Rotterdam* was an unexpected effect of the unconventional ship design. It concludes that a stricter adherence to the human factor requirements in the International Maritime Organisation's (IMO) Safety of Life at Sea (SOLAS) V/15 regulation could have reduced the likelihood of this effect. The accident report refers to several available guidelines supporting the understanding and use of SOLAS V/15, but acknowledges that since these are not mandatory, the ergonomic principles in SOLAS V/15 are open to interpretation.

There were several issues with the design of the *City of Rotterdam.* The location of the VHF radio below an off-axis window was not compliant with SOLAS IV/6, which requires radio installations to "ensure the greatest possible degree of safety", a goal that is very much open to interpretation. Furthermore, the SOLAS regulation V/22.1.9.1 requires that all front windows must be inclined, top out, to minimise reflections. The bridge windows on the *City of Rotterdam* were inclined in the opposite direction. However, the precaution of moving sources of light, including the bridge consoles, away from the windows to reduce the likelihood of reflections enabled the Panama Maritime Authority to issue an exemption. This resulted in the propulsion, wind and speed indicators being set back from the windows, making them unreadable from the conning position by the centreline bridge window, as required in SOLAS regulation V/19 (Picture 2).

Seafarers use adaptive strategies to get the work done

The report states that operating this ship for several years without navigational accidents was largely due to adaptations and coping strategies by the crew and pilots, such as the cord on the centreline window and mainly standing behind the centreline window. Although seafarers adapt to handle their work environment, in situations where several factors coincide the adaptations may add complexity to the situation. The wind, the tidal stream and the oncoming vessel were factors coinciding with the frequent communication on the VHF radio which made it difficult for the pilot to implement the strategy of mainly standing behind the centreline.

Seafarers do not influence ship bridge design

The accident investigation revealed that pilots with experience from sailing with the *City of Rotterdam* and its sister vessel *City of St Petersburg* found piloting the vessel "disconcerting" and "uncomfortable". They also expressed concern that the ships side could not be viewed while operating the helm, or the engine and bow thruster controls. As will be discussed in this thesis, usability requires end-user involvement. The accident report provides no indication of whether seafarers have been involved in any way during the design of this ship and if seafarers and pilots were given the opportunity to give feedback from operations. The findings in this thesis indicate that end-user involvement in ship bridge design is rare.

Seafarers are made responsible for the human-technology interaction on the bridge

Although design was found to be the main contributing factor to the accident, both the pilot and the master working on board *City of Rotterdam* at the time of the accident were sentenced to four months in prison for their involvement in the collision (SAFETY4SEA, 2017). After the accident, the owner installed a bow tip marker and increased the length of the cable of the VHF handset to allow the radio to be used while looking through the centre line window. In addition, notices were posted on the bridge to warn about the possibility of relative motion illusion, additional internal audits were performed to monitor bridge teams during pilotage and coastal navigation, and additional bridge resource management training was introduced. These actions may reduce the likelihood of similar accidents occurring. However, these are all measures aimed at improving the seafarers' performance i.e., the human part of the human-technology interaction. To improve safety learning from accidents, changes must also be made in other parts of the maritime system, including stakeholders such as shipowners, design offices and regulators, who have a huge influence on whether seafarers are placed in manageable circumstances.

Contents

Overview of figures, tables and pictures

Abbreviations

AB	Able seaman
AIS	Automatic identification system
AGCS	Allianz Global Corporate & Specialty
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
DP	Dynamic positioning
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
EFTA	European Free Trade Association
EMSA	European Maritime Safety Agency
EU	European Union
FoC	Flag of convenience
GNS	Global navigation satellite system
GNSS	Global Navigation Satellite System
HCD	Human-centred design
HF	Human Factors
HF/E	Human Factors/Ergonomics
HMI	Human-Machine Interface
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISM	International Safety Management Code
ISO	International Organization for Standardization
MED	Marine Equipment Directive
MSC	IMO’s Maritime Safety Committee
NIS	Norwegian International Ship Register
NMA	Norwegian Maritime Authority
NOR	Norwegian Ordinary Ship Register
OOW	Officer on watch
SA	Situation Awareness
SMACS	Sensemaking in safety-critical situations
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UCD	User-centred design
UNCTAD	United Nations Conference on Trade and Development
VHF	Very High Frequency
VTS	Vessel Traffic Service

1. Introduction

The United Nations Conference on Trade and Development (UNCTAD) describes maritime transport as “the backbone of international trade and the global economy” (UNCTAD, 2022a). Being an efficient and cost-effective method of transport, shipping transports more than 80% of international trade in goods (International Maritime Organization, 2022e). Our international society is thus dependent on a safe and efficient shipping industry. Today, there are over 50,000 merchant ships in international trade, which are registered in over 150 nations and manned by an estimated 1,647,500 seafarers (International Chamber of Shipping, 2022). The shipping industry is a high-risk industry, where accidents can lead to major financial loss and potentially have catastrophic consequences for human lives and the marine environment. Recent well-known examples of serious accidents include the grounding of the cruise ship *Costa Concordia* in January 2012 in which 32 people perished (Marine Casualties Investigative Body, 2013), the collision and subsequent capsizing of the frigate *KNM Helge Ingstad* in November 2018 (AIBN, 2019) and the grounding of the container ship *Ever Given* in the Suez Canal in March 2021, which blocked the global trade for six days (Reuters, 2021).

Fortunately, there seems to be positive developments with regard to safety at sea. For example, Allianz Global Corporate & Specialty (AGCS) reported a 50% drop in total losses[1] over the period 2011-2020, with 49 total losses in 2020 (Allianz Global Corporate & Specialty, 2021). The European Maritime Safety Agency (EMSA) reported that the overall average occurrence rate[2] for the period 2014-2020 had been reduced by 39.4% (European Maritime Safety Agency, 2021). However, there are reports indicating that the safety development is a bit more nuanced. For instance, Eliopoulou et al. (2016) reported that in the period 2000-2012, the frequencies of ship accidents in the world merchant fleet generally increased. However, the *safety level* of the various ship types was found not to have changed significantly, as, despite an increased frequency, the consequences of the accidents remained in average at the same level. To some concern, the Norwegian Maritime Authority’s (NMA) maritime accident statistics show an increase in both ship accidents and personal injuries from 2018 (Norwegian Maritime Authority, 2022b). The reason for this increase is not currently known. In addition to statistical trends, the sheer fact that EMSA registered 6,921 persons as injured and 550 persons

[1] *Total loss* means that a ship ceases to exist after an accident, either from actually being irrecoverable or from being subsequently scrapped (in cases where the cost of repair exceeds the insured value of the ship).
[2] The calculated ratios between the number of reported occurrences for different ship types and its corresponding fleet size.

as having lost their lives at sea in the period 2014-2020 (European Maritime Safety Agency, 2021) means that there is still work to be done to improve safety at sea.

Collision, contact and grounding/stranding are events that the EMSA refers to as *navigational casualties*, which represent 43% of all casualty events in the period 2014-2020 (European Maritime Safety Agency, 2021). Navigation, the "science of directing a craft by determining its position, course, and distance travelled" (Britannica, 2022), is a complex interaction between the seafarer and the technology on board the ship's bridge (da Conceição et al., 2017; Hutchins, 1995). The *ship bridge design*, which in this thesis includes the design of equipment, systems and overall layout of the bridge, strongly influences this human-technology interaction. The interaction between humans and other elements of a system is the central topic of the human factors discipline. Human factors in design can be described as «the influence the design of technological systems and the working environment has on the ability of people to behave and perform safely and reliably without putting their health and safety at risk» (McLeod, 2015, p. 1). Suboptimal usability[3] has repeatedly been found to contribute to maritime accidents (Grech et al., 2008; Lützhöft & Dekker, 2002; MAIB & DMAIB, 2021; Puisa, 2018; van de Merwe, 2016). However, when the human-technology interaction on the bridge breaks down, the cause is often attributed to *human error* rather than factors like design (Ibid.). When *human error* is found to be the cause of accidents, learning and improvement efforts tend to focus on changing human behaviour by adding procedures, instructions and checklists, while other parts of the sociotechnical system, like organisational and technological factors, are ignored (Schröder-Hinrichs et al., 2011; Woods et al., 2010).

The quote "We don't want design on the bridge, it should be functional!" from the introductory pages of this thesis, was stated by a captain during one of the field trips performed as part of the data collection in this study. The quote illustrates that *design* means different things to different people. In the research literature, an often-cited definition of design is that it concerns devising "courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 55). Especially relevant for this thesis is the concept of *human-centred design approach.* This is an approach that "aims to make systems usable and useful by focusing on the users, their needs and requirements" (International Organization for Standardization, 2010). As such, *design* should be a positive contribution to the work performed by seafarers on a ship's bridge. In contrast, the captain's quote can be seen as a view of *design* as fancy features without

[3] Usability is defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization, 2010).

the preferred or needed functionality. The quote can also be understood as an expression of frustration over ship bridge design that does not accommodate the seafarer's daily work tasks and responsibilities. It also serves to illustrate the gap in the understanding of *work-as-done* between the seafarers and the people and organisations that in different ways influence the design of equipment and the overall layout of the ship's bridge.

The International Maritime Organisation (IMO), which is responsible for the international regulatory framework for the shipping industry, has acknowledged the need to address human factors, i.e. usability, in ship bridge design through the SOLAS regulation V/15 (International Maritime Organization, 2002). There is also a substantial amount of research on ship bridge design, investigating work on the bridge (da Conceição et al., 2017; Forsman, 2015; Hutchins, 1995; Lützhöft, 2004; Prison et al., 2013), maritime designers and design processes (Ahola, 2018; Lurås & Nordby, 2015; Meck et al., 2009), stakeholders in maritime design processes (Gernez, 2018; Petersen et al., 2011; Österman, 2013; Österman et al., 2009) and development and innovation projects (Bjørneseth, 2021; Costa et al., 2017; Gernez, 2018; Javaux et al., 2015; Lurås, 2016; Mallam & Nordby, 2021). Still, improvement of usability in the maritime industry seems to be slow, exemplified by the fact that that the importance of grouping of functions on the bridge, which Vu argued for in 2018, was also advocated for by Wilhelmsen in 1971.

To sum up, suboptimal usability in ship bridge design persists despite the research, design methods, technology development and innovations and design regulations that exist today, suggesting that there are factors influencing the improvement of usability in ship bridge design that are yet to be explored and understood. Thus, the overall aim of this thesis is to contribute to improved safety at sea by increasing knowledge on factors in the maritime industry that may influence the improvement of usability in ship bridge design. The research is guided by the following research questions:

The main research question:
Why is usability in ship bridge design a persistent problem in the maritime industry?

The main research question is detailed through the following sub-questions:
RQ1: How can the human work in collaboration with technology on the ship's bridge be understood and described?
RQ2: How do different actors in the maritime industry understand and describe the human-technology interaction on the bridge?

RQ3: How do different actors in the maritime industry perceive their responsibility for usability in ship bridge design?

These questions are explored through a qualitative study comprising interviews, observations and document analysis, incorporating data from a variety of stakeholder groups: seafarers, shipowners, equipment manufacturers, a shipyard, a Flag State, classification societies, maritime insurers as well as accident investigation reports. The study found several factors that may influence usability in ship bridge design. Core stakeholders, including the seafarers, place the responsibility for adapting and managing the human-technology interaction on the ship's bridge on the seafarers, regardless of usability. There is less attention to the blunt-end stakeholders' responsibility for placing seafarers in manageable conditions. For many stakeholders, there does not seem to be any incentive to invest in usable products, as this study found that the SOLAS regulation V/15 is not actively enforced, and the profitability of usability investments is not apparent to them. The overall responsibility for usability in ship bridge design seems to be fragmented, as all stakeholders in this study direct the responsibility to several of the other stakeholders. Based on this study's findings, this thesis argues that there is a need for transferring existing human factors and safety knowledge to stakeholders in the maritime industry and to find ways of including the seafarers' perspectives in the existing ship bridge design, development and procurement processes.

1.1. The SMACS research project

The basis for this PhD scholarship was a project named Sensemaking in safety-critical situations (SMACS), which was funded by the Norwegian Research Council (grant number 267509). This was a four-year project running in the period 2017-2020, led by Stig Ole Johnsen at SINTEF Digital, Trondheim. The project group consisted of researchers affiliated with SINTEF Digital, IFE Institute for Energy Technology and the Department of Design, Norwegian University of Science and Technology (NTNU). The primary objective of the SMACS project was to build and disseminate knowledge on how to enhance the technological, human and organisational capabilities needed to be able to handle safety-critical situations in the maritime sector. The project thus had a holistic perspective and included work packages concerning design, training, regulations and professional culture on board ships. This broad perspective allowed the scope of the PhD work to develop and change over time, while still contributing to the SMACS research objectives. Some of the interviews and observations that form the empirical basis of this thesis were performed together with project members as part of work packages in the project. This is detailed in Chapter 5. Several papers were written together with SMACS project members, including Paper IV in this thesis.

1.2. Evolution of the research

I set out on the PhD journey with an interest in how design of technology influences human-machine interactions and thereby system safety. With the PhD scholarship being connected to the SMACS project, this naturally set certain premises for the study. At the outset, the PhD work focused on the sensemaking concept, which was central in the SMACS project. My initial goal was to develop design guidelines to support seafarers' sensemaking on the ship's bridge. Hence, the research initially focused on sensemaking and work on the bridge, as well as design processes performed by equipment manufacturers. Gradually I realised that 1) a ship's bridge is not only the result of design and development processes performed by designers and equipment manufacturers, but is also the result of other stakeholders' investments, as well as procurement and installation processes, and 2) there is already a great amount of knowledge concerning human-centred design available, both in general and for the maritime sector, in the form of regulations, standards and guidelines. The problem rather seemed to be the limited extent to which they are being utilised. Developing additional guidelines did not seem to be a fruitful direction to pursue, therefore, about mid-way in the PhD work, the research focus shifted to investigating a broader set of maritime stakeholders and their understanding of and perceived responsibility for usability in ship bridge design.

1.3. The Structure of the thesis

The remainder of this thesis is structured as follows: Chapter 2 provides background information about the maritime industry, the industry actors included in this thesis, the relevant design regulations and a description of the ship's bridge, including its typical equipment, layout and work organisation. In Chapter 3 an overview of relevant literature is provided, including research on work on the ship's bridge, maritime designers and design processes, stakeholders in ship bridge design and studies of maritime accident investigations. This chapter situates the current work within the research domain of maritime human factors and design and point to existing research gaps. Chapter 4 describes the theoretical framework and key concepts applied in this study, including design, human-centred design, *human error* and safety perspectives, sensemaking and seamanship. In Chapter 5, the research design and methods of this study are presented, including reflections on the scientific quality of the research. Chapter 6 provides a presentation of the five scientific publications included in this thesis. In Chapter 7, the findings from the presented publications are discussed in light of the research literature and the theoretical framework, focusing on the main contributions of the thesis. Chapter 8 concludes the work, outlines the thesis contributions and provides suggestions for further research.

The research is disseminated in one book chapter, two conference papers and two journal papers. An overview of the publications is found in Table 1 and the full texts are attached in the Appendix.

Table 1. The five publications included in the thesis.

No	Title	Year	Authors	Publication
I	Making sense of sensemaking in high-risk organizations	2021	Danielsen, B.-E.	S. O. Johnsen & T. Porathe (eds.), *Sensemaking in safety-critical and complex situations: Human Factors and Design.* CRC Press (published)
II	Still unresolved after all these years: human-technology interaction in the maritime domain	2021	Danielsen, B.-E., Lützhöft, M., & Porathe, T.	Stanton, N. (eds), *Advances in Human Aspects of Transportation.* AHFE 2021. Springer (published)
III	The contribution of ship bridge design to maritime accidents	2022	Danielsen, B.-E.	Katie Plant and Gesa Praetorius (eds.), *Human Factors in Transportation.* AHFE 2022. Springer (published)
IV	"Seafarers should be navigating by the stars": barriers to usability in ship bridge design	2022	Danielsen, B.-E., Lützhöft, M., Haavik, T., Johnsen, S.O. & Porathe, T.	*Cognition, Technology & Work, 24,675–691.* (published)
V	Somebody else's problem? Usability in ship bridge design seen from the perspective of different maritime actors	2022	Danielsen, B.-E. & Petersen, E.S.	TransNav, International Journal on Marine Navigation and Safety of Sea Transportation, 16 (4), 685-700. (published)

2. Background

This chapter presents background information about the research context which will serve as an important backdrop before proceeding to the next chapters. The chapter describes the technology and the work performed on ship bridges, some central characteristics of the maritime industry, the maritime actors included in this thesis, the ship design and building process and the regulations applicable for ship bridge design.

2.1. The ship's bridge

The bridge is "the centre where control is exercised over the behaviour of a vessel as a mobile entity" (Wilkinson, 1971, p. 313). From this location, the captain and deck officers perform navigation, manoeuvring, monitoring and control of the ship. The bridge may be located in the forecastle, mid-section or aft, depending on ship type and function. To provide an idea of the work environment in question, a general bridge layout is shown in Figure 1. The fore bridge windows provide a view of the surrounding area and in the consoles equipment like electronic charts, radar, steering equipment, engine control and communication systems are placed. The bridge layout and equipment may vary considerably, both within and between ship types. For instance, offshore supply vessels equipped with a Dynamic Positioning (DP) system may, in addition to the forward steering position, have an aft steering position where monitoring and control of the DP system is performed.

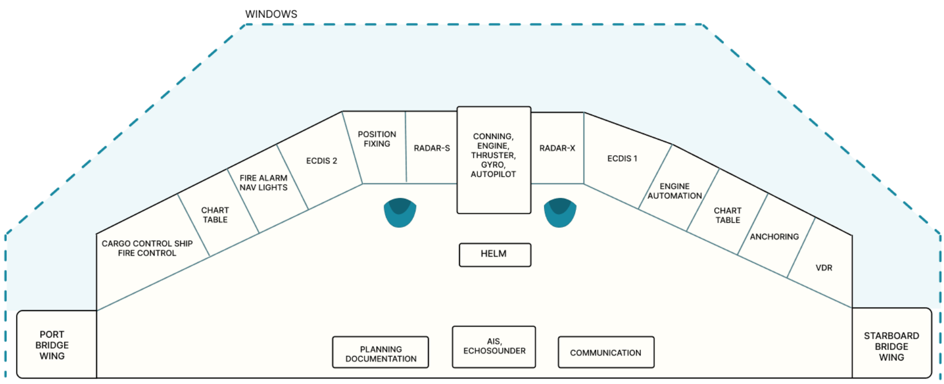


Figure 1. The general layout of a ship's bridge.

Picture 3 and Picture 4 are photographs from the field trips performed as part of this PhD project, illustrating how ship bridge design and layout can differ significantly between ships.

Picture 3. Main workstation on passenger ship built in 1983 (Photo: Brit-Eli Danielsen)

Picture 4. Main workstation on offshore supply vessel built in 2014 (Photo: Brit-Eli Danielsen).

The minimum requirements for the equipment installed on a ship's bridge is provided in SOLAS Chapter V, regulation 19. The requirements are connected to ship size and whether the ship is engaged in international voyages. The bridge of a ship of 50,000 gross tonnage and upwards must have the following instruments available:

- Electronic Chart Display and Information System (ECDIS)
- Radars and automatic radar plotting aid
- Magnetic compass and gyro compass
- Rudder, propeller, thrust indicators and controls
- Heading or track control system
- Autopilot
- Rate-of-turn indicator
- Speed and distance measuring device
- Automatic identification system (AIS)
- Global navigation satellite system (GNS) receivers
- Echo sounder
- VHF and intercom

The available tools and instruments on the bridge have changed over the years in pace with the general evolution of technology. One hundred years ago, navigation was performed by calculations based on observing celestial bodies. In the 1920s, paper charts, compass, sextant and depth soundings were the available tools to a navigator (Lützhöft, 2004). Today, navigation is performed with the help of the above-mentioned electronic instruments, in other words, it is possible for the deck officer to find the position of the ship by looking at the ECDIS display where the own ship's position is displayed as a symbol.

The technological development has also included the integration of instruments, meaning that they can be connected to exchange data with each other. Both navigation systems and other ship management systems, e.g., engine and ballast control, can be integrated to form an *integrated bridge system* (IBS). IMO's definition of IBS describe that the aim of integration is to increase "safe and efficient ship's management" (International Maritime Organization, 2022d) illustrating that safety is an important element in the technological development.

2.2. The work on the bridge

The crew on board a ship is hierarchically organised, with the master or captain being manager and in overall command of the ship. Next in command is the chief engineer, responsible for the engine department and the chief officer, responsible for the deck department (Lützhöft et al., 2011). In general, the ship's crew can be divided into the deck department, the engineering department, the steward's department and others depending on ship type. The deck department consists of deck officers and ratings. The deck officers are responsible for the safe and efficient navigation of the vessel, as well as the overall management of the vessel which includes administrative tasks such as scheduling, reporting, external coordination, cargo storage and handling, deck operations and maintenance. The work on a ship's bridge may be described as the following basic functions: navigating and manoeuvring, monitoring, manual steering, docking/undocking, planning and documentation, safety and communication (Lützhöft & Lundh, 2009). Seafarers' competence is regulated by the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (International Maritime Organization, 1978), which prescribes minimum standards relating to training, certification and watchkeeping for seafarers on an international level.

The bridge crew's responsibilities are carried out in shifts or watches, which may last for four to seven hours, depending on the arrangement on the individual ship. The deck officer assigned with the duties of watch keeping and navigation on a ship's bridge is known as the officer on watch (OOW). He or she may be aided by a helmsman and an Able seaman (AB) acting as lookout. The OOW is the master's representative and is responsible for the safe navigation of the ship on his/her watch (International Maritime Organization, 1978). In both the offshore vessels and passenger vessel visited during my field trips, there were four deck officers organised in two shifts, where the master and the chief officer were paired with an officer of lower rank in each shift.

2.3. Characteristics of the maritime industry

According to the International Maritime Organization "Shipping is perhaps the most international of all the world's great industries" (International Maritime Organization, 2022f). Globalization provides business opportunities but may also be a challenge for national authorities role in the enforcement of safety regulations (Almklov & Lamvik, 2018; Le Coze, 2017). The commercial operations, technical management, crewing, registration and ownership of a single ship may be spread across several countries. On a global scale, the top five ship-owning economies (Greece, China, Japan, Singapore and Hong Kong SAR) per January 2021 accounted for 52% of the world fleet tonnage combined. Half of the world's tonnage was owned by Asian companies, while Europe accounted for 40% of the ownership (UNCTAD, 2022b). Tonnage has increased considerably over the recent years, to a carrying capacity of 2.1 billion dwt[4] in January 2021, which is 63 million dwt more than the previous year (UNCTAD, 2022b). This is due to both an increase in ship size as well as an increase in the number of ships. Shipbuilding was in 2020 concentrated in China, the Republic of Korea and Japan. In 2020, these three economies accounted for 94% of the global shipbuilding in terms of gross tonnage[5], while ship recycling mainly occurred in Bangladesh and India (jointly accounting for 71%).

From the 1970s, following the growing free-market capitalism, shipowners increasingly registered their ships under a different flag than the country of the vessel owner, known as flags of convenience (FOC). Reasons for doing so include economic advantages like lower registration fees, minimal conditions for admission and relatively relaxed regulatory standards in some countries (Bhardwaj et al., 2019). This has led to Panama, Liberia and the Marshall Islands becoming the leading flags of registration (UNCTAD, 2022b).

The shipping industry involves different business sectors, depending on the type of cargo being carried (e.g., bulk, tank, container or specialised cargo), whether it is organized as tramp[6] or providing services which can be port tugs and bunker ships or services running on fixed schedules like container lines, passenger and cruise ships. The different sectors may have differently organised economic models and organisational structures to achieve their goals as businesses. A common characteristic, however, is the highly competitive terms of the industry, as described by Walters and Bailey (2013, p. 81):

> "Matching capacity to carry cargo with the needs of shippers/charterers is a core activity essential to the successful business of shipping. This includes not only providing the right service at the right price, but also the buying, building, chartering-in and chartering-out of ships in anticipation of international, but also local and regional, market conditions"

It is a common arrangement to outsource and charter ships which leads to a distinction between ownership and the operation of a ship (Walters & Bailey, 2013).

[4] The unit dead-weight tons (dwt) indicate the cargo carrying capacity of a ship
[5] The unit gross ton (gt) reflects the size of a ship
[6] A vessel which does not operate under any regular schedule, itinerary or ports of call. It trades on the spot market and calls any port where cargo may be obtained

2.4. Actors in the maritime industry

This section provides a description of the maritime actors relevant for this thesis; the IMO, the Flag States, the classification societies, shipowners, shipyards, equipment manufacturers, insurance companies and crew (seafarers). How these actors relate to each other is illustrated in Figure 2.

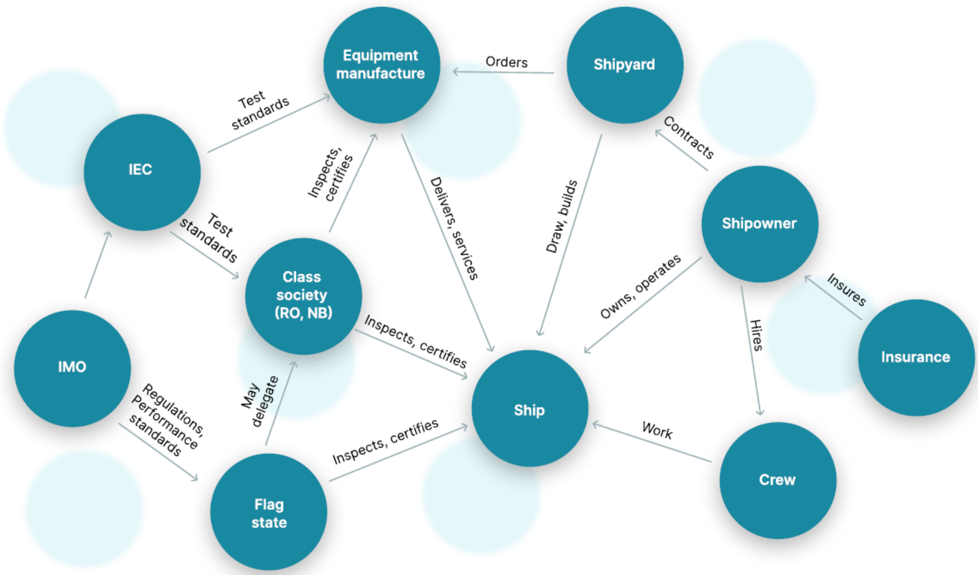


Figure 2. An overview of the maritime actors and their relations. The empty circles illustrates that the figure is not exhaustive, numerous other maritime actors exist.

The International Maritime Organization (IMO)

The IMO is a specialised agency of the United Nations. The international nature of shipping has necessitated regulations and standards to be developed on an international level to be effective. IMO is a forum where international regulations and standards can be agreed upon, adopted and implemented (International Maritime Organization, 2022e). Creating an international regulatory framework for the shipping industry is required "so that ship operators cannot address their financial issues by simply cutting corners and compromising on safety, security and environmental performance." (International Maritime Organization, 2022e). The IMO's formal mission statement is to:

> “promote safe, secure, environmentally sound, efficient and sustainable shipping through cooperation. This will be accomplished by adopting the highest practicable standards of maritime safety and security, efficiency of navigation and prevention and control of pollution from ships, as well as through consideration of the related legal matters and effective implementation of IMO’s instruments with a view to their universal and uniform application.” (International Maritime Organization, 2022a).

The IMO was formally established in 1948 and entered into force in 1958. Several conventions, including SOLAS, had already been established and were incorporated by the IMO when founded. The IMO is now responsible for more than 50 international conventions and agreements, in addition to the many protocols and amendments that have been adopted (International Maritime Organization, 2022b). The IMO currently has 175 Member States and three Associate Members, in addition to 66 intergovernmental organisations that have observer status and 85 international non-governmental organisations with consultative status, in order to ensure international information sharing and coordination. The Organization consists of an Assembly, a Council and five main Committees and several Sub-Committees that support the work of the main committees. The committees may communicate the interpretation and guidance of the conventions by circulars. The IMO conventions come into force through consensus by all member states. The consensus process has been accused of being an extremely slow procedure that often results in the lowest common denominator (Mitroussi, 2004). However, the IMO has taken measures to improve their processes, for instance through the method of tacit acceptance of the amendment process. The enforcement of the IMO conventions depends upon the Governments of the Member States as the IMO itself has no powers to enforce conventions (International Maritime Organization, 2022b).

Flag States

The flag state is responsible for the enforcement of national and international maritime regulations on ships flying their flag. The Norwegian Maritime Authority (NMA) is “the administrative and supervisory authority in matters related to safety of life, health, material values and the environment on vessels flying the Norwegian flag and foreign ships in Norwegian waters” (Norwegian Maritime Authority, 2022a). The NMA is subordinate to the Ministry of Trade, Industry and Fisheries and the Ministry of Climate and Environment. The activities of NMA “are governed by national and international legislation, agreements and political decisions” (Norwegian Maritime Authority, 2022a). One of the “driving forces” of the

NMA is to maintain and develop “a strong Norwegian flag” and its overall objective is to be “the preferred maritime administration” (Norwegian Maritime Authority, 2022a). The NMA actively participates in international organisations and in international legislation development. The NMA records and follows up on accidents as well as managing the Norwegian International Ship Register (NIS) and the Norwegian Ordinary Ship Register (NOR). Central to this thesis is the NMAs role of acting as a supervisory authority, which includes certification (for seafarers and vessels), document control, inspection and auditing to ensure equipment and vessels’ compliance with the legislation. The flag administrations may delegate the inspections and surveys either to surveyors nominated for the purpose or to recognised organisations (ROs).

Classification Societies

Classification societies are non-governmental organisations that establish technical standards for the construction of ships. They issue classification certificates that verify that the construction of a vessel complies with relevant standards. This certificate is necessary for the shipowner to register the ship in a flag state and obtain marine insurance. The certificate of class will include class notations that signify which rule requirements that are applicable for the assignment and retention of class. Class notations are either mandatory or optional, and can cover different aspects (e.g., ship type, structural or engine standard). Bridge and bridge equipment is not part of classification unless the shipowner wants a specific, navigation-related voluntary notation.

The flag state may delegate the responsibility for inspection and supervision of the flag state rules to a classification society, meaning they have a been appointed as a Recognised Organisation (RO). In Norway, five classification societies are appointed as ROs: American Bureau of Shipping, Bureau Veritas, DNV, Lloyd's Register, RINA and ClassNK. These are all members of the International Association of Classification Societies (IACS), a non-profit organisation of classification societies that establishes minimum maritime technical standards and requirements that are aligned with the IMO through its consultative status. Classification societies can also be approved as notified bodies, meaning they can issue the Marine Equipment Directive (MED) certification which is required for ships flying the flag of an EU or EFTA country.

Shipowners

Shipowners are a diverse group. The owners of ships may be organized as a company, it may be a person or an investment fund. Shipowner companies can range from small family-run companies owning one or a few ships to multinational companies owning hundreds of ships. The different functions like ship management, technical management, purchasing, insurance and crewing management may be departments within the company, or it may be outsourced to a third-party company. The shipping companies has access to a global labour force as the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) certificates of competence are internationally accepted. Shipowners have the possibility to optimize cost structures through replacing the crew, or parts of the crew, with workers from a different nationality where the claims for wages are lower. Shipowners' priorities are influenced by being part of a business sector with competition between companies and countries in the maritime industry. In addition, the maritime industry competes with other transport sectors (Størkersen, 2015)

Shipyards

Shipyards design and build new ships and provide service, maintenance repairs and conversions, modifications and upgrades of existing ships. Most shipyards have a design department and an engineering department. Naval architects are important professionals in these companies, being responsible for ship design, construction and project management. The primary aspect of naval architecture has to do with the main characteristics of a ship, such as the size, speed, stability, manoeuvrability, cargo carrying properties, and exterior and interior design. The design process usually follows the traditional engineering focused spiral concept of ship design (Evans, 1959).

Equipment manufacturers

Equipment manufacturers are companies that design, develop and sell a wide range of maritime equipment for ships, e.g., specialist hardware, software, electrical propulsion systems, bridge equipment and DP systems. Some equipment manufacturers operate in a specialised niche, delivering one or a few specific pieces of bridge equipment, while others deliver a complete range of bridge equipment that includes consoles and integrated bridge solutions. Design and development of equipment may require several engineering disciplines and designers. In addition, the sales department may be an important influence on decisions within equipment manufacturer organisations.

Insurance companies

Marine insurance is the shipowner's protection against financial loss due to accidents and incidents and is divided into two main areas: 1) Hull and machinery insurance, which covers the risk of property damage and 2) Protection and Indemnity (P&I) insurance, which covers open-ended risks, like third party liability for cargo, injuries to people or environmental damage. The high value of a ship has led to the insurance of a single ship often being divided over multiple companies in order to distribute the risk. The insurance process involves insurance brokers that ensure the whole ship gets insured, and insurance adjusters that manage the distribution between insurance companies in the case of damage.

Crew

The shipping industry is international and "a ship can be owned in one country, operated from another country, and registered by a third country, and crew can hail from any country" (Lützhöft et al., 2011). The seafarers being a global labour force is made possible by the IMO STCW (International Maritime Organization, 1978) which ensures the seafarers' basic requirements on an international level. As mentioned, there is often a distinction between ownership and operation of a ship (Walters & Bailey, 2013). Seafarers that are employed through a crewing agency may have their contract of employment with the shipowner, while still mainly interacting with the crewing agency. The recruitment period may be limited to a voyage or a contract for up to a year (Walters & Bailey, 2013). There is a global shortage of ship officers in the industry, which Bhattacharya (2015) connects to unsatisfactory work experiences, related to e.g. working conditions on board, job security and lack of adequate shore leave. The shipping industry's requirements for profitability have led to reduced manning on board as well as extended working hours (Ljung & Lützhöft, 2014; Lundh, 2010).

2.5. Ship design and building

The decision to initiate a ship design process is a business decision based on anticipated market conditions (Gernez et al., 2014; Walters & Bailey, 2013). Shipowners and investors generally focus on the earning potential of the ship, such as cargo carrying capacity, speed, versatility and efficiency (Lundh, 2010; Lützhöft et al., 2017). Already prior to the signing of the contract between shipyard and ship-owner for the construction of the ship, there has been multiple negotiations and considerations performed by the shipping company, financer and future owners (Dokkum, 2016). Hence, the focus tends to be on improving efficiency through investments in technologies rather than on operations and the people working on board (Bhattacharya, 2015). A shipowner has the possibility to buy a standard ship type developed and built in larger series by a yard. Series-production enables a shipyard to increase its production efficiency, which in turn lowers the cost per ship. However, most new ships are designed and constructed following the specific requirements of the shipping company (Dokkum, 2016).

The onboard systems are usually built up of commercial off-the-shelf (COTS) equipment, delivered by a vast number of maritime sub suppliers, each specialising in their separate niches (Lützhöft et al., 2017). On the ship's bridge this leads to a vast array of equipment and systems provided by multiple vendors (Nordby, Frydenberg, et al., 2018), with differences in look, feel, interaction paradigms and alarm indication concepts (Lützhöft et al., 2017).

2.6. Ship bridge design regulations

Ship bridge equipment and design is regulated through the IMO instruments. The International Convention for the Safety of Life at Sea (SOLAS) was established in 1914 as a response to the sinking of the *Titanic* in 1912. SOLAS was incorporated by the IMO at its foundation and is still the most important international maritime safety mechanism (Parsons & Allen, 2018). The SOLAS convention governs safety through 14 chapters that specify minimum standards for the construction, equipment and safe and secure operation of ships (International Maritime Organization, 2022g). Chapter V, Safety of Navigation, includes e.g., requirements for meteorological services for ships, search and rescue services, manning, routeing of ships and pilot transfer. SOLAS Chapter V, Regulation 22 describe requirements regarding visibility from the bridge while Chapter V, Regulation 19 concerns "Carriage requirements for shipborne navigational systems and equipment". Regulation 19 outlines specific requirements for the equipment that ships must have installed, for example compass, charts, ECDIS, radar, automatic identification system (AIS), echo sounder, speed measuring devices, track and heading control. For each of these instruments the IMO has issued performance standards that outline the required functionalities and qualities of the equipment. Due to the rather high-level language of the performance standards, the International Electrotechnical Committee (IEC) develops highly detailed test standards matching the IMO performance standards. The IEC Test Standards form the base for the issuing of Type Approval of navigational equipment and it is thus important for the equipment manufacturers to meet these requirements. In addition, ships flying the flag of a

European Union (EU) or European Free Trade Association (EFTA) country can only install marine equipment marked with the “wheel mark”. The “wheel mark” is the EU Marine Equipment Directive (MED) mark of conformity, which is issued by notified bodies that verify that the equipment is in compliance with relevant standards.

Of particular interest in this thesis is SOLAS Chapter V, Regulation 15, that sets forth “Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures” (International Maritime Organization, 2002). These seven principles require usability considerations in all decision affecting design and arrangement of bridge equipment and systems through rather strong wording (International Maritime Organization, 2002):

> “All decisions which are made for the purpose of applying the requirements of regulations 19, 22, 24, 25, 27 and 28 and which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge and bridge procedures shall be taken with the aim of:
>
> 1. facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions;
> 2. promoting effective and safe bridge resource management;
> 3. enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;
> 4. indicating the operational status of automated functions and integrated components, systems and/or sub-systems;
> 5. allowing for expeditious, continuous and effective information processing and decision making by the bridge team and the pilot;
> 6. preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and
> 7. minimizing the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action.”

In regulation V/15 there is a reference to the circular MSC/Circ.982. This circular, issued by the IMO’s Maritime Safety Committee (MSC), sets forth “Guidelines on Ergonomic Criteria for Bridge Equipment and Layout”. This guideline intends to support the provisions of regulation V/15 through focusing on physical ergonomics guidelines for bridge equipment and bridge layout. The guideline includes the recommendation for seven distinct workstations based on bridge functions and lists the recommended equipment for each workstation.

3. Relevant research on ship bridge design

In this chapter, relevant research on ship bridge design is presented to inform the topic and findings of this thesis, as well as to identify gaps in the literature that this thesis aims to address. More specifically, the chapter explores studies concerning human-technology interaction on the ship's bridge and how design issues influence this interaction, maritime designers and design processes, ship bridge design and development efforts, stakeholders in maritime design and the economic value of human-centred design, as well as studies concerning maritime accident investigations.

3.1. Design issues on the ship's bridge

The significance of human factors (or ergonomics) was acknowledged later in the maritime industry than in the aviation and nuclear industries, although maritime human factors work can be traced back to World War II (Lützhöft et al., 2011). The first studies addressing human limitations and system requirements on design of bridge equipment on merchant ships occurred in the late 1960s (Lützhöft et al., 2011). One of the earliest comprehensive studies of ship bridge design and bridge equipment from an ergonomic point of view was provided by Wilkinson (1971). Wilkinson raises the concern that the design and layout of ship bridges have not kept pace with advances in technology. He argues that the bridge is not the result of "a planned rational approach" (Wilkinson, 1971, p. 314) based on a full assessment of the work environment, but rather that it has gradually evolved based on the previous layout.

Further, Wilkinson attributes poor design to lack of feedback from operations to designers (naval architects and equipment manufacturers) and reports that seafarers adapt to the equipment regardless of its usability. Wilkinson criticises designers' lack of knowledge about the work on the bridge, highlighting the lack of working communication lines between the seafarers and the designers to provide feedback from operations. Another early study of the interaction between humans and technology on the ship bridge was performed by Morgan et al. (1986). This study found that the interaction between individuals in a navy bridge team was partly determined by the interaction with technology and technology procedures, and that this standardised performance of tasks left too little room for communication and cooperation between the team members. The authors argue that this can weaken the mechanisms that create the dynamics and flexibility presumed to strengthen a team's capacity to handle uncertainty and ambiguity. In the same vein, Sørensen et al. (2018) argue that the layout of ship bridge equipment and consoles has an observable impact on the ability of bridge teams to operate effectively, which necessitates a minimum manning requirement for the bridge to ensure safe resource management. Lützhöft (2004) performed a comprehensive ethnographic study of work on ship bridges and, in line with Wilkinson (1971), found that design and development of technology for ship bridges is done without the necessary knowledge about the context of use and end-users' needs. Lützhöft found that the increasingly automated systems on the bridge required the seafarers to do less manual work, but more cognitively demanding *integration work*. Similarly, Olsson and Jansson (2006) found that bridge officers on high-speed ferries often have to devote significant attention to information search and manipulation of controls, due to inappropriate integration and presentation of information. When Allen (2009) investigated British seafaring officers' perceptions of new technology, he found little generalised resistance towards new technology. However, the officers greatest concern was training, a fact that Allen connects to poor design and the need to constantly adapt to new interfaces as two bridges are rarely the same.

Several authors have addressed the increasing level of automation on ship bridges and how this has introduced new challenges to the human-technology interaction (Grech et al., 2008; Hetherington et al., 2006; Lützhöft & Dekker, 2002). Lützhöft and Dekker's (2002) study is a good illustration of this, where they traced the sequence of events that preceded the grounding of the *Royal Majesty* in 1996, from the viewpoint of the crew on the bridge. The analysis aimed at understanding why the crew's actions and assessments made sense at the time, and shows the consequences of *automation surprise*, i.e., when humans are not aware of or understand what the automation is doing. Lützhöft and Dekker (2002) suggest that automation creates new human weaknesses and amplifies existing ones. Lützhöft et al. (2011) argue that the role of the Officer on watch (OOW) has changed from actively navigating/conning the ship, to passively monitoring semiautomatic systems, which contributes to other known human-automation challenges such as *out-of-the-loop syndrome* and *de-skilling.*

The suboptimal usability found on ship bridges has been connected to the way technology is introduced and implemented on the bridge (Bhardwaj et al., 2019; Norris, 2007; Olsson & Jansson, 2006). MAIB and DMAIB (2021) found that ECDIS has been viewed in the same way as paper charts, despite it being a technology that provides a new form of knowledge, as well as increasing the amount of available data that requires management and interpretation. This necessitates different types of training, procedures and technological solutions. Bhardwaj et al. (2019) argue that the equipment implementation process is driven by economic logic of low-cost operations, which contributes to making the seafarers adapt to the new technology while having the same number of manual tasks.

3.2. Human-technology interaction on the bridge

While Hutchins's (1995) book *Cognition in the Wild* did not address ship bridge design from an ergonomic viewpoint, his seminal work on understanding the work on a naval ship bridge bears mentioning. Based on both anthropology and psychology, he describes the work on a naval ship bridge as a *distributed cognitive system*, i.e., larger than an individual and with cognitive properties produced by interactions between both technology and individuals. In the same vein, a ship's bridge can be understood as a *sociotechnical system,* where social (individual, organisation, society) and technical (machines, technology, material) factors interact to produce a (successful) system outcome (Costa, 2018; de Vries, 2017; Grech et al., 2008). Each ship can be viewed as a sociotechnical system that is part of a larger network of ships, shore structures and organisations, where the shipping industry itself is recognised as a complex sociotechnical system (Costa, 2018; da Conceição et al., 2017; Forsman, 2015; Grech et al., 2008).

Prison et al. (2013) studied ship manoeuvring and found that a sea voyage has three phases with different levels of complexity and required effort from the crew: close manoeuvring, archipelago and open sea. Further, they describe the ship handlers' work to accomplish a safe journey as "striving for harmony" between the ship and its surrounding environment. "Striving for harmony" requires the ship handler to account for the individual ships' manoeuvrability and navigation instruments, as well as dynamic environmental factors such as wind, waves, current and visibility. The ability to deal with these factors depends on what Prison et al. referred to as *ship sense*, a form of tacit knowledge about the manoeuvring of a ship that includes "knowing what information to look for, where to find it and how to use it to be able to manoeuvre the ship" (Prison et al., 2013, p. 117). Similarly, Forsman (2015) studied high-speed navigation and argued that as various aspects like the task, situation, context, weather and speed vary, the methodology to handle these needs to encompass the ability to adapt dynamically.

The concept of situation awareness (SA)[7] has been pointed out as important in relation to technology on the bridge (Grech et al., 2008). Grech et al. (2008) identified the factors that

[7] Endsley (1988) defines SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

influence loss of SA on a ship's bridge to be too high or too low workload, system complexity, automation, safety culture, teamwork and communication. Sandhåland et al. (2015a) examined accident reports concerning collisions between attendant vessels and offshore facilities on the Norwegian continental shelf during the period 2001–2011, and found that 18 of 23 accidents were preceded by loss of situation awareness. The authors established that inadequate operation planning, inadequate bridge design, insufficient training, communication failures and distracting elements were the underlying factors that contributed most significantly to the collisions. In a related field study of bridge operations on offshore supply vessels, Sandhåland et al. (2015b) found distinct variations in shipboard practices such as operational planning, communication procedures and distracting elements, that can influence SA. This study described SA as a *distributed phenomenon*, where SA-related information was held both by human and non-human agents on the bridge (Sandhåland et al., 2015b).

3.3. Maritime designers, design methods and processes

In 1980, Millar proposed that designers should consider the operational requirements of the seafarers in order to be able to improve design by grouping of instruments and harmonising the ship bridge design. Research has since revealed that maritime designers neither have practical seafaring experience nor direct access to seafarers (van de Merwe, 2016), nor access to data from questionnaires or online platforms (Vu & Lützhöft, 2020). Thus, it is challenging for designers to develop an understanding of the maritime end-users and their work environment (Ahola, 2018). Supporting this, Meck et al. (2009) interviewed designers from different nautical developmental units and found that the designers had very different perceptions of the navigator's role in relation to the technical systems. The designers' images of the navigator's role ranged from "servant to the engineering" to "power- and skilful bridge manager". The designers also had different notions of human factors and usability. Further, Meck et al. (2009) found that while designers are interested in, and aware of, the importance of integrating the user perspective in the design process, they lack concrete knowledge and methods for including user perspectives in their work. There are also no structural or organisational systems in place in the maritime sector that allow for systematic feedback loop between end-users and designers (Meck et al., 2009). In the same vein, Lurås et al. (2015) investigated how industrial and interaction designers experience designing for the Norwegian offshore industry. They found that offshore-specific design projects are complex at many levels, which imposes several challenges for designers and makes it difficult to acquire the necessary level of insight. Lurås and Nordby

(2015) argue that designers in the maritime industry should develop a *designer's sea sense,* which involves detailed knowledge about the environment for which they design. According to Lurås and Nordby (2015), field research to inform design in the maritime industries has rarely been performed, despite the fact that field research is paramount for designers to gain *sea sense.*

Researchers have suggested several methods for eliciting end-user information. Lurås and Nordby (2015) developed a guide for design-driven field research to aid designers in preparing for and performing field studies at sea. Frydenberg et al. (2019) suggested using a mixed-methods approach based on their experience in field research to investigate the use of AR on ship bridges, which facilitates serendipity in design-driven field research. A project named ONSITE by Oslo School of Architecture and Design worked on how human-centred design methods could fill the gap between ship design and operations (Gernez, 2018). The project focused on a field study methodology (Gernez & Nordby, 2020) and how the generated knowledge from the field could be applied in maritime design processes (Gernez, 2019; Nordby, Schaathun, et al., 2018). Research has also demonstrated that eye-tracking can be used to reveal suboptimal design in the ship bridge layout and in the software graphical user interface both in simulators and at sea (Bjørneseth et al., 2014; Hareide et al., 2017; Hareide et al., 2016). Ahola (2018) argues that using participatory design methodologies which focus on communication and cooperation between end-users and designers, can aid in eliciting the specialised knowledge and experience of onboard operations that seafarers possess. Costa and Lützhöft (2014) similarly argue for the importance of user-centred design (UCD), they found that seafarers perceive UCD as an added value in terms of physical, cognitive, psychosocial and organisational improvements.

Other design methods that do not require field work includes the study of Vu and Lützhöft (2018) which investigated the way seafarers perceive and group information elements from the displays of integrated navigation systems by using a method of card sorting. Vu et al. (2019) found that studying the frequency of use of functions and information available on an Integrated Navigation System can generate knowledge that can be utilised for designing menu tree structures, display layouts and interaction methods on the interface of navigation systems. Österman et al. (2016) found that representative users (as opposed to end-users) were able to generate several types of useful feedback on design parameters, using a combination of scenarios and 3D models of a proposed design of a ship bridge workstation, showing that these methods are useful as mediating objects supporting the end-user participation in design process. Similarly, a European project named CASCADe argued for using a model-based design approach and using virtual and physical simulations for testing and evaluating to better integrate human factors in the ship bridge design (Javaux et al., 2015).

3.4. Ship bridge design and development efforts

This section shows there has been significant activity by several research projects and studies, to develop solutions aimed at improving ship bridge design and ship bridge design processes. For instance, *OpenBridge* is a joint industry effort that seeks to solve some of the design challenges in the maritime industry through the development of free design guidelines and implementation tools to contribute to cross-vendor integration and consistent user interfaces (Nordby et al., 2019). *OpenBridge* has focused on generic user interface components and a number of core functions that require consistency, such as a standard navigation menu that is shared across all bridge systems (Mallam & Nordby, 2021). Also focusing on consistency across interfaces, the Rolls Royce Unified Bridge was a holistic bridge concept developed by a redesign and rearrangement of physical consoles, input devices and software interfaces (Bjørneseth, 2021). According to Bjørneseth (2021), the development followed a user-centred design process where the end-users were involved from the ideation phase, throughout the development process towards a finished product. Another solution that bears mentioning is a display design concept for DP operations developed as part of the SMACS-project (Hurlen, 2021). Hurlen et al. (2019) identified "critical information hidden from view" as a challenge for DP operators sensemaking. Configurable screens where individual users can organise the content and layout quite freely, leaves them vulnerable to overlook important information when unexpected situations occur. Hurlen (2021) suggests a fixed spatially dedicated overview display to be used in combination with flexible display elements, to support a 'at a glance' system overview regardless of the situation. The research project CyClaDes introduced a framework in the form of a web-based database that allows different stakeholders from the maritime industry to access existing information about crew-centred design (i.e., guidelines, tools and methodologies). The project also developed E-learning training packages designed to disseminate knowledge about crew-centred design and its benefits to different stakeholder groups (Costa et al., 2017; Praetorius, 2015; van de Merwe, 2016).

Other research projects and studies have focused on developing new and innovative solutions intended for ship bridges in the future. The Ulstein Bridge Concept (UBC) was a design research project focusing on the bridge environment of offshore service vessels. The design project included all functions of the bridge, from room layout to graphical user interfaces. The project produced the *Ulstein bridge vision*, a vision based on user needs, but also aiming at being innovative and develop solutions to be realised in the future (Kristiansen, 2014; Lurås, 2016). Strazdins et al. (2014) studied a possible future alarm solution in the form of a wearable tactile device application for smart alarm systems. The development was based on the hypothesis that tactile alarms can decrease user resistance and deliver more focused awareness with directional hints to particular areas of the bridge. Another innovative solution was proposed by Porathe (2006), who worked on 3-D nautical charts to be viewed from an egocentric bridge perspective, where the idea was to remove the need for mental rotations that requires cognitive work by the navigators. Route exchange is another new solution, which is part of a new design concept for decision-support systems on the ship's bridge, aiming at keeping the navigator in the loop while sharing information to the wider maritime system. The rationale behind route exchange is that by sharing intentions with fellow mariners and shore services, there is a greater chance that someone will detect anomalies, thus avoiding so called "single person failures" (Porathe, 2015, 2016). Bjørneseth et al. (2012) described the development of a multi touch gesture interaction for Dynamic Positioning vessels. The study found that the traditional touch screen button and menu interactions were quicker and less erroneous than the multi touch gesture interaction, a finding especially evident when tested in a motion platform simulator. As such, the study demonstrates the importance of bringing knowledge about the context of use into the design process.

3.5. Stakeholders in ship bridge design

While the work of designers, design processes and design projects is important for the design of ship bridges, human-centred design does not happen in a vacuum (Norman, 2013). The design of products may be subjected to market forces, competition, costs, schedules and conflicting requirements from a variety of stakeholders. In the maritime industry as a whole, there are numerous actors that are either directly involved in operations, transporting goods or people, or in the supporting areas, e.g., ship operators, shipowners, crew, shipbuilders, design firms, equipment suppliers, brokers, agents, repairers, IMO, flag states, coastal states, classification societies, insurance, incident management, education/training organisations, financiers, cargo owners and ports/terminals (Lützhöft et al., 2011). If we narrow the search for stakeholders down to the complex process of ship design and construction processes, there are still several stakeholders involved: classification societies, regulatory authorities, shipbuilders, naval architects, equipment suppliers, ship managers/operators and insurers (Rumawas & Asbjørnslett, 2014).

Of these stakeholders, regulators are especially important for ensuring safety (Reason, 1997). The IMO, which is responsible for the international regulatory framework for the shipping industry, has acknowledged the need to address human factors in ship bridge design through the SOLAS regulation V/15 (International Maritime Organization, 2002). To create the needed flexibility for the many stakeholders involved in complex design processes, regulation V/15 is structured as a goal-based regulation that sets forth objectives that the designed product or system *shall* achieve, without offering a detailed description of how to achieve them. This approach differs from prescriptive regulations that include detailed requirements for the design of equipment. The advantage of prescriptive regulations is that a specific standard is ensured, and they may be seen as easier to enforce by regulators as they constrain regulatory discretion. The advantage of goal-based regulations is the flexibility provided, allowing designers and developers to experiment and find new and innovative solutions (Decker, 2018; Hamann & Peschmann, 2013) and they may provide flexibility to address the dynamic context of use (Earthy & Sherwood Jones, 2006). However, there are risks associated with goal-based regulations. In the case of SOLAS V/15, it requires that stakeholders like designers, developers and surveyors possess a certain level of human factors knowledge as well as knowledge about the specific users and context of use (Earthy & Sherwood Jones, 2006). Differences in the level of knowledge of human factors and human-centred design posited by different maritime stakeholders has been reported (Costa et al., 2017; Vu & Lützhöft, 2020). In addition, data and information about the maritime end-users and the context of use may neither be available (Earthy & Sherwood Jones, 2006; Vu & Lützhöft, 2020) nor easily accessible (Lurås & Mainsah, 2013).

Different stakeholders' interest in and power to influence maritime human factors is very different (Vu & Lützhöft, 2020; Österman et al., 2009). The differing perspectives, priorities, work approaches and professional languages may be a challenge for a shared understanding between the stakeholders, as well as for project execution (Mallam et al., 2016). In a ship design process where stakeholders represent vastly different interests, conflicts and trade-offs may, for instance, result in an excessive addition of features as the design process unfolds (Garcia et al., 2019). Bjørneseth (2021) describes how a ship bridge design and development project performed by an equipment manufacturer is influenced by both the shipyard's strong cost focus and the customer's (i.e., shipowner) requirements, which involves a "high level of tailoring according to personal preference" (Bjørneseth, 2021, p. 150).

Although Gernez's (2018) work focused on the design of engine rooms on ships, the findings are relevant for the case at hand because also here the end-users are not involved in the design process. He emphasised the necessity of interaction between the engine integrator, ship designer and yard on one side, and the end-users on the other side, to bring the operational expertise into the design process and that these interactions should be facilitated. However, the stakeholders that are interested in increasing their HF knowledge may find it challenging. Costa et al. (2017) found that the human-centred design (HCD) literature is not easily accessible and interpretable by the type of companies referred to as *HCD novices*. The authors suggest that in industrial practice, it may be more efficient for a design team of engineers to have HCD knowledge come from an educated project manager or a Human Factors/Ergonomics (HF/E) specialist than having to spend time and resources into learning and understanding HCD from scratch.

Other authors have described how different mindsets between human factors and engineering professionals has resulted in tense field experiences (Petersen et al., 2011; Petersen et al., 2015). Petersen et al. (2015) sought to provide an improved understanding of the classic design engineering mindset, to improve the interaction between these disciplines. The traditional ship design methods tend to be engineering-focused and there seems to be a lack of attention to human element issues in naval architecture education and design methodologies (Ahola, 2018). To address this challenge, Abeysiriwardhane et al. (2016) constructed a pedagogical framework for integrating HCD knowledge into maritime education through undergraduate design projects which, according to the author, made a noteworthy contribution to improving the students' HCD understanding.

The research literature has also described different means to involve and engage stakeholders in design. Mallam et al. (2017) described a software prototype of a diagnostic visualisation tool created to facilitate participatory design processes throughout ship development. The platform intended to facilitate multidisciplinary stakeholder knowledge transfer, with the aim to implement and optimise user-centred design solutions in ship design. Kristiansen (2014) discovered that conceptual designs promoted discussions among the various disciplines of designers, engineers, management and users, and as such could be a valuable means for increased innovation in the maritime industry. In the same vein, Lurås and Nordby (2013) described how design presentations of a complete redesign of current ship bridges facilitated alignment of a wide range of stakeholders' expectations of future bridge development, functioning as a preparation for systemic changes needed for innovation.

3.6. Economic value of human-centred design in the maritime sector

The maritime industry is competitive, and many organisations work on very small profit margins, forcing shipping companies to prioritise short-term economic gains (Bhardwaj et al., 2019; Grech et al., 2008). New ship development is driven by economics, meaning that human-factor interventions need to be justified in terms of their likely benefits exceeding their anticipated cost (Grech et al., 2008; Mallam et al., 2017). In Størkersen (2015) exploration of maritime regulators' safety-related decisions, she found that market forces influence both regulation-making and enforcement. Størkersen argues that the competition, both within the maritime sector and between transport sectors, leads to disagreement concerning the priority of safety versus profit between maritime actors. This situation "paralyzes safety regulation development and constrains the maritime safety regulators" (Størkersen, 2015, p. 91).

Cost-benefit analysis of ergonomics is an area where human factors specialists have traditionally not been strong (Grech et al., 2008), which also applies for the maritime industry (Österman et al., 2010). Österman and Rose (2015) argued that there is a need for knowledge about, and methods for, measuring the financial effects of ergonomics, to enable companies to make well-informed decisions and prioritisations. Österman (2013) sought to demonstrate the effects of human factors considerations in terms of a value proposition, where the value for the employees were described in terms of improved health and well-being, learning, skill discretion and independence in life. Its value for the company included increased operational performance and flexibility, advantages in recruiting and retaining personnel, while for the overall maritime sector it included competitive strength, attractiveness of work and increased learning across the industry. On the societal level, the value of human factors considerations included reduced costs for health care and social security, reduced environmental impact and a sustainable working life.

3.7. Ship bridge design in maritime accident investigations

The maritime industry has a history of focusing on learning from and developing safety regulations after incidents and accidents (Pomeroy & Earthy, 2017; Schröder-Hinrichs et al., 2013). SOLAS regulation I/21 and MARPOL articles 8 and 12 require that maritime administrations perform an investigation into casualties occurring on ships flying its flag. The Casualty Investigation Code (International Maritime Organization, 2008) requires that a marine safety investigation to be conducted into every "very serious marine casualty", defined as a marine casualty involving the total loss of the ship or a death or severe damage to the environment. The accident investigation may be carried out by a commission or accident investigation board within the flag state. The main objective of the investigation is to provide a learning opportunity to prevent future accidents and incidents. Accident investigation reports have the potential to inform ship owners, managers and seafarers of the negative impacts that improper design can have on safety.

Previous studies of accident investigation reports have revealed human-technology interaction and design issues to be contributing factors to accidents. Puisa (2018) analysed 188 reports from accidents and incidents with passenger ships, and found one of the prominent issues to be incomplete hazard analysis during design. Design issues that involve interactions between technology and people were found to be particularly overlooked or not communicated to the operators. Similarly, Macrae (2009) studied 30 marine accident reports of collisions and groundings, and found that issues relating to bridge layout were often involved in both types of accidents. A finding specific for collisions was that the location of the chart room took members of the bridge team away from their workstations. Inadequate bridge design was also found to be one of the underlying factors in a study of accident reports from collisions between attendant vessels and offshore facilities in the North Sea (Sandhåland et al. 2015a). Other studies reporting issues in the human-technology interaction on the bridge are Chauvin et al. (2013) that found 'misuse of instruments' to be one of two main environmental factors in their analysis of human and organisational factors in 27 reports of collisions. Likewise, inadequate use or failing to use available navigation aids was also found to contribute to the accidents in 18 of 95 investigation reports studied by Nilsen et al. (2016).

Grech et al. (2008) reported that system complexity and automation are factors that influence loss of situation awareness (SA) on a ship's bridge. They also found a correlation between increasing levels of technology and increasing occurrences of loss of SA (Grech et al., 2008). Despite the fact that the technology on ships is more complex today, a comparison of the *Titanic* accident in 1912 and the *Costa Concordia* accident in 2012 indicated that the underlying human and organisational factors contributing to the accidents are similar (Schröder-Hinrichs et al., 2012). Further, the authors found that accident investigations and reactions to accidents do not seem to have changed within the 100-year time span either. Schröder-Hinrichs et al. (2012) suggest that this relates to how maritime actors think about safety, as their thinking is in line with the Safety I perspective focusing on preventing things that go wrong (as opposed to the Safety II perspective focusing on enhancing things that go right).

A study by Mallam et al. (2022) found that seafarers do not seem to utilise original accident reports, because they favour other information sources that provide a more narrative-driven style that relates to their specific work practices. Researchers have also pointed out that accident investigation reports may be an incomplete source of accident information, due to factors like *hindsight bias* which leads people to exaggerate what could have been predicted in foresight based on the outcome of an event (Dekker, 2002). Further, the causes found in accident investigations tend to reflect the underlying accident models used by the investigators, known as the 'What-You-Look-For-Is-What-You-Find' principle (Lundberg et al., 2009). This principle is followed by the 'What-You-Find-Is-What-You-Fix' principle, where the identified causes are turned into specific problems that can be resolved (Lundberg et al., 2009). Schröder-Hinrichs et al. (2012) claim that there is a focus on causality in maritime accident investigations, limiting the scope of the investigations to concrete causes and ignoring less obvious and indirectly influencing factors. Furthermore, despite the fact that maritime accident investigations are not meant to determine liability, Schröder-Hinrichs et al. (2011) argue that the focus of accident investigation reports on unsafe acts 'committed' by the sharp end implies fault, although not from a legal perspective.

3.8. Addressing the gaps

Overall, the literature review presented in this chapter found that ship bridge design issues have been a topic of maritime researchers for decades. Further, the review reveals that while a substantial amount of research on ship bridge design has been performed, the published research does not fully explain why these efforts do not seem to be reflected in the maritime industry.

Knowledge about the end-users and context of use is central to the designing of a work environment that accommodates work performance and safety. Several studies have described how seafarers manage their work and how automation and design issues influence their performance. Paper I and II complement and extend the research on how to understand and describe the work on the bridge by applying the concept of sensemaking.

Accident investigations have been an important source of information for the maritime industry and regulation development. Studies on maritime accident investigations have found design issues as one of the contributing factors to maritime accidents. Paper III focuses specifically on maritime accident investigation reports where design issues have been addressed, adding the perspective of how these accidents are responded to in the form of the investigation board's safety recommendations and shipowner's reported responses.

There are a few studies that include the stakeholders involved in the ship bridge design processes, but this research has mainly focused on the end-users, design methods, processes and design solutions. However, design solutions are subjected to market forces, competition, schedules, cost-effectiveness and other conflicting requirements from a variety of stakeholders. There is limited research on how these structures and mechanisms in the maritime industry influence usability in ship bridge design. Paper IV and V contribute to building knowledge on how the perspectives of a broad set of stakeholders, including those involved in the certification, procurement and implementation processes, influence the realisation of usability in ship bridge design in the maritime industry.

4. Theoretical framework and key concepts

While the previous chapter outlined previous relevant research on ship bridge design, this chapter is forward looking, by presenting definitions and descriptions of the key concepts and theoretical framework that forms the theoretical basis for the current study. Together these concepts and theories can be seen as the lens through which the data collection and interpretation, presented in subsequent chapters, is viewed. First, the terms design, human factors and human element are defined and explained, followed by the term *human error* and how it relates to central safety perspectives. Thereafter, human centred design and usability are presented before the concepts of sensemaking and seamanship are described.

4.1. Design

Design is a term applied to a broad range of things, in everyday life it is often associated with trendy products and beautiful forms that promote sales (Schneider, 2007). The term is both used to describe the process of designing and the designed object – the resulting product, system, or process. Within the design research discipline there is a diversity of ideas and methods gathered under the design label (Buchanan, 1992). Thus, there are numerous definitions of design in the research literature (Atwood et al., 2002; Ralph & Wand, 2009). Some of the well-known definitions are rather high-level definitions which may be future oriented, for instance, "design tells (shares) stories about the future" (Roesler et al., 2004). They may also be concerned with changes that have value for people, as in design is "committed to transforming the world for the benefit of human beings" (Schneider, 2007, p. 209), or design concerns devising "courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 55). A different focus is provided in the definition "design is making sense (of things)" (Krippendorf, 1989, p. 9), meaning that the designed products should be understandable or meaningful to people. Design and development of products and systems for ship bridges must adhere to regulations and customer requirements and the design processes are limited by factors like time and cost. Hence maritime designers do not have an unlimited possibility to find a 'preferred situation'. A definition of design that may be more accurate for an industrial context is suggested by Ralph and Wand (2009, p. 108): "a *specification* of an *object*, manifested by some *agent*, intended to accomplish *goals*, in a particular *environment*, using a set of *primitive components*, satisfying a set of *requirement*s, subject to some *constraints"*.

The design *process* is usually understood as the activities performed by the designer. However, the overall ship bridge work environment, is the result of multiple activities, companies and professionals involved at several stages of the design process. The *ship bridge design process* can thus be expanded to involve the design activities undertaken by the naval architects designing the ship, the equipment manufacturers designing the different pieces of equipment, as well as the procurement and installation process where the different pieces of equipment are combined to form the complete ship bridge work environment. In this thesis, s*hip bridge design* is used to describe the result of such a ship bridge design process and includes the design of equipment, systems and overall layout of the bridge. The use of the designed products and systems, including adaptations both *to* and *of* the technology, has been described as a *secondary design process* (Carroll, 2004; Hovorka, 2010). The secondary design process in the form of seafarers' adaptive strategies has been described by several researchers over the last decades (Bhardwaj, 2013; Lützhöft, 2004; Wilkinson, 1971). Adaptive strategies have also been described in other industries (Woods et al., 2010). For instance, in the operating room, Cook and Woods (1996) observed both that practitioners adapted to a new computer system, which they named *system tailoring*, and that practitioners adapted their behaviour to work with the new system, which they named *task tailoring*.

As will be discussed in section 5.1, *design research* takes on different meanings. Krippendorff (2012, p. 79) argues that "the viability of a design depends on its stakeholders' conceptions, commitments and resources", and that these are the issues which should be studied in design research, in order to support design and inform design decisions. Stakeholders can be defined as individuals, groups or organisations "who have an interest (stake) and the potential to influence the actions and aims of an organization, project or policy direction" (Brugha & Varvasovszky, 2000, p. 239). The stakeholders included in the current study have been chosen due to their potential to influence usability in ship bridge design. This study has investigated both different stakeholders' interest in and perceived possibility to influence ship bridge design, and the consequences that design decisions may have for the end-users.

4.2. *Human error* and safety perspectives

In the maritime context, the terms *human error*, *human factors* and *human element* have been applied with different definitions and been used interchangeably (Oltedal & Lützhöft, 2018; Wròbel, 2021). Therefore, a clarification of all three concepts is warranted before the term *human error* and how it relates to different safety perspectives are discussed. The understanding that maritime stakeholders have of human error and how it comes into being is important for how stakeholders prioritise matters like design, and is therefore a central issue for the present study.

Human factors (often used interchangeably with the term *ergonomics*) is a field that combines numerous disciplines, such as psychology, sociology, engineering, biomechanics, industrial design, physiology, anthropometry, interaction design, visual design, user experience, and user interface design, so different definitions of human factors exist (Human Factors and Ergonomics Society, 2022). The International Ergonomics Association (2021) defines human factors as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance". Human factors in design is particularly focused on "the influence the design of technological systems and the working environment has on the ability of people to behave and perform safely and reliably without putting their health and safety at risk" (McLeod, 2015). Further, human factors "takes into account physical, cognitive, sociotechnical, organizational, environmental and other relevant factors, as well as the complex interactions between the human and other humans, the environment, tools, products, equipment, and technology" (International Ergonomics Association, 2021). Human factors is thus a broad and holistic approach, focusing on the *interaction* between humans and other elements of a system, and the two related outcomes *human well-being* and overall *system performance.*

With regard to the case at hand, seafaring comprises certain human factors issues that are different from onshore workplaces, especially pertaining to the nature of seafaring working conditions. The people working on a ship experience long-term separation from home, social isolation, irregular work hours, high workload and environmental stressors like ship motion, noise and vibrations. High levels of work stress and fatigue is a known risk factor in shipping (Hetherington et al., 2006; Lützhöft et al., 2011).

The human element is a term first addressed in a resolution adopted by the IMO in 1997 and is important for how IMO addresses human factors. The IMO describes the human element as:

> a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection involving the entire spectrum of human activities performed by ships'

> crews, shore-based management, regulatory bodies and others. All need to co-operate to address human element issues effectively (International Maritime Organization, 2022c).

This is a rather broad definition, covering all activities performed by humans in the maritime system. Further, the IMO states that human element issues are a shared responsibility:

> The wide-ranging scope and importance of the human element makes it a shared responsibility of IMO, as the regulatory body; Member States, as implementers; companies, as providers of the necessary resources, safety policies and safety culture; and seafarers, as the individuals who physically operate ships (Ibid).

The IMO regulatory addresses the human element through the STCW and the International Safety Management (ISM) Code (Ibid).

Human error is often found to be the cause of or explanation for an accident (Woods et al., 2010). Accidents in the shipping industry are no exception. For instance, Dhillon (2007, p. 91) reports that around 80% of all accidents in the shipping industry "are rooted in human error". Likewise, Rothblum (2000) states that about 75-96% of marine casualties are caused by *human error*. According to Read et al. (2021) *human error* as a simple causal explanation seems to be preferred by both managers and by courts. There appears to be a fundamental human need to assert blame after severe accidents, in order to restore public trust and a sense of control (Read et al., 2021; Woods et al., 2010). The problem with deciding *human error* to be the cause of an accident is that it only requires local responses, like procedures and training, as remedies. This impedes investigating a broader set of factors that contribute to accidents, thereby hindering learning on a broader systemic or organisational level (Dekker, 2017; Reason, 1997; Woods et al., 2010).

Human error has been a central topic of safety research for several decades and builds on various disciplines, such as cognitive psychology, engineering and systems thinking (Le Coze, 2022). There are different perspectives on how to think about safety and how to understand accidents and *human error*, thus different models and concepts of *human error* have been developed. Reason (1990, 1997) applied a taxonomic approach to *human error*. He defined *human error* as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome" (Reason, 1990, p. 9). Reason classified errors into two kinds of failures: 1) the failure of actions to go as planned or intended (slips and lapses) and 2) the failure of planned or intended actions to achieve their desired outcome (mistakes). Reason (1990) argued that because *human error* takes a limited number of forms, errors can be predicted as long as we can understand the factors that give rise to them.

Reason (1997) described accidents as either *individual* or *organisational*. *Individual accidents* are characterised by individuals being both the agent and victim of the accident. On a ship, there are multiple possibilities for individual accidents, e.g., slipping, stumbling, falling, being harmed by electricity and exposure to emission of gas. *Organisational accidents* are "events that occur within complex modern technologies" and "have multiple causes involving many people operating at different levels of their respective companies" (Reason, 1997, p. 1). Navigational accidents, which is of interest in this thesis, fits into the category of organisational accidents. A very effective model of how organisational accidents can happen is Reason's Swiss cheese model (Reason, 1997). The model builds on the idea that systems have a *sharp end* and a *blunt end*. The *sharp end* is where people, or practitioners, directly interact with the hazardous process, while the *blunt end* consists of administrators, regulators, planners, supervisors, designers, technology suppliers etc., who control the resources, tools, technologies and impose the constraints, incentives and demands that the people in the sharp end must manage (Woods et al., 2010). In the Swiss cheese model, the various layers of defences or barriers in place to protect against an accident, are portrayed as layers of Swiss cheese (Figure 3). Reason argues that the existence of several barriers provides "defence in depth", meaning that several independent barriers can stop unwanted incidents at different stages.

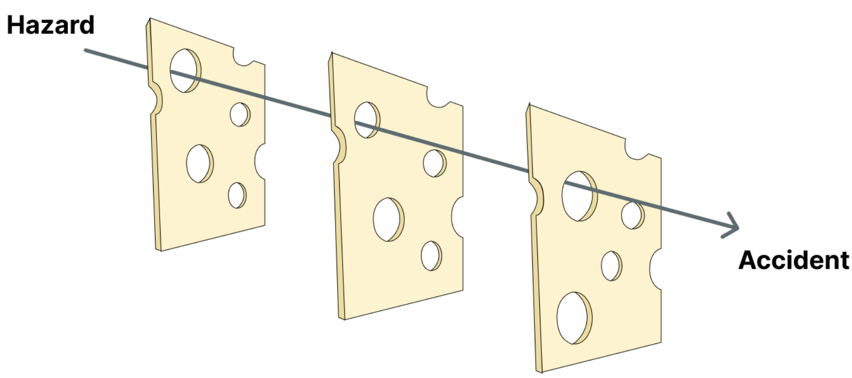


Figure 3. The Swiss cheese model redrawn from Reason (1997).

Barriers can be of a physical, procedural, or functional nature. The holes in the barriers, visualised by the holes in the cheese, are due to *active failures* and *latent conditions* (Reason, 1997). *Active failures* involve errors made by people in the sharp end. *Latent conditions*, on the other hand, can for example be poor design, maintenance failures, unworkable procedures, bad management decisions or clumsy automation (Reason, 1997). Latent conditions, like poor design, may lie dormant in the system over a long period of time before they combine with local circumstances and active failures to penetrate all layers of defence. The holes in the barriers are mobile and it is a rare occasion when a set of holes in the successive defences 'line up' to create the possibility for an accident trajectory to penetrate all barriers. The latent conditions can increase the likelihood of active failures, which is why Reason emphasised that sharp end operators tend to be inheritors of system defects that arise from the blunt end of the system. The Swiss cheese model has been important in illustrating that accidents have multiple causes on several levels, as well as directing attention from the individuals in the frontline, to the blunt end organisations and to the organisational contribution to the context that surrounds human action at the sharp end (Dekker, 2019).

In parallel to Reason's work, a strand of research with roots in cognitive systems engineering developed what has been called the *new view* on *human error* (Le Coze, 2022). This line of research is based on a systems perspective, where the system itself is the unit of analysis and accidents are viewed as emergent properties of complex systems, as opposed to linear cause and effect explanations (Dekker, 2019; Hollnagel et al., 2006). In this perspective, *human error* is not an explanation for failure, but rather something that demands an explanation (Dekker, 2002). *Human error* is seen as a symptom rather than a cause, and as a starting point for further investigations into how a complex system comprising people, organisations and technologies can have both successful and unsuccessful outcomes (Woods et al., 2010). One of the basic premises within this perspective is that "'[h]uman error' is an attribution after the fact" (Woods et al., 2010, p. 19), meaning that it is a judgement made with the benefit of hindsight about a series of events that ended with a bad outcome. The same human actions can be judged differently if the outcome is regarded to be positive. Another basic premise is that "[t]he design of artifacts affects the potential for erroneous actions and paths towards disaster" (Woods et al., 2010, p. 29). It is argued that artifacts, like computerised devices, shape people's cognition and collaboration. Design induced errors may for example be visible in the form of *automation surprise* or *mode error*s (Woods et al., 2010).

An influential system perspective on *human error* and safety is *resilience engineering* (RE), which builds on insights derived from other safety perspectives like High Reliability

Organizations (HRO), control theory, Perrowian complexity and man-made disaster theory (Woods et al., 2010). The RE perspective is about "the intrinsic ability of an organization (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of a continuous stress" (Hollnagel et al., 2006, p. 16). RE provides a complementary view of safety, in which "[s]afety is not about the *absence* of negatives; it is about the *presence* of capacities" (Dekker, 2019, p. 392). RE thus emphasises the need to change focus from things that go wrong (also referred to as the Safety I perspective) to the things that go right in an organisation, i.e., the presence of organisational factors leading to safe performance and how we can understand and enhance these factors and capacities. The Safety II perspective understands safety as the "system's ability to succeed under varying conditions" (Hollnagel et al., 2015, p. 4). Variability is a central concept in this perspective, with the idea being that "safety lies in the capacity of people, teams, and organizations to make things go right – even under varying circumstances" (Dekker, 2019, p. 392). It is the performance variability and the ability of individuals to continuously adapt their everyday work to situational changes that ensures that "everything goes right" (Hollnagel, 2014, p. 137). Rather than regarding people as a liability, this perspective argues that they should be seen as an asset that ensures the proper functioning of the modern technological systems like a ship's bridge. As maritime systems are becoming more complex, the Safety II perspective can be helpful as a complementary perspective to Safety I, to maintain and enhance maritime safety (Schröder-Hinrichs et al., 2016).

The RE literature also sheds light on the gap that exists between *work-as-imagined* and *work-as-done* (Dekker, 2019; Hollnagel, 2014). When an organisation's management is planning and managing operations, or when designers develop equipment and tools for work, the alignment with onboard work practices is largely based on *work-as-imagined.* It is challenging to predict how work is actually done or going to be done by others that are in a different time and place, often with incomplete information at hand. When work systems are designed according to *work-as-imagined*, the actual *work-as-done,* may consist of informal work systems and adaptations that are developed to manage local challenges. A gradually increasing gap between how a system is designed and how it is operated is cause for concern as it may be "an important ingredient in the drift into failure" (Dekker, 2006, p. 89).

4.3. Human-centred design

The aim of optimising performance rather than merely focusing on the prevention of failure is compatible with a *human-centred design approach.* Human-centred design (HCD) can be seen as both a design philosophy and a procedure (Norman, 2013). *User-centred design* (UCD) is a term sometimes used interchangeably with HCD, described by some authors as an overlapping or similar design approach (Gulliksen et al., 2003), while others make a distinction between them (Gasson, 2003; Tosi, 2020). In this thesis, HCD refers to design processes focusing on user needs and system performance. The ISO standard 9241:210 defines and outlines how a HCD process can be performed, as a process that "aims to make systems usable and useful by focusing on the users, their needs and requirements, and applying human factors/ergonomics, and usability knowledge and techniques" (International Organization for Standardization, 2010). *Usability* is in this standard defined as "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization, 2010).

HCD is "based on an explicit understanding of users, tasks and environments" (International Organization for Standardization, 2010), i.e., the *users* and the *context of use*. A central principle is that users should be actively involved throughout the design and development processes, and that design is driven by user-centred evaluation. HCD, as outlined in the ISO standard 9241:210, is an iterative process that consists of four linked activities:

- understanding and specifying the context of use
- specifying the user requirements
- producing design solutions
- evaluating the design

A range of human factors methods can be used within these four activities, as for example outlined by Maguire (2001).

By focusing on the users and context of use, a HCD process may contribute to bridge the gap between *work-as-imagined* by designers and *work-as-done* by end-users (ref. section 4.2). However, there has been tension between systems thinking and HCD (Lurås, 2016). The HCD approach has been criticised for not being able to address today's challenges of complex systems. On the other hand, systems thinking and the focus on system concepts may make it difficult to maintain focus on the human user (Lurås, 2016).

While the ISO standard 9241:210 focuses on the *users,* Krippendorff (2006) argues that HCD should also include an understanding of the network of stakeholders that may have different and potentially conflicting interests in the technology under consideration. Krippendorff (2006) points out that those who buy a technology may not be the ones using it, a description which is highly relevant of ship bridge equipment. Before a product reaches its intended user group, it may pass through the hands of many who use it for a variety of reasons, like solving an engineering problem or making profits from increased sales, making it crucial for human-centred designers to find ways to work with stakeholders to bring a design to realisation (Krippendorff, 2006).

4.4. Sensemaking

An in-depth review of sensemaking is provided in Paper I of this thesis. The sensemaking concept was central for the SMACS-project and has in this thesis been applied to describe and understand seafarers' work in collaboration with technology on the bridge. Sensemaking is a concept that can help us understand the human quest for meaning and thereby human behaviour, both in organisations and elsewhere (Weick, 1995; Weick et al., 2005). As a cognitive process sensemaking has been described as consisting of three interrelated processes: *creation*, *interpretation* and *enactment* (Sandberg & Tsoukas, 2015). The process of *creation* is about noticing and extracting *cues* from our experience. *Cues* are a small portion of the available information in our environment, they function as "seeds from which people develop a larger sense of what may be occurring" (Weick, 1995, p. 50). The *cues* create an initial sense of the situation. The initial sense is then *interpreted* into a more complete and narratively organised sense of the situation, followed by the *enactment* process which involves acting on the sense made. The actions may be vocabulary or physically and they may be part of gathering more information about the situation at hand. *Enactment* creates a slightly different environment to continue to make sense of (Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2015). This meaning-action process is an ongoing, continuous and elusive process. Sensemaking is not about achieving a full comprehension of the situation at hand, rather it is about "continuing redrafting of an emergent story" (Weick, 1995, p. 55). People only need a plausible explanation or narrative sufficient to continue their activity. "To deal with ambiguity, interdependent people search for meaning, settle for plausibility, and move on" (Weick et al., 2005, p. 419).

Sensemaking has been described as an active, conscious process triggered by issues, events or situations that are ambiguous, interrupt people's ongoing activity, or create uncertainty about how to act (Maitlis & Christianson, 2014). *Immanent* sensemaking is a form of sensemaking that occurs when people are immersed in routine work without being consciously aware of it, spontaneously responding to the situation as it develops (Sandberg & Tsoukas, 2015).

In the sensemaking literature the factors emotions, embodied sensations, social context, identity, technology and meaningfulness through work, has been found to influence sensemaking (Danielsen, 2021). There are few research articles focusing on sensemaking and technology, which is of interest in this thesis. One example is Weick's description of the design and the state of the methyl isocyanate plant control room in his analysis of the Bhopal disaster. According to Weick (2010) the control room was a "combination of missing and misleading cues" and "something of a nightmare for sensemaking" (Weick, 2010, p. 538). It was difficult for the operators to understand what was happening as "[t]he control board had 75 dials, many of which were not working […]. There were corroded lines, malfunctioning valves, faulty indicators, and missing control instruments" (Weick, 2010, p. 538). Research on sensemaking during crisis or safety-critical situations has included a range of sectors (Danielsen, 2021). In these situations, *adaptive* sensemaking has found to be most helpful (Maitlis & Sonenshein, 2010). *Adaptive* sensemaking means constantly gathering new information and revising interpretations (Ibid.). Adaptive capacities are also central for resilience. The connection between sensemaking and resilience has been made by several scholars, in the sense that sensemaking creates resilience but also that sources of resilience help to make sense of the situation (Kilskar et al., 2020).

Individual sensemaking occurs as an interplay with the environment. According to Snook (2000), in hindsight, viewing human actions as a struggle to make sense rather than decision-making makes way for a more complete account for all relevant factors contributing to an accident, enabling an understanding that can go beyond the label *human error*. Sensemaking promotes a view of humans as "good people struggling to make sense" rather than "bad ones making poor decisions" (Snook, 2000, p. 207).

4.5. Seamanship

In the maritime sector, the professional culture amongst seafarers is expressed by the term *seamanship*. Seamanship was also one key research issue in the SMACS project and has in this study been applied to shed light on both seafarers' and other stakeholders' understanding and expectations of the human-technology interaction on the ship's bridge. Seamanship is a term without a specified definition and its meaning vary with different areas of use, whether in textbooks, maritime regulations, accident investigations or in media. *Good seamanship* is for instance used in Rule 8 of the IMO International Regulations for Preventing Collision at Sea: "Any action to avoid collision shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship" (International Maritime Organization, 1972). In this case, good seamanship seems to describe how a certain situation should be handled. The rules should be followed, but it is also expected that the navigator evaluate the situation, make proper judgements and conduct adequate actions.

Amongst seafarers, *good seamanship* seems to be a normative positive word characterising the skills and abilities that individuals have gained through practise. Knudsen (2009) describe seamanship as "a blend of professional knowledge, professional pride, and experience-based common sense". Knudsen (2009) found that the term was used to express how written rules and procedures could be seen as a devaluation of the seafarers' competence. According to (Lamvik et al., 2010) *troubleshooting* is necessary, expected and highly appreciated aspect of seamanship. To be able to find solutions and make do with whatever you have at hand is important when spare parts or other forms of help are miles or days away.

Antonsen (2009) conducted a survey in which seafarers were asked about the meaning of good seamanship. The most frequent characteristic given was cooperation and the ability to maintain social relations and community. These are characteristics that may be especially important on board a ship where the seafarers live and work in a restricted physical and social environment for several weeks or months. Several researchers (Knudsen, 2009; Lamvik, 2002; Wahl & Kongsvik, 2018) have addressed the resemblance of the social system on board a ship with what (Goffman, 1961) described as *total institutions.* Prisons, military organisations, monasteries, boarding schools and mental hospitals are examples institutions in which a strong alignment among the residents in terms of behaviour and world views can be found. Coming back to Antonsen's (2009) survey, the second most frequent characteristic of seamanship was work performance, in this case referring to working safely and with high quality. Other responses included individual properties, such as being independent, responsible and reliable and competence, mainly referring to practical sailing experience.

In addition to the expected skills and abilities of a seafarer, seamanship is also used to describe a more general attitude towards life (Lamvik, 2002). Good seamanship is closely related to professional identity construction. Seamanship may be used to separate "real seafarers" from "the others". "The others" may be people on shore (landlubbers), employees in shipping companies, representatives from authorities or newly qualified seafarers without sailing time (Antonsen & Bye, 2015).

Good seamanship today is probably different from what was seen as good seamanship a few decades ago. Professional identity is of a highly dynamic and evolving nature and are related to the introduction of new technology (Korica & Molloy, 2010). Kongsvik et al. (2020) developed the concept *distributed maritime capabilities* to describe the changing role of the individual seafarer when knowledge and competence is increasingly distributed to technology, procedures and regulations.

5. Methodology

The data that forms the basis of this thesis consists of interviews, observations, accident investigation reports, as well as the literature discussed in Chapters 3 and 4. While the research presented in this thesis is part of the PhD programme in Design, it has an interdisciplinary approach. Thus, this Chapter describes the thesis methodology by first positioning it within *design research*. Further, the Chapter outlines the research design and describe the methods used for obtaining and analysing the data. The Chapter also includes information about the authors background and *research lens*, as well as reflection on research ethics and scientific quality.

This Chapter is a *retrospective reconstruction* (Coffey & Atkinson, 1996, p. 146), which is often the case in methodology texts. The PhD research endeavour has not been a linear process from start to finish, it has rather been of an abductive character, developing over time by going back and forth between empirical data and theory to discover interesting research topics and questions. In addition, dealing with unforeseen events and several changes of plans has been educational on many levels. As Townsend and Burgess (2009) point out: to conduct social research requires both flexibility and perseverance when real life hits your research plan.

5.1. Positioning the work within design research

Design research has often been separated into three types: research *by/through* design, research *for* design or research *into/about* design. While there are several definitions and nuances of these terms in the literature, three common definitions are provided in the following:

- Research *by/through* design can be understood as a research approach in which design practice is at the centre of the research. Knowledge is generated through designing artefacts, models, prototypes etc. and validating them to answer the research questions. In this sense, it is a form of action research (Schneider, 2007).
- Research *for* design is research conducted as part of a design project, to ensure that the design project is properly informed (Findeli et al., 2008). This kind of research does not necessarily generate new knowledge according to scientific standards.
- Research *into/about* design is research about design objects, design processes, design actors and stakeholders. It could also be about the meaning and significance of design for society, business, culture, etc. (Findeli et al., 2008). This type of design research increases the understanding of design from an outsider perspective (Sevaldson, 2010).

The research presented in this thesis is research *about* design, meaning that this study is investigating design from an outsider's point of view, not as a designer or through design practice. By studying ship bridge design from the perspectives of different maritime stakeholders, the thesis contributes to building knowledge about factors that influence ship bridge design within the maritime industry.

5.2. The author's research lens

In qualitative research, the researcher serves as the main research instrument for both collecting and analysing the data (Yin, 2016). Aspects like the researcher's academic and cultural background, personal preferences and fundamental assumptions and beliefs about how the world is perceived, will influence the researcher and thus the research process. One way to address this issue is by seeking to make the *research lens* as explicit as possible (Yin, 2016). In this section, the author's research lens is addressed through a short description of my professional background leading up to pursuing this PhD, as well as a discussion on my ontological and epistemological positioning. This section will thus also serve to enhance the transparency of the research process.

My interest in human factors and design originates from several years of working with research and development within the space sector. A significant part of this work concerned remote monitoring and control of experiments on board the International Space Station from a ground control room in Trondheim. I had several roles within this project, where some of the most interesting ones included working as a control room operator, training manager for the control room operators and project manager for designing and building a new control room. These roles gave me first-hand experience of working in a technology-dense environment, being completely dependent on technology to perform the tasks at hand. It also gave me the opportunity to reflect on what kind of prerequisites are necessary for the performance of the control room team, both concerning training and design. This led me in the direction of the human factors discipline and the topic of human-centred design.

Due to limited research experience with the maritime sector prior to this PhD work, the first part of the PhD period had an exploratory character where the focus was on familiarisation with the ship bridge as a workplace, the maritime actors and the structure of the maritime sector (see also section 1.2 Evolution of the research). Not being familiar with the field of research (Hockey, 1993) may be positive in the sense that the research is done with an open mind and without preconceptions about the particular context that may influence analysis and interpretations. On the other hand, there may be information during interviews and observations that the researcher does not understand or even notice due to a lack of in-depth understanding of the context. In my case, I sought to mitigate this by reading and being prepared for the data collection and by asking questions along the way if something was unclear.

5.2.1. The philosophical dimensions

Ontology is the philosophical study of reality and of what exists. The question of ontology in social research primarily has to do with how social entities are understood. This has traditionally been seen as a matter of *positivism* (also referred to as 'objectivism') versus *constructivism* (Bryman, 2016; Grix, 2002; Yin, 2016). Positivism is typically associated with the natural sciences and assumes a singular or objective reality, where social phenomena have an existence independent of social actors (Bryman, 2016; Wahyuni, 2012). On the other hand, constructivism is a worldview assuming multiple realities depending on the perspective of the observer. Social phenomena are in this view asserted as something continually constructed by social actors (Bryman, 2016; Wahyuni, 2012). Over time, the existence of a continuum of worldviews between these two extremes has manifested (Yin, 2016). A researcher can assume a worldview in the middle ground, a *pragmatist view* (Wahyuni, 2012; Yin, 2016). In pragmatism, the starting point is the research question which guides the choice of research framework. Pragmatism allows for a mixture of ontology and epistemology to be utilised to address the research questions and to understand social phenomena (Wahyuni, 2012). As my educational background is from the natural sciences, I regard my research lens to be situated within a pragmatist worldview. However, the work within this thesis is leaning towards the constructivism side of the worldview continuum. The research focus is on the different perspectives of people in the maritime industry, which resonates with constructivism. Also, Weick's sensemaking concept, which is central in the first two papers included in the thesis, developed towards a social constructivist perspective over the years (Sandberg & Tsoukas, 2015).

The researcher's worldview establishes the epistemological position, i.e., what can be known about social reality and the possible ways to gain acceptable knowledge (Grix, 2002). The two contrasting epistemological positions are *positivism* and *interpretivism* (Bryman, 2016; Grix, 2002). While *positivism* advocates using natural science methods to study social reality, *interpretivism* sees social phenomena as fundamentally different from the objects studied by the natural sciences, hence requiring a research strategy that can grasp subjective meanings and perspectives (Bryman, 2016; Grix, 2002). Within pragmatism, both observable phenomena and subjective meanings can provide acceptable knowledge, and thus both quantitative and qualitative methods can be used (Wahyuni, 2012). This thesis has an overall qualitative approach that "works with words and not with numbers" (Kvale, 1996, p. 32). However, the thesis also includes instances of using numbers to understand the data, e.g., in Paper III, in which both qualitative and quantitative analysis jointly contribute to the findings.

5.3. Research design

Research design is "the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions" (Yin, 2018). This thesis builds on *case studies*, defined by Yin (2018) as a study that "investigates a contemporary phenomenon (the "case") in depth and within its real-world context", where the phenomenon in this thesis is *ship bridge design.* According to Yin (2018), case studies are especially relevant when the research questions are 'how' or 'why' questions, the researcher has little or no control over the behavioural events and the boundaries between the phenomenon and the context may not be clear. Case studies can deal with a variety of data (Yin, 2018), which in this study includes data derived from interviews, observations and documents. This particular case study analysis aims at "explanation building" (Yin, 2018, p. 179) through investigating the phenomenon *ship bridge design* from different maritime actors' perspectives (Figure 4).

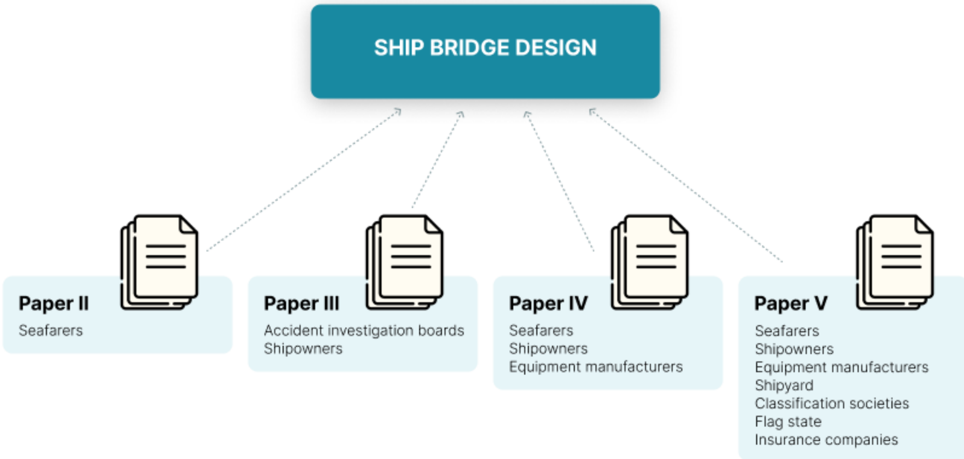


Figure 4. The phenomenon 'ship bridge design' is in this thesis investigated from different perspectives through four empirical papers.

The approach of generating knowledge about stakeholders' behaviour, attributes, inter-relations, interest and influence on a particular process or decision-making is known from the stakeholder research tradition (Brugha & Varvasovszky, 2000; Elias et al., 2002; Parmar et al., 2010; Trevino & Weaver, 1999; Wood et al., 2021). This knowledge can be used to develop strategies for managing stakeholders of projects or organisations in order to facilitate the implementation of specific decisions or organisational objectives (Brugha & Varvasovszky, 2000). In this thesis, the knowledge generated from the different stakeholder groups pertained to their perceived influence and interest in usability in ship bridge design, with the aim of shedding light on existing factors that may impede the progress in usability.

5.4. Data collection

This section describes the thesis data collection methods and how they were applied, including description of the data sample and how access was obtained. During the course of the PhD period, I performed interviews and more informal talks with 60 persons with different roles in the maritime sector. Although all these individuals contributed to my understanding of the topic at hand, they were not all included in the scientific papers that constitute this thesis. Table 2 presents an overview of the informants and in which paper this data was included.

Table 2. Overview of informants and the papers in which they were included.

Stakeholder groups	Job titles	Paper
21 **Seafarers**	Deck Officer/Captain	Paper II, IV and V
Shipowners: 5 representatives from 5 companies	Head of HSEQ[8] & Human Factors/ Electro Automation Engineer/Marine and HSEQ Manager/Vice President Newbuilding/ Senior Marine Advisor	Paper IV and V
Equipment manufacturers: 5 representatives from 3 companies	Vice President R&D/Senior Designer/ Principal Engineer HF and Maritime HMI/ Service Engineer and Project Manager/Salesperson	Paper IV and V
Classification societies: 4 representatives from 2 companies	Head of Section/HF Consultant	Paper V
Flag state: 3 representatives from 1 Flag state	Senior Engineer/Senior Advisor	Paper V
Marine insurance: 3 representatives from 2 companies	Senior Loss Prevention Executive/ Loss Prevention Director/Vice President	Paper V
Shipyard: 1 representative from 1 company	Naval Architect	Paper V
In total 42 informants		

5.4.1. Observations

Fieldwork in the form of five ship visits was performed in 2018 and 2019. I was given the opportunity to sail with two offshore supply vessels (OSV) that both had a rather new integrated ship bridge installed (referred to as the *HCD Case* in paper IV). The vessels were owned by a Norwegian company and built in, respectively, 2014 and 2016. Both vessels had four Norwegian deck officers onboard, who all participated in the study. Both vessels were built and operated by the same shipowner. The initial contact with the shipowner was done via an equipment manufacturer company supporting the SMACS project. The visits lasted four and five days and were performed in September 2018 and January 2019. Both OSVs were sailing on the Norwegian Continental Shelf and supplied several oil installations during my visit. I spent most of my time on the ship bridge, but also visited other parts of the ship, like the engine control room. I interacted with the crew during meals and observed safety training.

On the bridge, I took care not to disturb the officers while they were working. I would passively observe their work during high workload periods, e.g., while approaching an oil

[8] HSEQ: Health, safety, environment and quality

installation. When deemed possible, I interacted with them and asked questions about what they were doing, things I had observed and about the ship bridge equipment. Although my main interest was trying to understand how they were collaborating with the ship bridge technology, I got insight into other issues, like their view of the industry in general, and other actors, as well as more personal matters such as life as a seafarer and being away from their families for several weeks.

The method was ethnographic in the sense of being with a group for an extended period of time, observing behaviour, listening to conversations and asking questions (Bryman, 2016). At first, I brought my notebook to the bridge with the intention to write notes throughout the day. However, I soon figured that this brought attention both to me and to the fact that the crew was being observed, e.g., some of them would ask questions about what I was writing. Thus, I decided to rather take notes when I withdrew to my cabin. The disadvantage of this was the need to trust my memory, but the advantage was that the crew seemed to speak and behave more freely around me. On both trips, there were storms and high waves, which gave me first-hand experience of how tiring it is when everything is continuously moving, making it impossible to sleep or move around without holding onto something. With no previous experience from research in the maritime industry, this fieldwork was highly valuable for gaining insight into working and living at sea, or the *context of use* which is central when designing for usability.

Together with project member Gunnar Lamvik, I performed three additional short visits on board three Norwegian passenger ships in September and December 2018. The access was obtained by contacting the deck officers directly. The ships were built in 1983, 1993 and 1996, respectively, and had retrofitted ship bridges. Each visit lasted for about one hour, while the ships were docked. This allowed us to do semi-structured interviews with two Norwegian deck officers onboard each ship, while they gave us a tour around the bridge and demonstrated bridge equipment or features that exemplified the issues they raised.

5.4.2. Interviews

Qualitative interviews have been the main method for data collection in my research as this type of interview "attempts to understand the world from the subjects' point of view, to unfold the meaning of peoples' experiences" (Kvale, 1996, p. 1). The articles included in the thesis are based on semi-structured interviews with 42 informants. Three of these interviews were performed together with SMACS project manager Stig Ole Johnsen and six interviews were performed together with project member Gunnar Lamvik. The interviews were semi-structured (Kvale, 1996) and open-ended, focusing on the informants' experiences and opinions, and allowing informants to talk freely about different aspects of the topics we introduced. We would also follow up on relevant topics raised by the interviewees with additional questions. The interview data consisted written notes and audio recordings. The audio recorded interviews were all transcribed verbatim by me.

As described in section 1.2, the research initially focused on how ship bridge design accommodates seafarers' work. Interviews with seafarers were performed by visiting ships (see section 5.4.1) as well as interviews on shore, including a focus group interview (see section 5.4.3). The included seafarers were working on passenger ships, high-speed coastal vessels and offshore supply vessels. During ship visits, the interviews were supplemented with seafarers showing the available bridge equipment and explaining its use. We asked questions about how the bridge equipment supported their work tasks, preferred features and interactions, influence in design or procurement processes, their thoughts about technological developments in ship bridge equipment, as well as how they understood the notion of seamanship and how it relates to design of technology. By applying a *sequential sampling approach* (Bryman, 2016, p. 410), the scope first expanded to equipment manufacturers and the design process, then further to shipowners (with fleets consisting of bulk-carriers, oil- and gas-tankers, cruise ships, offshore support vessels), a flag state, class societies, a shipyard and insurers.

The majority of informants were Norwegians employed in Norwegian companies. However, three informants were from the United Kingdom, with experience from British companies and one also with experience from the United Arab Emirates. One Norwegian shipowner company informant was employed in the company's office in Singapore, illustrating the international character of the shipping industry. These stakeholder groups were asked about how their job related to ship bridge design and development processes, their interest in and influence on ship bridge design, how they related to other ship bridge design stakeholders and their understanding of the need and the responsibility for usability in ship bridge design.

The informants were either contacted directly, or through snowballing in which interviewees suggested or put me in contact with other potential informants. Apart from the seafarer group, most of the interviews were performed using a video conferencing tool. This was initially done for practical and financial reasons, e.g., when the informants were located abroad. From March 2020, the COVID-19 pandemic gave me no other choice. There was also a change in that many informants were forced to work from home during this period. The home-office situation was an obvious topic for the initial small talk and as such gave a good opportunity for *entering* the interview (Yin, 2016, p. 147).

Kvale (1996) emphasises that an interview is literally an *inter view,* where knowledge is constructed through the interaction between the interviewer and the interviewee. Using other means than face-to face interviews may potentially affect the interaction between interviewer and interviewee in terms of how natural the interaction is and the possibility for monitoring responses other than spoken words (Irvine et al., 2012) However, as video conferencing tools also affords the ability to pick up on non-verbal cues, I found the interaction with the informants via video conferencing had a similar quality to face-to-face interviews, in line with the findings of Nehls et al. (2015).

5.4.3. Focus group interview

In November 2019, a focus group interview with six Norwegian high-speed coastal vessel deck officers was performed together with project member Gunnar Lamvik. A focus group interview is a group interview, usually with more than four participants, which is focused in the sense that a specific theme or topic is explored and the group of interviewees have a certain experience in common (Bryman, 2016). Smithson (2000) defines it as a *controlled group discussion*. Opinions and meanings from the focus group can be seen as collectively constructed within the social situation rather than as something the individual participants bring to the table (Bryman, 2016; Smithson, 2000).

The focus group interview was arranged by contacting a lecturer at a Norwegian maritime education facility. The six deck officers were participating in a course, and we were given the opportunity to do the interview between lectures. The two course lecturers were also present during the interview. The lecturers took the role as passive observers but did participate with some comments near the end of the interview. The interview lasted for one hour and the session was audio recorded and later transcribed by me.

One of the advantages of using focus groups is that the individuals discuss and challenge each other's views. This means that the participants are forced to think and possibly revise their views, which may lead to more realistic accounts of what people think than is the case in one-to-one interviews (Bryman, 2016). We introduced the topics with open-ended questions supported by photos from our previous fieldwork. The photos were effective as means to introduce the topics and in stimulating the interviewees to remember situations and examples from their own seafaring experience. The group discussed the topics amongst themselves, and we asked follow-up questions, either when issues came up that we did not understand or when there were topics that we wanted them to elaborate on further. When the discussion around one topic naturally ended, we introduced a new topic. The two main themes introduced in the focus group interview were seamanship and usability in ship bridge design. The focus group discussed their take on the notion of seamanship, ship bridge design development over the last decades, typical design issues, seafarers' adaptations and seafarers' possibility for influencing ship bridge design. We also used the focus group for *respondent validation* by presenting some of our preliminary analysis that the officers commented on (see also section 5.7).

A limitation of the focus group interview method is the possibility of group effects, which may lead to only socially acceptable opinions to emerge or that some participants dominate the discussion while others are reticent (Bryman, 2016; Smithson, 2000). While it is difficult to know the extent to which group effects influenced our interviewees, our observation was that the discussions were fluid and, although some participants spoke less than others, all interviewees contributed to the discussions.

5.4.4. Accident investigation reports

The accident investigation reports for the study undertaken in Paper III were obtained by searching the publicly available reports issued by the Accident Investigation Board Norway (AIBN), the German Federal Bureau of Maritime Casualty Investigation (BSU), the Danish Maritime Accident Investigation Board (DMAIB) and the UK Marine Accident Investigation Branch (MAIB). These countries have the largest merchant fleet in North and West Europe by country of beneficial ownership (UNCTAD, 2022). I selected investigation reports that had identified design issues as contributing factors to the accidents. The search was limited to accidents involving merchant ships occurring in the period 2010-2020, to get an impression of whether ship bridge design is a current issue. The search resulted in 28 accident reports, four issued by AIBN, six by BSU, five by DMAIB and 13 by MAIB. The reports constituted 16 groundings, three allisions[9] and nine collisions. The reports were coded by me, and the three main themes of interest were the reported design issues, the safety recommendations by the investigation board and the shipowner's response.

[9] Allision occurs when a vessel strikes a stationary object

5.5. Data analysis

This section describes the process of analysing the obtained data. Although data analysis is described separately in this section, data analysis is part of the overall qualitative research process in a "constant interaction among research design, data collection, and data analysis" (Coffey & Atkinson, 1996, p. 193). The analysis of the interview and observation data was performed jointly, while the document analysis was a separate activity, which is reflected in the following sections.

5.5.1. Analysis of interviews and observations

The data consisted of field notes from the observations and transcribed audio recorded interviews. I initially approached the data by following the guide of thematic analysis provided by Braun and Clark (2008, p. 87):

1. Familiarising yourself with your data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report

The first phase, which involves familiarisation with the data, started during data collection and transcription, and continued by reading the material several times. Phase 2 of generating the initial *open codes* (Yin, 2016, p. 196) were done by using NVivo. These codes were generated by selecting segments of the data that appeared interesting with regard to the research question(s). Following Braun and Clark, these codes were close to the original data and sometimes included words or phrases from the original data. Phases 3 – 5 were a particularly iterative part of the process, where the initial codes were grouped and regrouped into *themes*, which (Braun & Clark, 2008, p. 82) define as something that "captures something important about the data in relation to the research question". At this point the analysis was done by the help of tables in Microsoft Word. Phase 6, the writing process, is also an analytical task (Braun & Clark, 2008; Coffey & Atkinson, 1996). The process of representing the findings through writing often resulted in discarding initial ideas and developing new ones. This made it necessary to repeat previous phases in the thematic analyses process, much in accordance with Braun and Clark's description of the process. The first thematic analysis of the data collected from seafarers was the basis for paper II concerning how seafarers manage and adapt to their work environment. The analysis also identified themes that were further developed through collecting data from two additional stakeholder groups, equipment manufacturers and shipowners, and the data was revisited and re-analysed, resulting in paper IV. The last round of data collection and analysis that was the basis for paper V, was targeted towards the developed themes of stakeholders' perceived influence and interest in ship bridge design.

5.5.2. Document analysis

Documents are not merely representations of a social reality, but can be seen as a level of social reality in their own right (Bowen, 2009; Bryman, 2016). Hence, documents should be examined in terms of what they are supposed to accomplish (Bowen, 2009). Accident investigations are initiated to determine the accidents' circumstances and causes, in order to learn from what happened and prevent future accidents and incidents. The findings in accident investigations reflect the underlying accident models used by the investigators (Lundberg et al., 2009). The study of accident investigation reports thus contributes to the research question of how different actors in maritime industry understand the work and human-technology interaction on the bridge.

The analysis of the accident investigation reports may be described as *qualitative content analysis* (Bryman, 2016). The three main categories of interest were decided before the analysis began: the reported design issues, the safety recommendations by the investigation board and the shipowners' response. These categories were identified in each investigation report and grouped according to themes. The safety recommendations and actions were then compared to the identified design issues, in order to interpret the underlying understanding of human-technology interaction on the bridge and the provided potential for learning and improvement of ship bridge design. As the investigation reports are produced for another purpose than research (Bowen, 2009), they often lacked detailed descriptions of the design or the human-technology interaction, which limited the possibility for in-depth analysis (se also section 3.6).

5.6. Research ethics

In general, ethical considerations should be part of all stages of the research process (Kvale, 1996). I was aware that having a researcher present to do observations or interviews may feel intrusive or disruptive for the participants (Tjora, 2018). It is an important ethical principle that the applied research methods do not harm or make the participants uncomfortable (Tjora, 2018). My questions did not concern personal or private matters, rather topics that the informants were interested in, making them eager to share their opinions and experiences.

The research project was reported to the Norwegian Centre for Research Data. All interviewees were informed about the topics of the project and that participation was voluntary. The use of audio recording was done with permission from the informants. The informants were also informed about their possibility to withdraw from the study at any time, without providing any explanation. Informed consent was signed by the informants I met physically, while the informants interviewed via Teams were provided the informed consent by e-mail and confirmed that they had received and understood the content at the beginning of the interview. The interview and observation data as well as transcripts were anonymised, and the data storage location was only accessible by me.

5.7. Scientific quality

Reliability and validity are important criteria for evaluating quantitative research but are also used for evaluating qualitative research. However, it has been argued that reliability and validity presuppose that there are absolute truths about the social world to be uncovered by the researcher (Bryman, 2016). The view that there can be several accounts of the social world (Lincoln & Guba, 1986) and that "we produce versions of the social world through our data collection and our process of analysis" (Coffey & Atkinson, 1996, p. 15) warrants alternative quality criteria for qualitative research (Bryman, 2016). Lincoln and Guba (1986) propose to assess qualitative studies in accordance with the principles of *trustworthiness* and *authenticity. Trustworthiness* includes four sub-criteria (Bryman, 2016):

1) *credibility* (which parallels internal validity),
2) *transferability* (which parallels external validity),
3) *dependability* (which parallels reliability), and
4) *confirmability* (which parallels objectivity).

Credibility concerns the feasibility or credibility of the account of the social world at which the researcher has arrived (Bryman, 2016). To establish the credibility of the findings, I applied various measures based on the suggestions of Lincoln and Guba (1986). The fieldwork, interviews and informal conversations with various stakeholders in the maritime industry ensured *prolonged engagement with the phenomenon in the field*. *Peer debriefing* was obtained through discussions with supervisors and fellow researchers throughout the project period. While transcripts of audio recorded material and the initial coding was performed only by me, the collaboration and supervision by fellow researchers and supervisors in data collection, analysis and writing of publications strengthened the credibility of the findings. In addition, *informal testing* of information was performed continuously during interviews, by discussing observations or information obtained from previous interviews and observations. Lincoln and Guba (1986) also recommend *triangulation*, a principle that “pertains to the goal of seeking at least three ways of verifying or corroborating a procedure, piece of data, or finding” (Yin, 2016, p. 87). Triangulation can be achieved by applying multiple data sources, having several investigators working on the study, applying multiple theoretical perspectives or using multiple methods. However, Coffey and Atkinson (1996) oppose the idea of triangulation as it implies that findings from different methods and sources can be summed up to produce a single, valid representation of the social world. The multiple data sources, methods and theoretical perspectives applied in this study have not aimed at triangulating specific pieces of data or specific findings, but rather to build knowledge of different maritime actors’ perspectives that may explain the persistent existence of suboptimal usability in ship bridge design.

Transferability concerns whether the findings can be applicable or generalisable to other contexts (Bryman, 2016). The data sample in this study was limited to the stakeholders that seemed most relevant with regard to their influence on ship bridge design. A potential weakness is that the number of informants from each stakeholder group is limited. However, the richness of the data collected has allowed for an analysis that identified interesting patterns across the stakeholder groups, which may be relevant for the maritime industry in general, but also other contexts. Most of the informants are Norwegian and the findings may first and foremost reflect a situation specific for the Norwegian and/or European maritime sector. The conclusions drawn may still have broad relevance, as the maritime stakeholders operate, compete and are regulated internationally.

As qualitative research tends to be context specific, *thick descriptions* of the data and context are necessary to provide others the possibility to make judgements about transferability (Lincoln & Guba, 1986). The description of the research context, data sources and the findings provided in this thesis aim to provide others a basis for judging the potential transferability. Yin (2018) emphasises that generalisation from case studies can be in the form of *analytic* *generalisations,* which is a conceptual level higher than the specific case. The theoretical framework described in Chapter 4 may strengthen the transferability of findings across contexts.

Dependability, which parallels reliability in quantitative research, can be established by adopting an auditing approach, where complete records are kept of all phases of the research process and made accessible for auditing by others (Bryman, 2016; Lincoln & Guba, 1986). The research process here has been made available for auditing through this thesis, with thorough descriptions of background, context, aim, research design, methods, findings and conclusions. Records of the research process and empirical material have been kept throughout the study period. In addition to myself, my supervisors are familiar with the complete empirical material and developments made throughout the research process. In addition, co-authors and the peer review process for scientific publications have ensured auditing of the findings and interpretations.

Confirmability concerns whether the researcher can show that they have acted in good faith and not allowed personal values or theoretical preferences to unjustifiably influence the research process (Bryman, 2016). Confirmability can also be judged through auditing by others (Lincoln & Guba, 1986) and, as described for dependability, the credibility of this study can be judged based on the description of the research process provided in this thesis. The possible biases I have as a researcher have been discussed in section 5.2.

Authenticity

The *authenticity* criterion concerns the broader political impact of the research, but has typically not been applied in the assessment of qualitative studies (Bryman, 2016). As part of authenticity, the fairness criterion concerns whether the research fairly represents different viewpoints in the social setting (Lincoln & Guba, 1986). Different viewpoints have been at the core of this research, as the viewpoint of multiple stakeholders in the maritime industry has been investigated in the different papers. Yin (2016) refers to authenticity as the soundness of the data sources – whether the informants have made accurate representations of themselves and whether documents have been produced under knowable circumstances. As a researcher, one cannot be sure whether the informants are telling the truth or adjusting their accounts to what they think the researcher is interested in, or what others, like company management, would like to hear. I have no reason to suspect that this was the case with my informants, much due to the nature of the topic at hand. They were informed about what the data was going to be used for and that it would be anonymised and treated according to data protection legislation. My impression was that they spoke freely about their experiences and opinions. The examined accident investigation reports are official documents and regarded as being produced under knowable circumstances.

6. Results – Presentation of papers

This chapter presents synopses of the papers included in this thesis: one book chapter, two conference papers and two journal papers. The complete texts are attached in Appendix I. This summary is provided to give an overview of the content and the findings from each paper before the findings are discussed in Chapter 7. All papers contribute to shed light on the main research question: Why is usability in ship bridge design a persistent problem in the maritime industry and how can usability in ship bridge design be improved? An overview of which sub-questions the papers mainly contribute to is provided in Table 3. A list of the additional papers written during the PhD period is presented at the end of this chapter.

Table 3. An overview of the papers included in the thesis and which research questions they contribute to.

No	Title	RQ1	RQ2	RQ3
I	Making sense of sensemaking in high-risk organizations	■		
II	Still unresolved after all these years: Human-technology interaction in the maritime domain	■	■	
III	The contribution of ship bridge design to maritime accidents		■	
IV	"Seafarers should be navigating by the stars": Barriers to usability in ship bridge design		■	■
V	Somebody else's problem? Usability in ship bridge design seen from the perspective of different maritime actors			■

6.1. Paper I

Danielsen, B.-E. (2021). Making sense of sensemaking in high-risk organizations. In S. O. Johnsen & T. Porathe (Eds.), *Sensemaking in safety-critical and complex situations: Human Factors and Design*. CRC Press. https://doi.org/10.1201/9781003003816

This chapter was part of the book *Sensemaking in safety critical and complex situations: Human factors and design*, which was a SMACS project deliverable. Sensemaking is a central concept in this book and my chapter served as an introduction to the sensemaking concept through a review of sensemaking literature. The basis for the chapter was the work of Weick (1995) and subsequent related research and literature reviews (e.g., Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2015). Weick (1995) describes sensemaking as an active process - people do not passively perceive and interpret situations, they actively play a role in constructing the situations of which they are trying to make sense. The sensemaking perspective effectively illustrates how people do not perceive everything in the surrounding environment, but rather pick up cues from which they develop a larger sense of the situation they are in. The chapter introduced the following definition of sensemaking which served as the basis for the SMACS project (Maitlis & Christianson, 2014, p. 67):

a process, prompted by violated expectations, that involves attending to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn

This definition reflects the sensemaking research which has mainly been confined to study episodes where an activity has been interrupted. Sandberg and Tsoukas (2015) introduced *immanent* sensemaking to describe sensemaking during routine work, where people are not consciously aware of how they respond to situations as they develop. This chapter gives an overview of the main factors that have been identified in previous research as influencing sensemaking: expectations, emotions, embodied sensations, social context, identity, technology and meaningfulness through work.

How design of technology relates to sensemaking in organisations was a core interest in the SMACS project. However, relatively few studies investigating this issue was found. Previous research on sensemaking and technology has focused on how organisational sensemaking is influenced by the medium of communication in which people in organisations interact, or how the introduction of new technology triggers sensemaking about the technology itself or sensemaking related to professional identity. Sensemaking as it unfolds during safety-critical situations has been studied in a range of sectors and two central themes have been found as central for sensemaking in these circumstances: shared meanings and emotions (Maitlis & Sonenshein, 2010). Maitlis and Sonenshein (2010) argue that *adaptive* sensemaking is most useful in safety-critical situations. They argue that as situations continuously evolve and change, new information must be gathered, and interpretations must be continuously revised.

The sensemaking perspective can help accident analysis to emphasise the context and system-level by changing the focus from why individuals made the wrong decision to why it made sense at the time to do what they did. Sensemaking can complement our understanding of human behaviour developed from other concepts, such as situation awareness and decision-making, and can as such provide useful knowledge to future design of safety-critical systems.

6.2. Paper II

Danielsen, B.-E., Lützhöft, M., & Porathe, T. (2021). Still unresolved after all these years: Human-technology interaction in the maritime domain. In: Stanton, N. (eds), *Advances in Human Aspects of Transportation*. International Conference on Applied Human Factors and Ergonomics 2021. Vol. 270, 463-470. Springer. https://doi.org/10.1007/978-3-030-80012-3_53

This paper is about the seafarers' experience and perspectives on ship bridge design. The theoretical foundation for the study was sensemaking and seamanship, both concepts being part of the SMACS project research agenda. The data was collected during field trips on board five ships, where observation and interviews were performed. The study also includes interviews with seafarers on shore, in total 21 seafarers.

The seafarers in this study described seamanship in line with previous research, emphasising the importance of sailing experience and using one's own good judgement. An interesting finding was that seafarers described seamanship as being essential for sensemaking. For instance, the informants explained using seamanship to sort out the important information from the abundance of information available on the bridge. Seamanship was also described as important for being able to recognise the specificity of the situation, whether or not you are in a situation where "alarm bells should be going off in your head" (seafarer quote).

The paper outlines many examples of design issues that were observed during the field studies on board the three older ship bridges: lacking the possibility to dim screens and other lights, cluttered consoles with little grouping of functions, an abundance of buttons (many not functioning), buttons and levers being small and cumbersome to work and many alarms having similar sounds. Furthermore, there were issues such as poorly functioning touch screens, lengthy menus to navigate through and screens with information that the seafarers found unnecessary. We also observed officers climbing on consoles to reach equipment.

The paper also describes the many examples of *adaptations of design* observed alongside the design issues on these ships. Adaptations included self-made covers for dimming screens, partly covering screens to cover unnecessary functions, covers over non-functioning buttons, pallets to stand on, lengthening of levers and written notes, as well as the instalment of a computer mouse to be able to use screens from the main working position. Similar design issues and adaptations of design was also described by the informants interviewed on shore. The paper argues that it is reasonable to assume that when things cannot be physically adapted to function better, this can lead to new and possibly suboptimal ways of working. One of the informants expressed this sentiment as: “adapting to the system is seamanship in practice”. Seafarers adapting their work to the system is referred to as *adaptation to design,* which is a more tacit and invisible response than *adaptation of design*.

Being excellent at troubleshooting is part of good seamanship (Lamvik et al., 2010) and the adaptations are seen by seafarers as necessary to get the job done in a safe and practical manner. The seafarers in our study had very little influence on ship bridge design and expressed frustration with the people that make design decisions not seeming to understand their work and the work context. According to the seafarers, the design issues and adaptations were not visible to the maritime stakeholders that design, build, procure and install ship bridge equipment, and none of the seafarers knew of a system in place for feedback from operations.

The paper concludes that there is a gap between those who design, develop and install equipment on ship bridges and the end-users – the seafarers. For those working in organisations ashore, the act of troubleshooting and finding creative solutions may be deceiving, as the equipment on board may seem to be working well, or at least well enough, to keep operations going. This identified gap resonates with decades of research in the maritime industry. The study suggests future research should investigate stakeholders in the blunt end, to possibly find where human-centred design activities can be introduced.

6.3. Paper III

Danielsen, B.-E. (2022). The contribution of ship bridge design to maritime accidents. In: Katie Plant and Gesa Praetorius (eds.), *Human Factors in Transportation*. International Conference on Applied Human Factors and Ergonomics 2022. Vol. 60, 714–722. Springer. http://doi.org/10.54941/ahfe1002509

This paper presents a review of 28 publicly available accident investigation reports from the maritime investigation boards in Norway, Denmark, Germany and the United Kingdom. I selected reports from the last decade where design of ship bridge equipment or bridge layout had been identified as contributing factors to the accident. Previous research has shown that maritime accident investigations tend to focus on technical components and pay less attention to how human, technological and organisational factors interact in sociotechnical systems (Schröder-Hinrichs et al., 2011). By selecting investigation reports from the last decade, I sought to get an impression of how design of technology as part of the sociotechnical system is currently handled in maritime investigations. The review identified six categories of design issues: 1) bridge layout, 2) not using available electronic equipment, 3) unexpected use of electronic equipment, 4) mode confusion, 5) lack of information about system status, 6) trust in electronic equipment. These categories correspond with human-technology issues described in previous research (Oltedal & Lützhöft, 2018; Woods et al., 2010).

I also examined the safety recommendations issued by the investigation boards and the reported response by shipowners. The safety recommendations are in most cases directed to the shipowner or ship operator. Most recommendations advised a revision of the safety management system, procedures or checklists. Other reoccurring recommendations included Electronic Chart Display and Information System (ECDIS) training or bridge resource management (BRM) training. Merely five of the 28 reports had recommendations directly addressing the design issue, and only one of these had a recommendation directed towards the equipment manufacturer about revising their design. Similarly, the shipowner responses mainly consisted of revising existing, or introducing new, procedures or checklists, and performing BRM or ECDIS training. Another frequent response was that they had distributed a circular, report, or safety bulletin about the accident to the fleet. In eight cases, the shipowners reported doing a change or upgrade of bridge equipment or bridge layout. These were local fixes intended to ensure the exact same accident would not happen again. An example of this was placing a counterweight on the steering wheel to force it into neutral position when not in use.

Although identifying design issues as contributing factors to accidents is an important step towards improving and managing this risk, the safety recommendations and shipowner response of introducing procedures and checklists places the main responsibility for an improved human-technology interaction on the human operator. This type of response may prevent the exact accident from happening again. However, it does not contribute to learning on an organisational or system level. The paper concludes that the operational consequences of poor ship bridge design are being shouldered by the seafarers. I argue that applying a systems approach to accident investigations may contribute to investigations going beyond the cause *human error* and providing recommendations for solutions and lessons learned on a systems level, to a broader set of relevant stakeholders, such as regulators, designers, purchasers and installers.

6.4. Paper IV

Danielsen, B.-E., Lützhöft, M., Haavik, T., Johnsen, S.O. & Porathe, T. (2022). "Seafarers should be navigating by the stars": Barriers to usability in ship bridge design. *Cognition, Technology & Work*, 24, 675–691. https://doi.org/10.1007/s10111-022-00700-8

Paper IV is a continuation of the work presented in paper II. It expands the scope from seafarers to also include the two central stakeholder groups equipment manufacturers and shipowners. The empirical foundation for this paper consists of interviews with seafarers, shipowners and equipment manufacturers, in total 31 informants. The data was divided into two groups, referred to as the *Traditional Case* and the *Human-centred Design (HCD)* Case. All three stakeholder groups were represented in each case. The *Traditional Case* represents the design situation in the shipping industry today, while the *HCD Case* represents a ship bridge development and design process where human factors considerations were implemented.

The findings from the *Traditional Case* showed that seafarers must handle suboptimal ship bridge design in their daily work, and they have little or no influence on the design. The *Traditional Case* shipowners' main concern was that their investment in a ship should be profitable, and they did not see the need to invest more than necessary on the ship's bridge. The *Traditional Case* shipowners expressed that safety of navigation was taken care of by complying with regulations. These shipowners were of the opinion that focus should be on the seafarers' competence in using the equipment, as one of them stated, they should be "able to navigate just by the stars". The equipment manufacturers in this case found it important to include end-user needs in their design processes. However, they found access to seafarers to be limited and trade-offs between time, cost and customer (shipowner) requests made it difficult to include end-user needs in their design processes.

In the *HCD case,* the *s*eafarers generally described their work environment in positive terms, the ship bridge developed based on HCD principles was considered to support their work tasks well. The shipowner in this case found it important to be closely involved in ship bridge design decisions. They were of the opinion that they benefited on investing in ship bridge equipment, in the form of enhanced crew well-being. The equipment manufacturer in this case performed an extensive human-centred design process that was made possible through an externally funded research project. As such, this example might not be representative for usual development budgets, but it may still serve to illustrate that human-centred design is possible to perform in the maritime industry. The *HCD Case* equipment manufacturer found that the main challenges when performing a human-centred design process were that current regulations and classification scheme did not allow for certain innovations, and that additional time and cost during the development phase was hard to defend both internally in their company and externally, as the demand for human-centred design in the maritime market was limited.

The paper concluded that suboptimal usability in ship bridge design is related to the different aims and perspectives between the core stakeholders, including different conceptions of *work as done* in the operative environment. We also found that the blunt end stakeholders focus on short-term profitability goals and perceive the relation between usability and profitability as a trade-off rather than of synergy. The paper suggested that a way forward could be to develop processes, enablers and management tools to 1) update the understanding of the professional competence needed in the technology-dense work environment on ship bridges today, 2) strengthen the awareness of the advantages of HCD, 3) enable implementation of HCD into existing processes and 4) provide metrics for business cases.

6.5. Paper V

Danielsen, B.-E. & Petersen, E.S. (2022). Somebody else's problem? Usability in ship bridge design seen from the perspective of different maritime actors. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation,* 16 (4), 685-700. https://doi.org/10.12716/1001.16.04.10

This paper is a continuation of the work presented in paper II and IV. It expands the scope from the stakeholder groups seafarers, equipment manufacturers and shipowners, to also include classification societies, a flag state, a shipyard and marine insurers. In total, semi-structured interviews with 42 informants from these stakeholder groups form the empirical foundation of the paper.

The basis for this study is that navigation is a complex interaction between human, organisational, environmental and technological factors on the ship's bridge and that suboptimal usability in the technology is a risk factor that may contribute to maritime accidents. The achievement of usability in equipment and systems ideally requires a human-centred design approach that includes the involvement of end-users throughout the design and development process. Despite considerable research, design and development efforts aiming to improve usability in ship bridge design, and the fact that the IMO has acknowledged the need for human factors considerations in ship bridge design through the SOLAS V/15 regulation, suboptimal usability in ship bridge design seems to be a persistent challenge. By investigating maritime stakeholder's perspectives, including their influence on, interest in and responsibility for usability in ship bridge design, the paper aims to shed light on factors influencing the limited progression in the industry.

The seafarers were found to be the stakeholder group with the highest interest in usability in ship bridge and equipment design, as they are directly affected by it through their daily work. However, they had little or no influence on the design and development process, nor the purchasing process. The other stakeholders acknowledged that suboptimal usability in ship bridge design does exists, but their expressed interest in and perceived possibility to influence ship bridge design varied. What they seemed to have in common was a shared tacit understanding of the goal-based SOLAS V/15 as a "dormant requirement" (*informant quote*) and focusing on compliance to SOLAS V/19, which, together with performance standards and test standards, provide prescriptive requirements for bridge design.

The IMO instrument is essential for the safety of shipping, and we argue that the IMO has made the necessary human factors requirements through SOLAS V/15. However, this goal-based requirement seems to be difficult to follow up in design, development and survey work. In addition, the regulators are subjected to conflicting interests between safety and economic/political considerations. What appears to be absent enforcement of SOLAS V/15 leaves usability up to the different maritime stakeholders. The resulting fragmentation of responsibility for usability is illustrated by the fact that the different stakeholders considered the responsibility for usability to sit with one or several of the other stakeholders, seeing it as somebody else's problem. As an example, most shipowners expressed that usability was the responsibility of shipyards, equipment manufacturers and regulations, while seafarers, equipment manufacturers, class societies, flag state and insurance companies meant it was the shipowners' responsibility. A noteworthy observation from Paper V is that the insurance representatives believed that shipowners were responsible for usability, but their awareness campaigns were still directed at seafarers and their use of equipment. Overall, there is seemingly a lack of incentives to prioritise usability, as it is neither strictly followed up through certification of bridge and bridge equipment designs, nor is it perceived as cost-effective by the stakeholders, as usable equipment may conceivably have a higher investment cost and does not produce tangible economic benefits, like lower insurance premiums.

The paper suggests that a way forward for long-term improvements of usability can be making the usability considerations relating to bridge design and the design of bridge equipment in current regulations more explicit and subject to more focused validation. In addition, we recommend that transfer of generic human factors knowledge to more technically oriented stakeholders become a best practice. The paper also argues for finding opportunities for small steps to improve usability in the short term. Specifically, we suggest to include seafarers as 'experts' when 'expert evaluation' is required in the process of plan approval, system assessment and type-approval of maritime equipment. Such a practice can bring the perspective of the end-users, and their understanding of the context-of-use, into the ship bridge design and equipment manufacturing processes, without any change of rules, regulations or other practices.

6.6. Additional papers

The papers written as part of the PhD work that are not included in the thesis are listed below. Some of these are conference papers disseminating preliminary work that was further developed to the papers included in the thesis.

Danielsen, B.-E. (2018). Sensemaking on the bridge: A theoretical approach to maritime information design. In *International Conference on Human Systems Engineering and Design: Future Trends and Applications* (pp. 76-81). Springer.

Kilskar, S. S., Danielsen, B. E., & Johnsen, S. O. (2018). Sensemaking and resilience in safety-critical situations: A literature review. *Safety and Reliability–Safe Societies in a Changing World. Proceedings of ESREL 2018, June 17-21, 2018, Trondheim, Norway*.

Danielsen, B.-E. & Lamvik, G. (2019). Making sense of bridge design: How seamanship may challenge technology-as-designed. In *Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany*.

Johnsen, S. O., Kilskar, S. S., & Danielsen, B. E. (2019). Improvements in rules and regulations to support sensemaking in safety-critical maritime operations. In *Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany*.

Danielsen, B. E., Bjørneseth, F. B., & Vik, B. (2019). Chasing the end-user perspective in bridge design. *Proceedings of Ergoship 2019*.

Kilskar, S. S., Danielsen, B.-E., & Johnsen, S. O. (2020). Sensemaking in critical situations and in relation to resilience - A review. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B Mechanical Engineering*, 6(1).

Johnsen, S. O., & Danielsen, B. E. (2021). Examination of design and human factors supporting sensemaking, resilience and performance in the ship accident Helge Ingstad in Norway. In *International Conference on Applied Human Factors and Ergonomics* (pp. 3-11). Springer.

7. Discussion

This chapter synthesises and reflects on the findings presented in Chapter 6, and discusses how they shed light on the main research question: *Why is usability in ship bridge design a persistent problem in the maritime industry?* While the first sections answer the research questions, the last section suggests how usability in ship bridge design can be improved based on this study's findings.

7.1. Seafarers and ship bridge design

Research question 1 concerns how the human work in collaboration with technology on the ship's bridge can be understood and described. Papers I and II, address this question. This research also sheds light on *work-as-done* on the bridge. The ship's bridge has been described as a *sociotechnical system,* where the social factors (individual, organisational, societal) and the technical factors (machines, technology, material) together constitute the system and produce the system outcome (Costa, 2018; Grech et al., 2008). Previous research has found both cognition and situation awareness not to be restricted to the individual mind, but rather distributed between people working together, and between people and technology on the bridge (Hutchins, 1995; Sandhåland et al., 2015b). Snook (2000, p. 207) argues that when analysing an accident, the sensemaking concept can help change the focus from the individual decision-maker to "somewhere 'out there' where context and individual overlap", thus making it possible to gain a more balanced account of all factors influencing individual actions. In addition to the understanding of people's behaviour as embedded parts of the sociotechnical system, sensemaking may be an important complement to other concepts for understanding how people behave, such as situation awareness or decision-making theories. Weick (1995) argues that people are not rational decision-makers who passively perceive the environment and evaluate all choices for action. Sensemaking explains how people *actively* pick up cues from the environment based on several factors, such as their prior understanding of the situation and their previous experiences. From the cues, people develop a plausible story of what is going on, which allows them to continue with their activities. These insights are important for the design of the interface between technology and humans that are part of sociotechnical systems, like a ship's bridge.

The present study finds that sensemaking as described by seafarers, appears to be closely related to the notion of seamanship. To my knowledge, this relation has not been described previously in the research literature. The informants described seamanship as an important capability to sort out the important information from the less important information available on the bridge. Seamanship was also described as necessary for being able to recognise the specificity of the situation, whether you are in a situation where "alarm bells should be going off in your head" (seafarer quote). The professional experience and judgement that are essential parts of the seamanship notion thus seem to influence the ability to notice or "bracket" (Maitlis & Christianson, 2014) the important and relevant cues from the flow of experience and information in the ship bridge environment.

Both sensemaking and seamanship are complex concepts with no generally agreed-upon definitions. However, in addition to seafarers seeming to connect the two concepts, there are theoretical similarities between them. For instance, practical sailing experience is central for being able to exercise good seamanship. Experience is also an important component in people's *expectations,* which strongly influence which cues that are noticed in the environment (Maitlis & Christianson, 2014). Professional identity is also part of seamanship, while sensemaking is "grounded in identity construction" (Weick, 1995, p. 18). While this study does not touch further upon the potential intersecting or interconnected nature of these two concepts, our findings indicate a relation worthwhile of further investigation.

In line with previous research (Grech et al., 2008; Lützhöft, 2004; Lützhöft & Dekker, 2002; MAIB & DMAIB, 2021; Puisa, 2018; van de Merwe, 2016; Wilkinson, 1971), Paper II reports a variety of design issues observed during ship visits, confirming that suboptimal usability in ship bridge design is a current and prevalent issue. Some of these ship bridge work environments call to mind the control room at Bhopal, which (Weick, 2010, p. 538) described as "something of a nightmare for sensemaking". As seen in our study, design issues on the bridge are handled by applying adaptive strategies. Being excellent at troubleshooting and making do with what you have at hand is key to good seamanship (Lamvik et al., 2010), and is reflected through creative ways of, what we in Paper II describe as, *adaptation of design.* One of several observed examples of *adaptation of design* is shown in Picture 5.

Picture 5. Example of 'adaptation of design'. A plexiglass plate is covering non-functioning buttons and a hole is carved out above the one button that is functioning. At the same time, the plate functions as a mouse mat. Photo: Brit-Eli Danielsen.

In paper II, we also refer to *adaptation to design,* to describe how seafarers in a less visible way adapt their work to the system. The quote from a seafarer, "adapting to the system is seamanship in practice" illustrates that seafarers are aware of using this strategy and they see it as a part of the notion of seamanship. However, *adaptation to design* was not observed during the fieldwork. Recognising this type of adaptation requires observation of work for a longer period, optimally before a new technology is introduced, immediately after introduction and after the technology has been in use for an extended period of time (Lützhöft, 2004). This would be an interesting opportunity for future research.

Operators adapting to the technology has previously been described in the research literature. Wilkinson (1971) reported seafarers adapting to equipment already in 1971. Lützhöft (2004) found that seafarers performed what she described as "integration work", which includes integrating representations of data and information, and integrating human and machine work, to build a functioning human-machine system (Lützhöft, 2004). Similar strategies have been described in several other industries (Woods et al., 2010). For instance, in the operating room, Cook and Woods (1996) observed what they named *system tailoring*, i.e., when practitioners adapted to the new computer system and *task tailoring* when they adapted their behaviour. Adaptations are the result of learning (often from near misses and incidents) and trying to make sense of the system. But as Woods et al. (2010) emphasise, there are limits to successful adaptations, adaptations that work well in routine operations may, when conditions change, be ineffective or brittle, effectively illustrated by the *City of Rotterdam* accident (Marine Accident Investigation Branch, 2017).

The seafarers in our study expressed frustration over not having influence on bridge equipment and design, and frustration over decision-makers on shore not understanding the work being performed on the bridge. However, they still took responsibility for bridging the usability gap to make the human-technology interaction on the bridge work. As previously mentioned, the adaptation strategies seem to be part of what is expected from a seafarer exhibiting good seamanship. In line with previous research, the seafarers in our study described good seamanship as coherent with individual characteristics, like competence and autonomy (Antonsen, 2009; Knudsen, 2009). However, Kongsvik et al. (2020) argued that this notion of seamanship may be losing its relevance, due to the development where knowledge and competence is increasingly distributed from the individual seafarer, to technology, procedures and regulations. The authors introduced a new concept, *distributed maritime capabilities*, to reflect these changes. The findings in this thesis also suggests that a shift from a focus on individual to distributed capabilities may make it more evident that onshore organisations also have responsibility for the capabilities needed for safe navigation and for placing seafarers in manageable circumstances.

This section has outlined the ship bridge as a sociotechnical system where cognition and knowledge are distributed between the seafarers and between the seafarers and the technology on the bridge. Suboptimal usability in ship bridge design challenges the collaboration between the seafarers and the technology. The observed *adaptation of design* may be seen as traces of the seafarers' sensemaking activities and of the responsibility they take for the human-technology interaction on the bridge. A central finding is that although the seafarers' knowledge or perspectives are not included in ship bridge design processes, they are shouldering the risks inferred by suboptimal usability in ship bridge design.

7.2. "Seafarers should be able to navigate by the stars"

Research question 2 concerns how different maritime actors understand and describe the human-technology interaction on the ship's bridge. Papers III and IV, which include data from seafarers, shipowners, equipment manufacturers and accident investigation reports, are the main contributors to this question. While the seafarers' perspective was the topic of section 7.1, the current section will focus on the blunt end stakeholders' perspectives.

Paper IV investigated two different ship bridge design cases, referred to as the *Human-centred Design (HCD) Case* and the *Traditional Case*. The stakeholder groups seafarers, shipowners and equipment manufacturers were represented in each case. The *HCD Case* represented a ship bridge development and design case where human factors considerations had been implemented. The resulting bridge solution accommodated seafarers work well, considering factors such as grouping of functions, alarm handling, computer interfaces and overall layout (Paper II and IV). The *Traditional Case* consisted of informants from several sectors of the maritime industry and served as a representation of the design situation in the shipping industry today. One of the main differences between the *HCD Case* and the *Traditional Case* was the shipowner's perspectives, interest and active involvement in the ship bridge design process. Another important finding was that the ship bridge design developed in the *HCD Case* required cooperation between all the involved stakeholder groups: the seafarers, the equipment manufacturer and the shipowner.

In line with the findings of Meck et al. (2009), the equipment manufacturers in both cases expressed a high interest in including seafarers in their design and development processes in order to develop usable products. Further, the degree to which the shipowners expressed interest in usability in ship bridge design varied significantly, ranging from a high interest in the *HCD Case,* to medium/low in the *Traditional Case*. The different levels of interest may reflect the shipowner organisations being at different usability maturity levels (Lützhöft & Vu, 2018). Although the *Traditional Case* shipowners were aware of the existence of suboptimal usability in ship bridge design, safety was perceived as being ensured as long as the bridge equipment complied with the regulations. They believed the focus should rather be on the seafarers' competence in handling the equipment. "Seafarers should be able to navigate just by the stars", a quote from a *Traditional Case* shipowner informant, illustrates this view.

The focus on seafarers, their competence and actions, was also evident in the analysis of accident investigation reports (Paper III). Although design was found to be a contributing factor to the accidents, the main recommendations and responses after the accidents were to introduce procedures, checklists and training rather than changing the design of technology. Woods et al. (2010, p. 195) describe this type of response as attempts to "eliminate the consequences of poor adaptations by attempting to drive out all adaptations." Policing strict adherence to procedures in an attempt to eliminate errors can limit the seafarers' discretionary space and their possibility to adapt to the ever-changing context. Considering the variability in seafarers' work, which can range from weather conditions to technological or organisational issues, the ability to adapt to the variable context is a key ingredient that according to the Safety II perspective contribute to safety (Hollnagel, 2014; Hollnagel et al., 2006).

That the seafarers' competence should bridge the usability gap by applying adaptation strategies seems to not only be accepted, but also expected by onshore organisations, as also pointed out by Bhardwaj (2013). This creates a double bind for the seafarers, or in the words of Woods et al. (2010, p. 195): "fail to adapt and goals will not be met but adaptation if unsuccessful will result in sanctions." When people in the blunt end solely place the main responsibility for the human-technology interaction on the bridge on the seafarers, it implies that they are neither aware of how design of technology influences sharp end operators' work, nor are they aware of their own role in influencing the conditions in which sharp end operators work. The view that people in the blunt end seem to hold of seafarers' responsibilities and competence are consistent with old ideas of seamanship, when the ship being isolated at sea made the ability to "make everything work" crucial (Bhardwaj, 2013; Lamvik et al., 2010). Schröder-Hinrichs et al. (2012, p. 152) argued that while maritime technology has changed significantly in the 100 years between the *Titanic* accident in 1912 and the *Costa Concordia* accident in 2012, "the thinking and attitudes of management have changed less and may possibly not have changed at all, at least when it comes to such issues as risk taking and prioritization of issues relating to operational safety". As the work environment on the bridge has changed due to increased instrumentation, digitalisation, and automation, the possibility for seafarers to have full system comprehension and be able to diagnose and fix problems themselves is reduced. The seafarers' role on the bridge is changing towards them becoming system monitors, and these changes warrant a more nuanced view on both seafarers' and other stakeholders' responsibilities for ship bridge design (Kongsvik et al., 2020).

While section 7.1 described how seafarers see it as their responsibility to make the human-technology interaction on the bridge work, this section described how core blunt end stakeholders seem to share the view that seafarers are responsible for managing the available equipment on the bridge, regardless of usability. The understanding of the seafarers' roles and responsibilities held by both stakeholders in the blunt and sharp end, does not seem to have changed in line with the technology development over the last decades. Old ideas of work may thus be a counterforce in the improvement of usability in ship bridge design.

7.3. The responsibility for usability - somebody else's problem?

Research question 3 concerns how the different actors in the maritime industry perceive their responsibility for usability in ship bridge design. Paper V is the main contributor to this question, with data material expanded from previous papers to include seven additional stakeholder groups: seafarers, shipowners, equipment manufacturers, shipyard, insurance companies, classification societies and a flag state. We found that while all informants recognised the existence of suboptimal usability in ship bridge design, the perceived influence and interest in usability in ship bridge design varied both within and between the stakeholder groups. What the stakeholders did have in common was placing the responsibility for usability with other stakeholders than themselves. Figure 5 shows with whom the stakeholders thought the responsibility sits. The arrows pointing in all directions also illustrates that the overall responsibility for usability in the maritime industry seem to pulverise between the stakeholders. Importantly, Figure 5 is a simplified illustration, leaving out more fine-grained interfaces between sub-divisions in the organisations. The maritime industry is a globalised industry relying on multiple organisations forming networked structures with many interfaces between organisations (Le Coze, 2017). The figure does indicate that a larger network of maritime stakeholders exists.

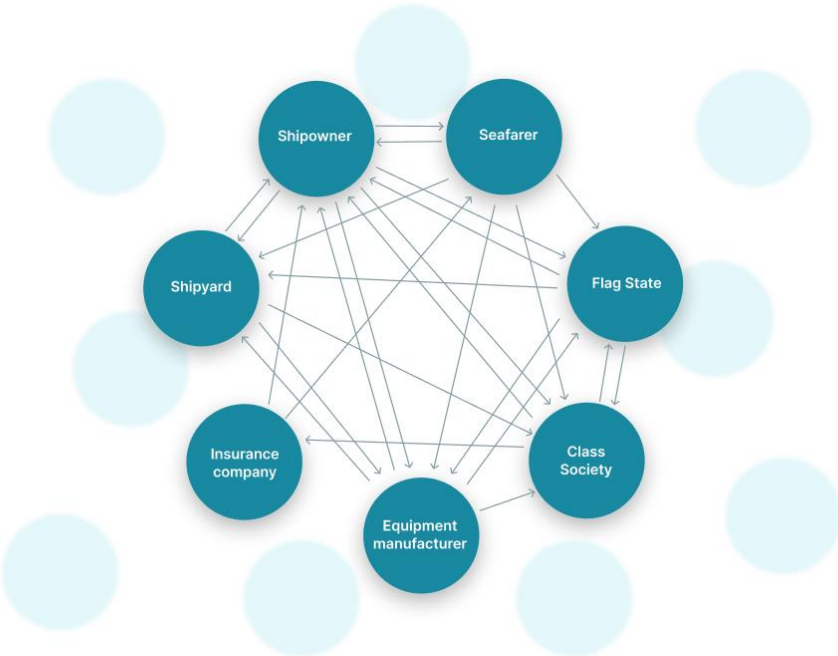


Figure 5. The allocation of responsibility for usability in ship bridge design, as perceived by the different stakeholders. The arrows pointing towards seafarers reflects the perceived responsibility for handling the equipment. The background circles indicate the existence of additional stakeholders, who may also have influence on usability in ship bridge design.

Another pattern seen in Figure 5 is that all stakeholder groups point to the shipowners as being one of the responsible actors for usability in ship bridge design. The reason for placing responsibility on the shipowner was that the shipowner is the stakeholder investing their money in the ship, while the others merely provide products or services that the shipowner in the end pays for. As described in section 7.2, most of the shipowners in this study did not agree with this view. The shipowner group referred to several other stakeholders as being responsible for usability, and they emphasised that responsibility for usability must be ensured through regulations. Complying with regulations appears to be important for the shipowners, and for many of them being compliant was considered sufficient for ensuring safe navigation. Efforts or investments beyond regulatory requirements were not seen as necessary.

7.3.1. Regulators' responsibility

According to Reason (1997, p. 188), regulators "are potentially one of the most important defences against organizational accidents." The IMO has clearly acknowledged the need for human factors considerations (i.e., usability in ship bridge design) through the SOLAS V/15 regulation. However, in this study, the SOLAS V/15 was neither found to be applied systematically in design and development processes, purchasing processes, nor in the survey work by the regulators. In contrast, the SOLAS regulation V/19, which together with the related performance standards and test standards, provide prescriptive requirements for bridge design, was considered important to follow. The *flag state* is responsible for enforcing the international regulations on ships flying their flag. However, the global nature of the maritime industry means that national authorities have a more limited role, and maintaining an independent national oversight of international networked governance configurations may be a challenge (Almklov & Lamvik, 2018; Le Coze, 2017). In addition, as shown in Paper V, it is challenging for the flag state to enforce the SOLAS V/15 regulation. One of the challenges brought up by the informants was performing survey work based on “abstract” goal-based requirements. This is what Decker (2018) describes as a major practical challenge in survey work, as there may be different means to achieve the goals; the challenge lies with how to assess and decide the precise point at which a goal may be judged to have been fulfilled.

The overall trend has for several decades been to move towards goal-based regulations (Reason, 1997), with goal-based standards having been discussed by the IMO since 2002 (Hamann & Peschmann, 2013). The key potential benefit of goal-based regulations is that the actors themselves can identify the needed steps to achieve the goal adapted to their own organisation (Decker, 2018; Reason, 1997). Goal-based regulations can also provide the needed flexibility to address the dynamic context of use (Earthy & Sherwood Jones, 2006). However, there are certain risks associated with goal-based regulations such as SOLAS V/15. Achieving a goal such as usability requires that stakeholders like designers, developers and surveyors possess a certain level of human factors knowledge, as well as knowledge about the specific users and context of use (Earthy & Sherwood Jones, 2006). Fulfilling the goals of SOLAS V/15 may thus be difficult due to the varying levels of knowledge of human factors and human-centred design posited by different maritime stakeholders (Costa et al., 2017; Vu & Lützhöft, 2020), as well as the lack of available data about, and access to, the maritime end-users and the context of use (Earthy & Sherwood Jones, 2006; Lurås & Mainsah, 2013; Vu & Lützhöft, 2020).

Another factor influencing the flag state enforcement of SOLAS V/15 was apparent as the informants from the Norwegian Maritime Authority (NMA) emphasised the importance of ensuring what they called “predictable conditions” for the shipping industry in Norway. The implementation of national rules and different ways of enforcing rules between different nations, was seen as factors that could enhance the risk of ships flagging out. These findings are in line with Størkersen's (2015) study on maritime safety regulations, where she found that the prioritisation of profit by both politicians and maritime actors constrains the maritime safety regulators. According to the flag state informants, SOLAS V/15 was not actively followed up within their supervisory work, confirmed by one class society representative describing SOLAS V/15 as a "dormant requirement". The flag state informants pointed to "the industry" as an important actor to drive design regulations forward, which also emphasise the seemingly fragmented responsibility for usability.

To summarise, the maritime actors included in this study all express that usability in ship bridge design is somebody else's problem. The unclear responsibility for usability seems to have led to a pulverisation of responsibility in the network of maritime organisations. The flag state, being responsible for the national enforcement of the IMO regulations, seems to be constrained by economic considerations and the fact that a goal-based regulation like SOLAS V/15 is difficult to follow up through survey work. The SOLAS V/15 is thus left as a 'dormant requirement'.

7.4. Profitability and usability

The general globalisation has led to a power shift towards financial actors which tend to prioritise short term profits over long term investments and focusing on the return on investments (Le Coze, 2017). This trend is also taking effect in the maritime industry. Being part of a competitive industry forces all actors focus on maximising profit (Walters & Bailey, 2013), which can involve prioritising profit over safety (Størkersen, 2015) or production over protection (Reason, 1997). In organisations, prioritisations between safety and other goals such as profit and efficiency, are based on ranging something on its perceived importance, which is influenced by one's knowledge concerning what might actually have an impact on safety. The design of the *City of Rotterdam* prioritised a bow shape that would save fuel, with none of the involved maritime actors considering its impact on the work on the bridge. It might be that the actors were not aware of or did not understand the influence the bridge design could have, but the result was still that profitability was prioritised over usability, which ended up having considerable ramifications.

The discussion so far has shown that for many maritime actors, there does not seem to be any incentives to consider usability in ship bridge design, as design regulations are not enforced and there is no clear profit to be gained from ergonomic investments. Long term gains, such as a reduced number of potential future accidents, are difficult to value in economic terms. There is a lack of routines and methods for performing cost-effect estimations of ergonomic investments in shipping industry (Österman & Rose, 2015; Österman et al., 2010). There seems to be a need for tangible cost estimations showing that investing in usability in ship bridge design can be seen as offering synergy, rather than being an economic trade-off. The shipowners do not seem to be aware of the additional positive effects that human-centred design can bring, not only for the seafarers, but for their own business (Costa & Lützhöft, 2014; Österman, 2013). Based on this, and in line with Dul (2012), I argue that the human factors discipline in general should expand its focus from narrowly focusing on the end-users and how their work context can be improved, to how other stakeholders and decision-makers with different roles and goals can obtain the necessary knowledge to prioritise ergonomic investments

7.5. A way forward?

The finding that SOLAS V/15 is seen as a 'dormant requirement' suggests that these goal-based requirements could be made more explicit and operational, to aid practical implementation in design and development processes as well as to support inspection and survey work. Regulation and guideline developments are long-term improvement processes. Another suggestion for a long-term improvement is that HF knowledge should be made more easily available, as well as more actively transferred to the relevant maritime actors. Previously, researchers have suggested to introduce HCD knowledge in naval architecture education (Abeysiriwardhane et al., 2016; Ahola, 2018). There are also other examples of spreading human factors knowledge, such as the Nautical Institute that works to reach a broad set of maritime actors through the Alert! Project (The Nautical Institute, 2022) and its human element bulletins. However, one may question whether resources like these only reach the audience already interested in human factors and, if so, whether additional or new ways of reaching different stakeholders should be considered.

A central principle of a human-centred design process is that end-users should be actively involved throughout the design and development processes (International Organization for Standardization, 2010). In this thesis, the *ship bridge design process* has been described as the design activities undertaken by the naval architects designing the ship, the equipment manufacturers designing the different pieces of equipment, as well as the procurement and installation process where the different pieces of equipment are combined to form the complete ship bridge work environment. A broad definition of the design process allows a broader search for instances where end-users can be involved, beyond the equipment designers' work. The suggestion presented in paper V is one such possible way to include the seafarers' perspective, by representing the seafarers in the process of plan approval, system assessment and type-approval of maritime equipment. The present test methods described in the test standards often call for *expert evaluation,* but a definition of *expert* is not provided. We argue that the definition of *expert* should include a relevant seafaring career and current seafaring experience. Having seafarers judging whether criteria like 'intuitive' and 'logical grouping' are met, could be a way of introducing the end-user perspectives in ship bridge design and equipment development. This is a practical short-term solution, not intended to replace performing a human-centred design processes, but it is a suggestion that is possible to implement in the industry without any major changes being made to regulations and other processes. Small steps forward like these can be implemented in addition to the identified long-term efforts like transferring human factors knowledge to stakeholders and making requirements of SOLAS V/15 more explicit and operational. Giving the seafarers a voice during processes such as type approval can potentially improve usability and in the longer run, this can build a pool of knowledge that could become a resource for design engineering to improve their products and services, a need which has been called for by equipment manufacturers (Vu & Lützhöft, 2020).

8. Conclusion

The overall aim of this thesis has been to contribute to safety at sea by developing knowledge about factors in the maritime industry that influence the improvement of usability in ship bridge design. Theoretically positioned within the disciplines of human factors, design and safety, the research questions have been explored through a qualitative study involving several groups of maritime stakeholders and accident investigation reports. Through the analysis of interviews, documents and fieldwork, this study has produced five scientific publications that shed light on usability in ship bridge design from different perspectives. This thesis builds on existing theory and literature and does not attempt to redirect or redefine the direction of the research field. The current work moves the field forward within the space of fellow researchers' contributions. Following Sternberg's (1999) model, the contributions in this thesis thus constitute a *forward incrementation*. By including the perspectives of a broad set of maritime stakeholders, this work has contributed to additional insights into why suboptimal usability in ship bridge design seems to be a persistent challenge in the maritime industry. The main contributions of this thesis can be summarised as follows:

- An empirical contribution to the ship bridge design body of knowledge showing that seafarers, the end-users, are the stakeholder with highest interest in ship bridge design, yet they have little or no influence on ship bridge design processes. Nevertheless, the seafarers see it as part of their job to take responsibility for shouldering the risks imposed by suboptimal usability by applying adaptive, and often creative, work strategies.
- Improved comprehension of *work-as-done* on the bridge, by introducing the sensemaking concept to understand how people behave as embedded parts of the sociotechnical system on the bridge. Furthermore, this study has expanded the understanding of *work-as-done* through the identification of an interconnection between the concepts of sensemaking and seamanship, illuminating how professional identity influences work and the adaptive strategies applied by seafarers.
- Increased knowledge about the maritime stakeholders' understanding of the human-technology interaction on the ship's bridge. This study found that core stakeholders place the responsibility for managing the available technology on the bridge on the seafarers, regardless of usability. This finding suggests that the prevailing ideas of

seamanship and work on the bridge have not changed in line with technological developments in the ship bridge work environment.

- Insights into factors that influence maritime stakeholders' design prioritisations. From many stakeholders' perspective, there is a lack of both economic and regulatory incentives for prioritising usability in ship bridge design. This may in part be caused by limited attention to, and a lack of knowledge about, the positive business contributions that usability can foster, in the form of both safety and efficiency. As maritime actors are part of a highly competitive industry, they prioritise short-term profit goals over ergonomic investments in ship bridge design, which is made possible by the lack of national enforcement of the SOLAS V/15 regulation concerning human factors considerations in ship bridge design.
- Improved understanding of how contradicting ideas of responsibility among the different maritime stakeholders may hamper improvement of usability in ship bridge design. All stakeholders in this study believed the responsibility for usability in ship bridge design sat elsewhere. While the stakeholders' expressed varied levels of interest and perceived possibility to influence ship bridge design, none of the stakeholders seem to have claimed the role as potential drivers for human-centred design processes.
- A presentation of how a human-centred design process can be achieved in the maritime industry, through the description of the *Human-Centred Design (HCD) Case,* a human-centred ship bridge design project that resulted in a usable ship bridge work environment. By studying this case, we were able to identify certain prerequisites, like dedicated human factors experts, funding and the active involvement of several stakeholder groups.

8.1. Implications for academia

The aspired theoretical relevance of this work has been pursued by both building on previous research and exploring aspects of ship bridge design processes that have not previously been addressed. As the literature review in Chapter 3 shows, there already exists a significant amount of research, design and development work concerning ship bridge design. However, this work does not seem to be reflected in the industry. This thesis demonstrates how developing what researchers and designers may consider to be *good design,* is not sufficient to make changes in the industry, as a variety of stakeholders and factors influence its implementation. While the human factors discipline has traditionally focused on the end-users, the findings in this thesis contribute to the study of a broader set of stakeholders and how their perspectives and priorities can influence the human factors goals of *human well-being* and *system performance*.

Moreover, the findings emphasise that academia should strive to transfer existing human factors knowledge in a format that that can be applied by the different actors in the industry. There is also a need for additional knowledge concerning the economic effects of ergonomic investments which could enable the maritime actors to make better informed economic prioritisations concerning ship bridge design,

At a time when maritime research is focusing on remote operations, autonomous maritime systems and unmanned ships, this thesis shows that there is still work to do concerning human-technology interactions also in conventional shipping. The predicted paradigm shift towards autonomous marine systems and remote-operated vessels will probably not happen in the very near future, so the risk imposed by suboptimal usability in ship bridge design on conventional ships will be a challenge in many years to come.

8.2. Implications for industry

The findings in this thesis may also have implications for actors in the maritime industry. This study confirms previous research on the influence that ship bridge design has on safety and the persistence of suboptimal usability in design. The thesis illuminates the importance of considering suboptimal usability a risk, which, like other risks in a company, should be actively managed. In line with previous research, this thesis emphasises the importance of involving the end-users in design processes and design decisions. What may be interesting to actors in the industry is our suggestion that seafarers can be included in processes like plan approval, system assessment and type-approval of maritime equipment without requiring major changes in regulations, processes or investments. Furthermore, becoming aware of the fact that responsibility for usability seems to pulverise between actors in the maritime industry should inspire actors to take responsibility, or at a minimum, contribute to clarifying the allocation of responsibility. The findings in this thesis may also be useful for designers and people working with human factors in the industry, highlighting the need to direct attention to, and communicate with, a broad set of decision-makers in addition to the end-users. Maritime regulators may learn from the findings concerning how the absent enforcement of SOLAS V/15 impacts the industry, and that industry actors do not necessarily take their part of the fragmented responsibility for usability. Although goal-based regulations have several advantages, there is a risk attached to leaving their realisation to the actors in the industry without a proper mandate.

8.3. Future work

As with any research project, other choices could have been made during all phases and this study could have taken many other directions. An obvious continuation of this work would be to expand the study in terms of number of informants in each stakeholder group or have additional stakeholder groups or additional maritime sectors represented, which could give a broader picture of the maritime industry. Alternatively, one of the maritime sectors could be chosen to do an in-depth study of its stakeholders and structures that influence ship bridge design.

Another interesting approach would be, in addition to investigating the barriers to usability in the industry, to also focus on the possible *enablers*, i.e., factors that the different stakeholders themselves see as enablers to prioritising time and money to improve usability in ship bridge design. As this study found that profitability is a main concern for maritime stakeholders, further research on cost-effectiveness of ergonomic investments is needed. Moreover, further exploring the possibility for practical, short-term solutions for introducing the end-user perspective in ship bridge design, development, procurement and implementation processes, could be a fruitful way forward to gradually improve usability in ship bridge design.

Sensemaking in relation to technology, and the intersecting or interconnected nature of sensemaking and seamanship, are possible avenues for future research. Seafarers' sensemaking has received little attention in the literature and research in this line could further illuminate how professional identity influences work and the adaptive strategies applied by seafarers.

A different avenue that could have been interesting to pursue, is investigating the surveyors' role. As surveyors perform the inspections and approvals of ship bridge equipment and systems, part of their role can be seen as translators of the regulations. Exploring the surveyor's work in relation to usability, including their understanding, possibilities and constrains, could possibly give further insights into factors influencing usability in ship bridge design.

In addition to these suggestions there are numerous other prospective research opportunities. However, future endeavours of devising "courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 55) must keep in mind that in order to change the design situation on board ship bridges into preferred ones, one must include the actions of multiple companies and professionals involved at several stages in the ship bridge design process. And possibly most important, it is imperative that the seafarers' voices are heard and understood.

Picture 6. The North Sea seen from the bridge of an offshore supply vessel. Photo: Brit-Eli Danielsen.

References

Abeysiriwardhane, A., Lützhöft, M., Petersen, E. S., & Enshaei, H. (2016). Human-centred design knowledge into maritime engineering education; theoretical framework. *Australasian Journal of Engineering Education*, *21*(2), 49-60.

Ahola, M., Murto, P., Mallam, S. (2018). When people are the mission of a ship—design and user research in the marine industry. *Marine Design XIII*, 285-290.

AIBN. (2019). *Report on the collision on 8 november 2018 between the frigate HNoMS Helge Ingstad and the oil tanker Sola TS outside the Sture terminal in the Hjeltefjord in Hordaland county*. Accident Investigation Board Norway

Allen, P. (2009). Perceptions of technology at sea amongst British seafaring officers. *Ergonomics*, *52*(10), 1206-1214.

Allianz Global Corporate & Specialty. (2021). *Safety and Shipping Review 2021. An annual review of trends and developments in shipping losses and safety*. https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2021.pdf

Almklov, P. G., & Lamvik, G. M. (2018). Taming a globalized industry–Forces and counter forces influencing maritime safety. *Marine Policy*, *96*, 175-183.

Antonsen, S. (2009). The relationship between culture and safety on offshore supply vessels. *Safety science*, *47*(8), 1118-1128.

Antonsen, S., & Bye, R. (2015). "Vi" og "de andre". In S. K. Antonsen, T. (Ed.), *Sikkerhet i norske farvann*. Gyldendal Norsk Forlag AS.

Atwood, M. E., McCain, K. W., & Williams, J. C. (2002). How does the design community think about design? Designing interactive systems: processes, practices, methods, and techniques,

Bhardwaj, S. (2013). Technology, and the upskilling or deskilling conundrum. *WMU Journal of Maritime Affairs*, *12*, 245-253.

Bhardwaj, S., Bhattacharya, S., Tangc, L., & Howellc, K. E. (2019). Technology introduction on ships: The tension between safety and economic rationality. *Safety science*, *115*, 329-338.

Bhattacharya, Y. (2015). Employee Engagement as a Predictor of Seafarer Retention : A Study among Indian Officers. *The Asian Journal of Shipping and Logistics*, *31*(2), 295-318.

Bjørneseth, F., Clarke, L., Dunlop, M., & Komandur, S. (2014). Towards an understanding of operator focus using eye-tracking in safety-critical maritime settings. Human Factors in Ship Design & Operation, London, UK.

Bjørneseth, F. B. (2021). Unified Bridge - Design Concepts and Results. In S. O. Johnsen & T. Porathe (Eds.), *Sensemaking in safety critical and complex situations: Human factors and design*. CRC Press.

Bjørneseth, F. B., Dunlop, M. D., & Hornecker, E. (2012). Assessing the effectiveness of direct gesture interaction for a safety critical maritime application. *International Journal of Human Computer Studies*, *70*(10), 729-745.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27-40.

Braun, V., & Clark, V. (2008). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Britannica. (2022). *Navigation*. Retrieved 15.06.22 from https://www.britannica.com/technology/navigation-technology

Brugha, R., & Varvasovszky, Z. (2000). Stakeholder analysis: a review. *Health policy and planning*, *15*(3), 239-246.

Bryman, A. (2016). *Social Research Methods* (5 ed.). Oxford University Press.

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, *8*(2), 5-21.

Carroll, J. (2004). Completing Design in Use: Closing the Appropriation Cycle. ECIS, Chauvin, C., Lardjane, S., Morel, G., Clostermann, J.-P., & Langard, B. (2013). Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *59*, 26-37.

Coffey, A., & Atkinson, P. (1996). *Making sense of qualitative data: complimentary research strategies*. Sage Publications.

Cook, R. I., & Woods, D. D. (1996). Adapting to new tecnology in the operating room. *Human Factors*, *38*(4), 593-613.

Costa, N., & Lützhöft, M. (2014). The values of ergonomics in ship design and operation. Human Factors in Ship Design & Operation, London, UK.

Costa, N. A. (2018). *Human-centred design for maritime technology and organizational change* Chalmers Univeristy of Technology]. Gothenburg, Sweden.

Costa, N. A., Holder, E., & MacKinnon, S. N. (2017). Implementing human centred design in the context of a graphical user interface redesign for ship manoeuvring. *International Journal of Human - Computer Studies*, *100*, 55-65.

da Conceição, V. P., Dahlman, J., & Navarro, A. (2017). What is maritime navigation? Unfolding the complexity of a Sociotechnical System. Human Factors and Ergonomics Society Annual Meeting,

Danielsen, B.-E. (2021). Making sense of sensemaking in high-risk organizations. In S. O. Johnsen & T. Porathe (Eds.), *Sensemaking i safety-critical and complex situations: Human Factors and Design*. CRC Press.

de Vries, L. (2017). Work as done? Understanding the practice of sociotechnical work in the maritime domain. *Journal of Cognitive Engineering and Decision Making*, *11*(3), 270-295.

Decker, C. (2018). Goals-based and rules-based approaches to regulation. *BEIS Research Paper*, *8*.

Dekker, S. (2006). Resilience engineering: chronicling the emergence of confused consensus. In E. Hollnagel, D. D. Woods, & N. Levenson (Eds.), *Resilience Engineering Concepts and Precepts*. Ashgate Publishing Limited.

Dekker, S. (2017). *The field guide to human error investigations*. Routledge.

Dekker, S. (2019). *Foundations of safety science. A century of understanding accidents and disasters*. CRC Press.

Dekker, S. W. A. (2002). Reconstructing human contributions to accidents: the new view on error and performance. *Journal of Safety Research*, *33*(3), 371-385.

Dhillon, B. S. (2007). *Human reliability and error in transportation systems*. Springer Science & Business Media.

Dokkum, K. v. (2016). *Ship knowledge. Ship design, construction and operation* (9 ed.). DOKMAR Maritime Publishers BV.

Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W. S., Wilson, J.R., van der Doelen, B. . (2012). A strategy for human factors/ergonomics: developing the discipline and profession. *Ergonomics*, *55*(4), 377-395.

Earthy, J., & Sherwood Jones, B. (2006). *Design for the Human Factor; The Move to Goal Based Rules* World Maritime Technology Conference,

Elias, A. A., Cavana, R. Y., & Jackson, L. S. (2002). Stakeholder analysis for R&D project management. *R&D Management*, *32*(4), 301-310.

Eliopoulou, E., Papanikolaou, A., & Voulgarellis, M. (2016). Statistical analysis of ship accidents and review of safety level. *Safety science*, *85*, 282-292.

European Maritime Safety Agency. (2021). *Annual overview of marine casualties and incidents 2021*.

Evans, J. H. (1959). Basic Design Concepts. *Journal of American Society of Naval Engineers*, 671-678.

Findeli, A., Brouillet, D., Martin, S., Moineau, C., & Tarrago, R. (2008). Research through design and transdisciplinarity: a tentative contribution to the methodology of design research. *Focused–Current Design Research Projects and Methods. Swiss Design Network Symposium*, 67-91.

Forsman, F. (2015). *Navigation Methodology and Teamwork in High Tempo Operations* Chalmers University of Technology]. Gothenburg, Sweden.

Frydenberg, S., Eikenes, J. O., & Nordby, K. (2019). Serendipity in the field. Facilitating serendipity in design-driven field studies on ship bridges. *The Design Journal*, *22*, 1899-1912.

Garcia, J. J., Pettersen, S. S., Rehn, C. F., Erikstad, S. O., Brett, P. O., & Asbjørnslett, B. E. (2019). Overspecified vessel design solutions in multi-stakeholder design problems. *Research in Engineering Design*, *30*(4), 473-487.

Gasson, S. (2003). Human-centered vs. user-centered approaches to information system design. *Journal of Information Technology Theory and Application (JITTA)*, *5*(2), 29-46.

Gernez, E. (2019). Connecting ship operation and architecture in ship design processes. *Journal of Ship Production and Design*, *35*(01), 88-101.

Gernez, E., & Nordby, K. (2020). A 10-day course to plan and execute field studies for maritime design processes. *The International Journal of Marine Design*.

Gernez, E., Nordby, K., & Sevaldson, B. (2014). Enabling a Service design perspective on Ship design. *Transactions of The Royal Institution of Naval Architects*, *156*, 29-39.

Gernez, E., Nordby, K., Seim, Ø., Brett, P. O., & Hauge, R. (2018). *Human-centered, collaborative, field-driven design—a case study* Marine Design XIII,

Goffman, E. (1961). *Asylums*. Penguin Books.

Grech, M., Horberry, T., & Koester, T. (2008). *Human factors in the maritime domain*. CRC press.

Grix, J. (2002). Introducing Students to the Generic Terminology of Social Research. *Politics*, *22*(3), 175-186.

Gulliksen, J., Göransson, B., Boivie, I., Blomkvist, S., Persson, J., & Cajander, Å. (2003). Key principles for user-centred systems design. *Behaviour and Information Technology*, *22*(6), 397-409.

Hamann, R., & Peschmann, J. (2013). Goal-Based Standards and RiskBased Design. *Ship Technology Research*, *60*(2), 46-56.

Hareide, O. S., Mjelde, F. V., Glomsvoll, O., & Ostnes, R. (2017). Developing a high-speed craft route monitor window. International Conference on Augmented Cognition,

Hareide, O. S., Ostnes, R., & Mjelde, F. V. (2016). Understanding the Eye of the Navigator. European Navigation Conference Proceedings,

Hetherington, C., Flin, R., & Mearns, K. (2006). Safety in shipping: The human element. *Journal of Safety Research*, *37*(4), 401-411.

Hockey, J. (1993). Research methods - researching peers and familiar settings. *Research Papers in Education*, *8*(2), 199-225.

Hollnagel, E. (2014). *Safety-I and Safety-II: The past and future of safety management*. CRC Press.

Hollnagel, E., Wears, R. L., & Braithwaite, J. (2015). *From Safety-I to Safety-II: a white paper*. T. r. h. c. net.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience Engineering : Concepts and Precepts*. Ashgate Publishing Ltd.

Hovorka, D. S., & Germonprez, M. (2010). Reflecting, Tinkering, and Tailoring: Implications for Theories of Information System Design. *From CSCW to Web 2.0: European Developments in Collaborative Design*, 135-149.

Human Factors and Ergonomics Society. (2022). *What is human factors and ergonomics?* Retrieved 13.12.2022 from https://www.hfes.org/About-HFES/What-is-Human-Factors-and-Ergonomics

Hurlen, L. (2021). HMI Measures for improved sensemaking in dynamic positioning operations. In S. O. Johnsen & T. Porathe (Eds.), *Sensemaking in safety critical and complex situations. Human factors and design.* CRC Press.

Hurlen, L., Skjerve, A. B., & Bye, A. (2019). Sensemaking in high-risk situations. The challenges faced by dynamic positioning operators. 29th European Safety and Reliability Conference, Hannover, Germany.

Hutchins, E. (1995). *Cognition in the Wild*. MIT press.

International Chamber of Shipping. (2022). *Shipping and World Trade: Global Supply and Demand for Seafarers*. Retrieved 23.03.2022 from https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-global-supply-and-demand-for-seafarers/

International Ergonomics Association. (2021). *Triennial Report of the International Ergonomics Association 2018-2021*. International Ergonomics Association.

https://secureservercdn.net/50.62.89.79/m4v.211.myftpupload.com/wp-content/uploads/2021/06/IEA-Triennial-Report-2015-2018.pdf

International Maritime Organization. (1972). *Convention on the International Regulations for Preventing Collisions at Sea (COLREGs)*. International Maritime Organization.

International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), (1978).

International Maritime Organization. (2002). *SOLAS Chapter V Regulation 15 Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures*. International Maritime Organization.

International Maritime Organization. (2008). *Resolution MSC.255(84). Adoption of the Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code).* International Maritime Organization.

International Maritime Organization. (2022a). *Brief History of IMO*. Retrieved 08.06.22 from https://www.imo.org/en/About/HistoryOfIMO/Pages/Default.aspx

International Maritime Organization. (2022b). *Conventions*. Retrieved 08.06.22 from https://www.imo.org/en/About/Conventions/Pages/Default.aspx

International Maritime Organization. (2022c). *Human element*. International Maritime Organization. Retrieved 18.07.22 from https://www.imo.org/en/OurWork/HumanElement/Pages/Default.aspx

International Maritime Organization. (2022d). *Integrated bridge systems (IBS)*. Retrieved 07.04.2022 from https://www.imo.org/en/OurWork/Safety/Pages/IntegratedBridgeSystems.aspx

International Maritime Organization. (2022e). *Introduction to IMO*. Retrieved 03.03.2022 from https://www.imo.org/en/About/Pages/Default.aspx

International Maritime Organization. (2022f). *Maritime Safety*. Retrieved 30.01.2022 from https://www.imo.org/en/OurWork/Safety/Pages/default.aspx

International Maritime Organization. (2022g). *Safety of Life at Sea (SOLAS)*. Retrieved 30.01.2022 from https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

International Organization for Standardization. (2010). ISO 9241 Ergonomics of human-system interaction - Part 210 Human-centred design for interactive systems. In. www.standard.no.

Irvine, A., Drew, P., & Sainsbury, R. (2012). 'Am I not answering your questions properly?' Clarification, adequacy and responsiveness in semi-structured telephone and face-to-face interviews. *Qualitative Research*, *13*(1), 87-106.

Javaux, D., Luedtke, A., Adami, E., Allen, P., Denker, C., Mikkelsen, T. G., Lohrmann, P., Mextor, H., Sternon, R., Sobiech, C., Vanderstraeten, P., Goens, C. v., & Vroonen, G. (2015). Model-based Adaptive Bridge Design in the Maritime Domain. The CASCADe Project. *Procedia Manufacturing*, *3*, 4557-4564.

Kilskar, S. S., Danielsen, B.-E., & Johnsen, S. O. (2020). Sensemaking in critical situations and in relation to resilience - a review. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B Mechanical Engineering*, *6*(1).

Knudsen, F. (2009). Paperwork at the service of safety? Workers' reluctance against written procedures exemplified by the concept of 'seamanship'. *Safety science*, *47*(2), 295-303.

Kongsvik, T., Haavik, T., Bye, R., & Almklov, P. (2020). Re-boxing seamanship: From individual to systemic capabilities. *Safety science*, *130*, 104871.

Korica, M., & Molloy, E. (2010). Making sense of professional identities: Stories of medical professionals and new technologies. *Human Relations*, *63 (12)*, 1879-1901.

Krippendorf, K. (1989). On the essential contexts of artifacts or on the propositon that "Design is making sense (of things)". *Design Issues*, *5*(2), 9-39.

Krippendorff, K. (2006). *The sematic turn - a new foundation for design*. CRC Press.

Krippendorff, K. (2012). Design research, an oxymoron? In R. Michel (Ed.), *Design research now* (pp. 67-80). Birkhäuser.

Kristiansen, H. (2014). Conceptual design as a driver for innovation in offshore ship bridge development. *Maritime Transport VI*, 386-398.

Kvale, S. (1996). *Interviews: an introduction to qualitative research interviewing*. Sage.

Lamvik, G., Wahl, A., & Buvik, M. (2010). Professional culture, work practice and reliable operations in shipping.*Reliability, Risk and Safety: Theory and Applications* European Safety and Reliability Conference, Prague, Czech Republic.

Lamvik, G. M. (2002). *The Filipino Seafarer: A Life between Sacrifice and Shopping* Norwegian University of Science and Technology]. Trondheim.

Le Coze, J.-C. (2017). Globalization and high-risk systems. *Policy and Practice in Health and Safety*, *15*(1), 57-81.

Le Coze, J. C. (2022). The 'new view' of human error. Origins, ambiguities, successes and critiques. *Safety science*, *154*(105853).

Lincoln, Y. S., & Guba, E. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. In D. D. Williams (Ed.), *Naturalistic evaluation: New directions for evaluation*. Jossey-Bass.

Ljung, M., & Lützhöft, M. (2014). Functions, performances and perceptions of work on ships. *WMU Journal of Maritime Affairs*, *13*, 231-250.

Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-You-Look-For-Is-What-You-Find–The consequences of underlying accident models in eight accident investigation manuals. *Safety science*, *47*(10), 1297-1311.

Lundh, M. (2010). *A Life on the Ocean Wave. Exploring the interaction between the crew and their adaption to the development of the work situation on board Swedish merchant ships* Chalmers University of Technology]. Gothenburg, Sweden.

Lurås, S. (2016). *Systemic design in complex contexts : an enquiry through designing a ship's bridge* Oslo School of Architecture and Design]. Oslo.

Lurås, S., & Mainsah, H. (2013). Reaching hard-to-reach users using online media to get a glimpse of work in marine contexts. *interactions*, *20*(6), 32-35.

Lurås, S., & Nordby, K. (2013, 9-11 Oct 2013). *Radical design processes for systemic change* Relating Systems Thinking and Design, Oslo, Norway.

Lurås, S., & Nordby, K. (2015). Shaping designers' sea sense: A guide for design-driven field research at sea. International Conference on Marine Design 2015,

Lurås, S., Sevaldson, B., & Lützhöft, M. (2015). Meeting the complex and unfamiliar: Lessons from design in the offshore industry.

Lützhöft, M. (2004). *"The technology is great when it works": Maritime Technology and Human Integration on the Ship's Bridge* Linköping University]. Linköping.

Lützhöft, M., Grech, M. R., & Porathe, T. (2011). Information environment, fatigue, and culture in the maritime domain. *Reviews of human factors ergonomics*, *7*(1), 280-322.

Lützhöft, M., & Lundh, M. (2009). Maritime application of control systems. In T. Ivergård & B. Hunt (Eds.), *Handbook of control room design and ergonomics. A perspective for the future*. CRC Press.

Lützhöft, M., Petersen, E. S., & Abeysiriwardhane, A. (2017). The Psychology of Ship Architecture and Design. In M. MacLachlan (Ed.), *Maritime Psychology. Research in Organizational & Health Behavior at Sea*. Springer.

Lützhöft, M., & Vu, V. D. (2018). Design for Safety. In H. A. Oltedal & M. Lützhöft (Eds.), *Managing Maritime Safety*. Routledge.

Lützhöft, M. H., & Dekker, S. W. A. (2002). On your watch: Automation on the bridge. *Journal of Navigation*, *55*(1), 83-96.

Macrae, C. (2009). Human factors at sea: common patterns of error in groundings and collisions. *Maritime Policy & Management*, *36*, 21-38.

Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies*, *55*, 587-634.

MAIB, & DMAIB. (2021). *Application and Usability of ECDIS. A MAIB and DMAIB collaborative study on ECDIS use from the perspective of practitioners*. Marine Accident Investigation Branch & Danish Maritime Accident Investigation Board. https://www.gov.uk/government/publications/application-and-usability-of-ecdis-safety-study

Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: taking stock and moving forward. *The Academy of Management Annals*, *8*(1), 57-125.

Maitlis, S., & Sonenshein, S. (2010). Sensemaking in crisis and change: Inspiration and insights from Weick (1988). *Journal of Management Studies*, *47*(3), 551-580.

Mallam, S. C., Lundh, M., & MacKinnon, S. N. (2016). Supporting participatory practices in ship design and construction - challenges and opportunities. Human factors and ergonomics society annual meting,

Mallam, S. C., Lundh, M., & MacKinnon, S. N. (2017). Integrating participatory practices in ship design and construction. *Ergonomics in Design*, *25*(2), 4-11.

Mallam, S. C., & Nordby, K. (2021). Supporting Consistent Design and Sensemaking across Ship Bridge Equipment through Open Innovation. In T. Porathe & S. O. Johnsen (Eds.), *Sensemaking in Safety Critical and Complex Situations* (pp. 155-171). CRC Press.

Mallam, S. C., Wahl, A. M., & Aas, J. (2022). Reintroducing the sharp-end operator to organizational learning: How accident reports are used by maritime officers. *Safety science*, *147*(105632).

Marine Accident Investigation Branch. (2017). *Report on the investigation of the collision between the pure car carrier City of Rotterdam and the ro-ro freight ferry Primula Seaways, River Humber, United Kingdom, 3 December 2015*.

Marine Casualties Investigative Body. (2013). *Cruise Ship COSTA CONCORDIA Marine casualty on January 13, 2012 Report on the safety technical investigation*.

McLeod, R. W. (2015). *Designing for human reliability: Human factors engineering in the oil, gas, and process industries*. Gulf Professional Publishing.

Meck, U., Strohschneider, S., & Brüggemann, U. (2009). Interaction Design in Ship Building: an Investigation Into the Integration of the User Perspective Into Ship Bridge Design. *Journal of Maritime Research*, *6*(1), 15-32.

Millar, I. C. (1980). The need for a structured policy towards reducing human-factor errors in marine accidents. *Maritime Policy & Management*, *7*(1), 9-15.

Mitroussi, K. (2004). Quality in shipping: IMO's role and problems of implementation. *Disaster Prevention and Management*, *13*(1), 50-58.

Morgan, B. B. J., Glickman, A. S., Woodard, E. A., Blaiwes, A. S., & Salas, E. (1986). *Measurement of Team Behaviors in a Navy Environment*.

Nehls, K., Smith, B. D., & Schneider, H. A. (2015). Video-conferencing interviews in qualitative research. In S. Hai-Jew (Ed.), *Enhancing qualitatative and mixed methods research with technology*. IGI Global.

Nilsen, M., Almklov, P., Haugen, S., & Bye, R. J. (2016). A discussion of risk influencing factors for maritime accidents based on investigation reports.*Risk, reliability and safety: innovating theory and Practice: proceedings of ESREL 2016* ESREL 2016, Glasgow, Scotland, 25–29 September 2016.

Nordby, K., Frydenberg, S., & Fauske, J. (2018). *Demonstrating a maritime design system for realising consistent design of multi-vendor ship's bridges* RINA - International Conference on Human Factors, London, UK.

Nordby, K., Mallam, S. C., & Lützhöft, M. (2019). Open user interface architecture for digital multivendor ship bridge systems. *WMU Journal of Maritime Affairs*, *18*, 297-318.

Nordby, K., Schaathun, H. G., Gernez, E., & Lurås, S. (2018). A Conceptual Framework for Reporting Field Research for Design in the Maritime Industries. *The International Journal of Marine Design*.

Norman, D. A. (2013). *The design of everyday things* (Rev. and exp. ed. ed.). Basic Books.

Norris, A. (2007). AIS Implementation – Success or Failure? . *Journal of Navigation*, *60*(1).

Norwegian Maritime Authority. (2022a). *About us*. Retrieved 08.06.22 from https://www.sdir.no/en/about-us/

Norwegian Maritime Authority. (2022b). *Live ulykkesstatistikk*. Retrieved 15.06.22 from https://www.sdir.no/sjofart/ulykker-risiko-og-sikkerhet/ulykkesstatistikk/live-ulykkesstatistikk/

Olsson, E., & Jansson, A. (2006). Work on the bridge - studies of officers on high-speed ferries. *Behaviour and Information Technology*, *25*(1), 37-64.

Oltedal, H. A., & Lützhöft, M. (2018). *Managing Maritime Safety*. Routledge.

Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & De Colle, S. (2010). Stakeholder theory: The state of the art. *Academy of Management Annals*, *4*(1), 403-445.

Parsons, J., & Allen, C. (2018). The history of safety management. In H. A. Oltedal & M. Lützhöft (Eds.), *Managing maritime safety*. Routledge.

Petersen, E. S., Dittmann, K., & Lutzhoft, M. (2011). Making the phantom real: a case of applied maritime human factors. 3rd International Symposium on Ship Operations, Management and Economics 2011,

Petersen, E. S., Nyce, J. M., & Lützhöft, M. (2015). Interacting with classic design engineering. *Interacting with Computers*, *27*(4), 440-457.

Pomeroy, R. V., & Earthy, J. V. (2017). Merchant shipping's reliance on learning from incidents – A habit that needs to change for a challenging future. *Safety science*, *99*, 45-57.

Porathe, T. (2006). *3-D nautical charts and safe navigation* Mälardalen University]. Västerås.

Porathe, T. (2015). Human error and e-navigation: developing the nautical chart as reslient decision support. HCI International, Los Angeles, USA.

Porathe, T. (2016). A navigating navigator onboard or a monitoring operator ashore? Towards safe, effective, and sustainable maritime transportation: findings from five recent EU projects. *Transportation Research Procedia*, *14*(2352), 233-242.

Praetorius, G., Kataria, A., Petersen, E. S., Schröder-Hinrichs, J. U., Baldauf, M., & Kähler, N. . (2015). Increased awareness for maritime human factors through e-learning in crew-centered design. *Procedia Manufacturing*, *3*, 2824-2831.

Prison, J., Dahlman, J., & Lundh, M. (2013). Ship sense-striving for harmony in ship manoeuvring [Article]. *WMU Journal of Maritime Affairs*, *12*(1), 115-127.

Puisa, R., Lin, L., Bolbot, V., & Vassalos, D. (2018). Unravelling causal factors of maritime incidents and accidents. *Safety science*, *110*, 124-141.

Ralph, P., & Wand, Y. (2009). A proposal for a formal definition of the design concept. In *Design requirements engineering: A ten-year perspective* (pp. 103-136). Springer.

Read, G. J., Shorrock, S., Walker, G. H., & Salmon, P. M. (2021). State of science: Evolving perspectives on 'human error'. *Ergonomics,*, *64*(9), 1091-1114.

Reason, J. (1990). *Human error*. Cambridge university press.

Reason, J. (1997). *Managing the risks of organizational accidents*. Ashgate Publishing.

Reuters. (2021). *Factbox: The Ever Given's stranding in the Suez Canal*. Retrieved 23.09.21 from https://www.reuters.com/world/middle-east/ever-givens-stranding-suez-canal-2021-07-06/

Roesler, A., Woods, D. D., Schoenwald, J., Chapman, R., Feil, M., Puskeiler, A., & Tinapple, D. (2004). *Design tells (shares) stories about the future*.

Rothblum, A. M. (2000). Human error and marine safety. National Safety Council Congress and Expo, Orlando, FL.

Rumawas, V., & Asbjørnslett, B. E. (2014). A content analysis of human factors in ships design. *The International Journal of Maritime Engineering*, *156*, 251-264.

SAFETY4SEA. (2017). *Captain and pilot sentenced for City of Rotterdam collision*. SAFETY4SEA. Retrieved 08.03.2022 from https://safety4sea.com/captain-and-pilot-sentenced-for-city-of-rotterdam-collision/

Sandberg, J., & Tsoukas, H. (2015). Making sense of the sensemaking perspective: Its constituents, limitations, and opportunities for further development. *Journal of Organizational Behavior*, *36*, S6-S32.

Sandhåland, H., Oltedal, H., & Eid, J. (2015a). Situation awareness in bridge operations – A study of collisions between attendant vessels and offshore facilities in the North Sea. *Safety science*, *79*, 277-285.
Sandhåland, H., Oltedal, H. A., Hystad, S. W., & Eid, J. (2015b). Distributed situation awareness in complex collaborative systems: A field study of bridge operations on platform supply vessels. *Journal of Occupational and Organizational Psychology*, *88*(2), 273-294.
Schneider, B. (2007). Design as practice, science and research. In R. Michel (Ed.), *Design research now: essays and selected projects*. Birkhäuser.
Schröder-Hinrichs, J.-U., Hollnagel, E., & Baldauf, M. (2012). From Titanic to Costa Concordia—a century of lessons not learned. *WMU Journal of Maritime Affairs*, *11*, 151-167.
Schröder-Hinrichs, J.-U., Hollnagel, E., Baldauf, M., Hofmann, S., & Kataria, A. (2013). Maritime human factors and IMO policy. *Maritime Policy & Management*, *40*(3), 243-260.
Schröder-Hinrichs, J.-U., Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. (2016). Introducing the Concept of Resilience into Maritime Safety. 6th Symposium on Resilience Engineering, Lisbon, Portugal.
Schröder-Hinrichs, J. U., Baldauf, M., & Ghirxi, K. T. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. *Accident Analysis and Prevention*, *43*, 1187-1196.
Sevaldson, B. (2010). Discussion and movements in design research. *FORMakademisk*, *3*(1), 8-35.
Simon, H. A. (1969). *The Sciences of the Artificial*. M.I.T. Press.
Smithson, J. (2000). Using and analysing focus groups: limitations and possibilities. *International Journal of Social Research Methodology*, *3*(2), 103-119.
Snook, S. A. (2000). *Friendly fire: The accidental shootdown of U.S. Black Hawks over Northern Iraq*. Princeton University Press.
Sternberg, R. J. (1999). A propulsion model of types of creative contributions. *Review of general psychology*, *3*(2), 83-100.
Strazdins, G., Komandur, S., & Bjørneseth, F. B. (2014). Towards Tactile Alarms Systems for Increased Awareness in Smart Environments.
Størkersen, K. V. (2015). Survival versus safety at sea. Regulators' portrayal of paralysis in safety regulation development. *Safety science*, *75*, 90-99.
Sørensen, L., Lützhöft, M., & Earthy, J. (2018). Solas V/15 - Bridging design and work. RINA, Royal Institution of Naval Architects - International Conference on Human Factors 2018,
The Nautical Institute. (2022). *HE-Alert!* The Nautical Institute. Retrieved 17.11.2022 from https://www.nautinst.org/technical-resources/he-alert.html
Tjora, A. (2018). *Kvalitative forskningsmetoder i praksis* (3 ed.). Gyldendal akademisk.
Tosi, F. (2020). From User-Centred Design to Human-Centred Design and the User Experience. In *Design for Ergonomics* (pp. 47-59). Springer.
Townsend, K., & Burgess, J. (2009). *Method in the madness: reserach stories you won't read in textbooks*. Chandos Publishing.
Trevino, L. K., & Weaver, G. R. (1999). The stakeholder research tradition: Converging theorists—not convergent theory. *Academy of management review*, *24*(2), 222-227.
UNCTAD. (2022a). Retrieved 03.03.2022 from https://unctad.org/webflyer/review-maritime-transport-2021
UNCTAD. (2022b). *UNCTAD Handbook of statistics 2021*. UNCTAD. https://hbs.unctad.org/merchant-fleet/
van de Merwe, F., Kähler, N., & Securius, P. (2016). Crew-centred design of ships–the CyClaDes project. Transport Research Arena,
Vu, V.-D., & Lützhöft, M. (2018). Improving maritime usability - user-led information grouping on navigational displays. Human Factors,
Vu, V. D., & Lützhöft, M. (2020). Improving human-centred design application in the maritime industry - challenges and opportunities. Human Factors, London, UK.

Vu, V. D., Lützhöft, M., & Emad, G. R. (2019). Frequency of use–the first step toward human-centred interfaces for marine navigation systems. *J. Navig*, *72*, 1089-1107.

Wahl, A. M., & Kongsvik, T. (2018). Crew resource management training in the maritime industry: a literature review. *WMU Journal of Maritime Affairs 17*, 377-396.

Wahyuni, D. (2012). The research design maze: understanding paradigms, cases, methods and methodologies. *Journal of applied management accounting research*, *10*(1), 69-80.

Walters, D., & Bailey, N. (2013). *Lives in Peril: Profit or Safety in the Global Maritime Industry?* Palgrave MacMillan.

Weick, K. E. (1995). *Sensemaking in organizations*. Sage.

Weick, K. E. (2010). Reflections on enacted sensemaking in the Bhopal disaster. *Journal of Management Studies*, *47*(3), 537-550.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organization science*, *16*(4), 409-421.

Wilkinson, G. R. (1971). Wheelhouse and bridge design. *Journal of Navigation*, *24*(3), 313-324.

Wood, D. J., Mitchell, R. K., Agle, B. R., & Bryan, L. M. (2021). Stakeholder Identification and Salience After 20 Years: Progress, Problems, and Prospects. *Business & Society*, *60*(1), 196-245.

Woods, D. D., Dekker, S., Cook, R., Johannesen, L., & Sarter, N. (2010). *Behind human error* (2 ed.). Ashgate Publising Ltd.

Wròbel, K. (2021). Searching for the origins of the myth: 80% human error impact on maritime safety. *Reliability Engineering and Syatem Safety*, *2016*, 107942.

Yin, R. K. (2016). *Qualitative research from start to finish* (2 ed.). The Guildford Press.

Yin, R. K. (2018). *Case study research and applications: design and methods* (6e ed.). SAGE Publications.

Österman, C. (2013). Beyond the ethic case: a value proposition of proactive human factors management. *AMET Maritime Journal*, *1*, 14-41.

Österman, C., Berlin, C., & Bligård, L.-O. (2016). Involving users in a ship bridge re-design process using scenarios and mock-up models. *International Journal of Industrial Ergonomics*, *53*, 236-244.

Österman, C., Ljung, M., & Lützhöft, M. (2009). Who Cares and Who Pays?: The Stakeholders of Maritime Human Factors. Human Factors, Royal Institute of Naval Architects.

Österman, C., & Rose, L. (2015). Assessing financial impact of maritime ergonomics on company level: a case study. *Maritime Policy & Management*, *42*(6), 555-570.

Österman, C., Rose, L., & Osvalder, A.-L. (2010). Exploring maritime ergonomics from a bottom line perspective. *WMU Journal of Maritime Affairs*, *9*(2), 153-168.

Appendix 1: Declaration of authorship

I have been the primary author of all articles included in this thesis. An overview of the co-authors' contributions are given in Table 4. The author contributions are divided into the following tasks:

A. Initial research idea and concept
B. Data collection
C. Data analysis
D. Writing and design of the draft of the article
E. A critical review of the article

Table 4. Overview of the contributions from each author to the publications included in this thesis.

Author	Article				
	I	II	III	IV	V
Brit-Eli Danielsen	A-E	A-E	A-E	A-E	A-E
Margareta Lützhöft		C,D,E		D,E	
Thomas Porathe		E		E	
Torgeir Kolstø Haavik				E	
Stig Ole Johnsen				B,E	
Erik Styhr Petersen					C,D,E

Appendix 2: Interview guides

Two interview guides are included, the first one was used during the initial ship visits, while the second one was used during the last round of interviews.

Interview guide ship visits

Presentation of myself, phd project and research interest.
Information about data management, informed consent.

What is your background, education and previous experience (ships/equipment), how long on this ship?
Tour of the bridge, crew to describe layout, equipment.
What is your opinion about this bridge, overall and specific equipment (design of interfaces, screens, buttons)
When was this bridge installed, has there been small/big changes since then?
Who decides when new equipment shall be installed and where?
Where can you give feedback about ship bridge equipment?
Have you been involved in any design processes?
What are your most important tasks?
Alarm management?
Is it easy to find the information you need?
Does this [system/design/instrument/layout] ever cause you problems when you are trying to do your job?
Can the layout or equipment design be annoying/confusing?
Are there examples of good design, equipment, interfaces that you prefer, why?

What does the term *seamanship* or *good seamanship* mean to you?
Is it still relevant?
Has it changed with in line with the technology development?

Things to have in mind during observation:

Layout, equipment (from which vendors), proximity, grouping, adaptations (written notes, covers, dimming arrangements, buttons not in use), ergonomics: possibility for adjusting distance, height, dimming.

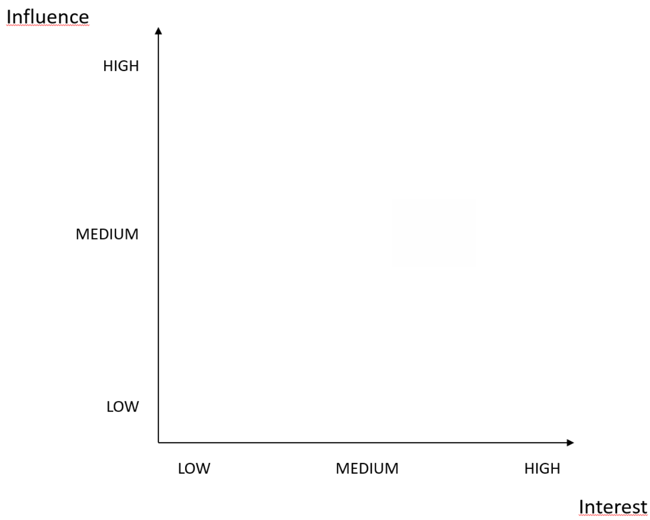
- vibration
- noise
- light
- heating
- ventilation
- temperature
- humidity
- surfaces
- dimensions workstations

- Readability
- Intuitiveness
- Consistency
- Logical grouping
- Clarity of language
- Feedback
- Memory load
- Equally catering for novices and experts
- User control

Interview guide stakeholders

Presentation of myself, phd project and research interest (how the different stakeholders are involved directly or indirectly in ship bridge design, from regulators to other actors - shipyards, shipowners, equipment manufacturers etc.)
Information about data management, informed consent.

Describe your position (what do you do on a typical day) and background?
Show influence/interest diagram.
(Influence: role, formal and informal influence, relations to other stakeholders, resources, knowledge - Interest: role, goal, impact on, affected by)



If you think about the newbuild phase and the ship bridge design in particular– where would you put your organization in this chart?

Why?

What kind of influence does your organization have? What do you do? When?

What kind of interest does your organization have?

Do you think your placement in the chart should be somewhere else? Where?

Is it possible to move there? Why would that be difficult? What could enable that move?

What about the other actors influencing direct or indirect the ship bridge design, where would they be in this chart? (Shipyard, shipowner, equipment manufacturer, classification company, flag state, end-users)

Appendix 3: Thematic Analysis

This appendix describes the analysis process of the data from the seafarer group (n=21). The data, in the form of field notes and transcribed interviews, were uploaded to the software NVivo. The initial codes were generated by reading through the material and selecting segments of text that seemed interesting with regard to the research questions. This resulted in 251 initial codes (due to the large number of codes they are not included in the appendix). Each code had 1-3 references in the text material. I didn't find NVivo to be very helpful after this step, so the codes were transferred to a Word document. The next step was to group the codes into themes, as shown in Figure a. This step resulted in 12 initial themes.

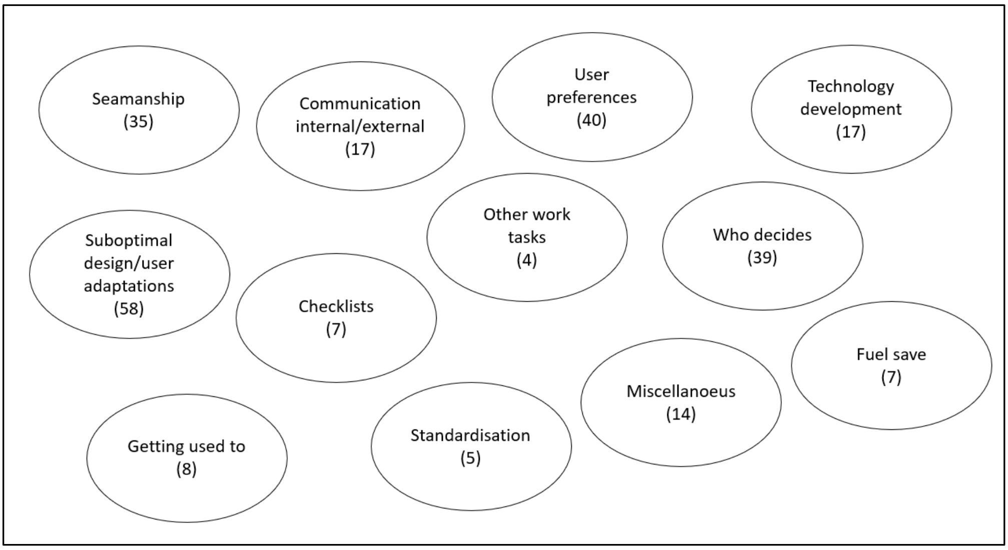


Figure a. The initial codes were grouped into themes. The number indicates the number of codes in each theme.

The themes were then reviewed, and it was decided that three of the initial themes would go on to form main themes, whereas others formed sub-themes, as shown in Figure b**Error! Reference source not found.**. The reason for themes to be become sub-themes was e.g., that it did not have enough data to support it, or two themes were considered to actually be one theme.

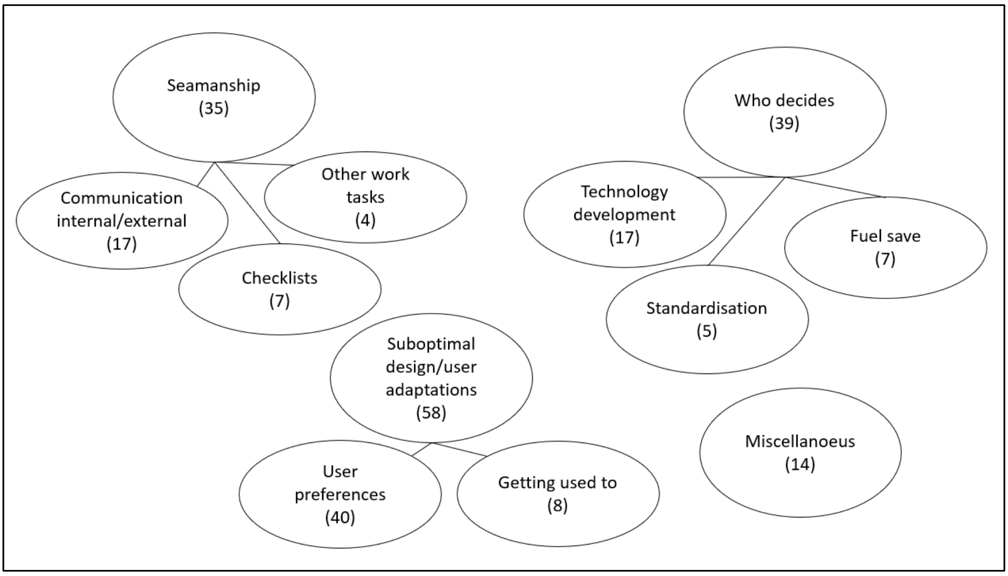


Figure b. Refinement of themes by choosing main themes and sub-themes.

The next step was defining and naming the main themes (Figure c). Two of these themes, "Seamanship as seafarers see it" and "Adaptation of and to bridge design" were the topic of Paper II, while "Influence on ship bridge design" was included in paper IV and V.

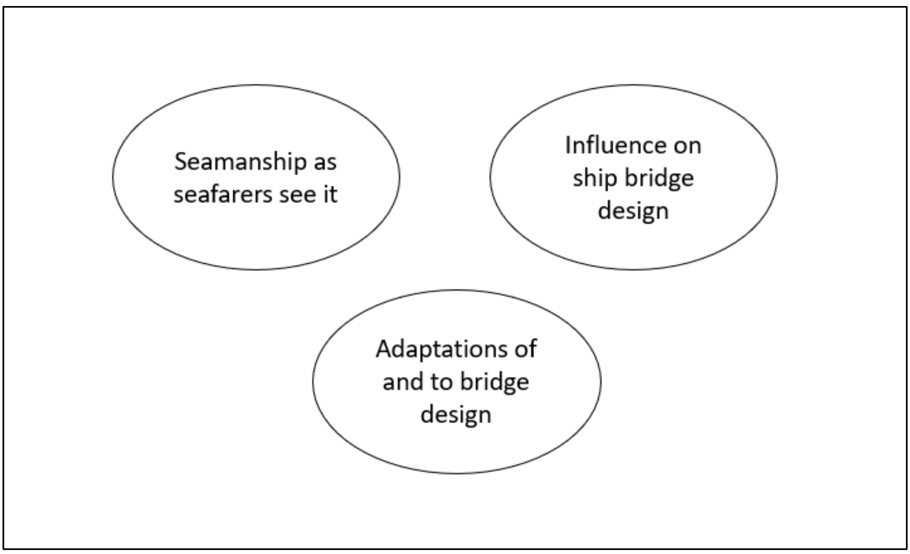


Figure c. The final three main themes from the seafarer group.

Appendix 4: Five research papers

Paper I
Danielsen, B.-E. (2021). Making sense of sensemaking in high-risk organizations. In S. O. Johnsen & T. Porathe (eds.), *Sensemaking in safety-critical and complex situations: Human Factors and Design*. CRC Press.

Paper II
Danielsen, B.-E., Lützhöft, M., & Porathe, T. (2021). Still unresolved after all these years: Human-technology interaction in the maritime domain. In: Stanton, N. (eds), *Advances in Human Aspects of Transportation*. AHFE 2021. 270, 463-470. Springer.

Paper III
Danielsen, B.-E. (2022). The contribution of ship bridge design to maritime accidents. In: Katie Plant and Gesa Praetorius (eds.), *Human Factors in Transportation*. AHFE 2022. 60, 714–722. Springer.

Paper IV
Danielsen, B.-E., Lützhöft, M., Haavik, T., Johnsen, S.O. & Porathe, T. (2022). "Seafarers should be navigating by the stars": Barriers to usability in ship bridge design. *Cognition, Technology & Work,* 24, 675–691.

Paper V
Danielsen, B.-E. & Petersen, E.S. (2022). Somebody else's problem? Usability in ship bridge design seen from the perspective of different maritime actors. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation,* 16 (4), 685-700.

Paper I

4 Making Sense of Sensemaking in High-Risk Organizations

B. E. Danielsen
NTNU

CONTENTS

INTRODUCTION

Safety in high-risk organizations is created by the everyday behavior of all employees in the organization – at all levels – as they go about getting their job done (Gregory & Shanahan, 2017). Sensemaking – the fundamental human quest for meaning – is the basis for human behavior, in formal organizations as well as life in general (Weick, Sutcliffe, & Obstfeld, 2005). Sensemaking has been an influential perspective in organization studies and is strongly associated with the work of Karl Weick and his change of focus from decision-making and organizational outcomes to how individuals and organizations make sense of or give meaning to events and experiences (Weick, 1995). Sensemaking research has intensified over the last decades; however, it has been scattered over several different domains with differing approaches. In relation to the extensive literature on sensemaking, this chapter is a brief review of the sensemaking literature to establish an understanding of the concept, especially how it is understood in the context of sharp-end operators in high-risk organizations. Mainly, work on the bridge of a maritime vessel is used as an example to illustrate sensemaking in a high-risk environment.

This chapter is structured as follows: The next section presents the overall concept of sensemaking, a definition of sensemaking and how it relates to decision-making and situation awareness (SA). Thereafter, the third section describes how sensemaking is understood as a cognitive process, followed by the fourth section describing some of the debated core aspects of the sensemaking concept. A review of the main factors influencing sensemaking is presented in fifth section. The sixth section discusses sensemaking in safety-critical situations before the last section concludes with a summary and thoughts about future research opportunities.

THE CONCEPT OF SENSEMAKING

Sensemaking seems self-explanatory as it literally means "the making of sense"; however, as a cognitive concept, it reaches beyond merely being another word for "understanding" or "interpreting" (Weick, 1995). Interpretation implies there is something in the environment to be discovered; however, sensemaking is not a passive diagnosis, it refers to the processes where people actively play a role in constructing the very situations they try to make sense of (Weick, 1995). "Sensemaking is about sizing up a situation while you simultaneously act and partially determine the nature of what you discover" (Weick & Sutcliffe, 2015, p. 32).

Sensemaking both precedes and follows decision-making (Maitlis, 2005). Sensemaking is about "the interplay of action and interpretation rather than the influence of evaluation on choice" (Weick et al., 2005, p. 409). Snook (2000) effectively describes how sensemaking differs from decision-making in his analysis of a friendly fire incident over Iraq in 1994 where two US Air Force F-15 fighters accidentally shot down two helicopters killing all 26 peacekeepers on board. Snook points out that the F-15 pilots did not "decide" to pull the trigger. They were trying to make sense of the situation they were in. Ambiguous stimuli and strong expectations made the pilots believe they saw an enemy helicopter, "seeing through the mind's eye" as Snook puts it. Blaming the pilots for making the wrong decision would mean overlooking the "potent situation factors that influence action. Framing the individual-level puzzle as a question of meaning rather than deciding shifts the emphasis away from individual decision makers toward a point somewhere 'out there' where context and individual action overlap" (Snook, 2000, p. 207). Snook emphasizes that the individual sensemaking occurs as an interplay with the environment or embedded in context. To view human actions as a struggle to make sense rather than decision-making makes way for a more complete account for all relevant factors contributing to an accident, not merely individual judgment or "human error". It promotes a view of humans as "good people struggling to make sense" rather than "bad ones making poor decisions" (Snook, 2000, p. 207).

Sensemaking also differs from the widely used concept of SA (Endsley, 1995). SA is an individually achieved state of knowledge, based on the perception of elements in the environment and the comprehension of their meaning, which is used to make predictions about the future (Endsley, 1995). In contrast, the study of sensemaking is about the process of achieving these kinds of outcomes. Where SA seems to describe a more passive perception of data, sensemaking is about how people actively construct what counts as data in the first place (Klein, Phillips, Rall, & Peluso, 2007). The SA construct has been important within human factors research; it has been widely studied across many different domains. Still, it has been regarded as problematic that missing cues or displayed information is commonly described as "loss of situation awareness". This way of representing SA as a construct in the mind has made it possible to blame sharp-end operators for mishaps because they made the mistake of losing their SA (Dekker, 2015).

Sensemaking Definition

There is no unified definition of sensemaking. In the research literature it is often used without an associated definition, and when explicitly defined it is given a variety of meanings (Maitlis & Christianson, 2014). In their comprehensive literature review, Maitlis and Christianson (2014, p. 67) developed a definition of sensemaking rooted in recurrent themes across sensemaking definitions:

> a process, prompted by violated expectations, that involves attending to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn.

The various aspects on sensemaking from this definition will be discussed below.

THE SENSEMAKING PROCESS

Sensemaking understood as a cognitive process has been described as consisting of three interrelated processes: *creation, interpretation and enactment* (Sandberg & Tsoukas, 2015). The creation process involves noticing and extracting *cues* from our lived experience, creating an initial sense of the situation. In the interpretation process, the initial sense is then interpreted to a more complete and narratively organized sense of the situation. Following the interpretation process, the enactment process involves acting on the sense made. The actions create a slightly different or new environment to continue to make sense of (Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2015). This meaning-action process is an ongoing cycle and sensemaking never starts or stops as people are in an "almost infinite stream of events and inputs" (Weick et al., 2005, p. 411).

Triggers for Sensemaking

What makes something from this stream of events noticed and carved out as a cue for sensemaking? The sensemaking literature finds that issues, events or situations become triggers for sensemaking when they are ambiguous, interrupt people's ongoing activity, make them realize the inadequacy of their current understanding and create uncertainty about how to act (Klein et al., 2007; Maitlis & Christianson, 2014). The events triggering organizational sensemaking range from minor to major events and they may be planned or unplanned (Sandberg & Tsoukas, 2015). A triggering event does not necessarily emerge unexpectedly, it may be constructed by the actors themselves, e.g. by noticing or failing to notice cues (Ibid.). Cues are "seeds from which people develop a larger sense of what may be occurring" (Weick, 1995, p. 50).

Sometimes vague cues are not noticed, other times cues are significant enough to be noticed but still do not trigger sensemaking. Instead, they are accommodated, explained away or normalized (Maitlis & Christianson, 2014). How it makes sense to explain away cues is thoroughly described in Lützhöft and Dekker's (2002) analysis of the grounding of the *Royal Majesty* east of Nantucket in 1995. The ship lost her satellite signals just after departure from Bermuda and the GPS forwarded estimated positions to the autopilot. This went unnoticed by the crew as the automated bridge functions supported their mental model of a safe trip following the planned track to Boston. The crew explained away or did not attend to cues emerging along the way that would indicate a different story, like lookout reports and warning broadcasted on VHF. On June 10, 1995 she ran aground 17 nautical miles from her planned track towards Boston.

The study of sensemaking has mainly been confined to study episodes where an ongoing activity has been interrupted and need to be restored (Sandberg & Tsoukas, 2015). According to Sandberg and Tsoukas (2015), this is problematic as specific episodes certainly are an aspect of organizational life, but most of the time organizational life consists of routine work where people do things without deliberately thinking about how they do them. This does not mean that routine work is senseless, rather that people are involved in mundane or *immanent* sensemaking (Sandberg & Tsoukas, 2015). This is sensemaking as people are immersed in practice without being consciously aware of it, and they spontaneously respond to the situation as it develops. Sandberg and Tsoukas (2015) argue that the study of immanent sensemaking is as a way forward to extend the sensemaking concept. This line of enquiry would correspond to the safety II perspective on safety where the focus is on the everyday performance where things go right under varying conditions (Hollnagel, Woods, & Leveson, 2006).

Sensemaking and Enactment

Enactment is not only a stage in the sensemaking process but at the very core of the sensemaking concept (Sandberg & Tsoukas, 2015; Weick, 1988, 1995). Action is an integral part of sensemaking as it is a part of gathering more information about the situation at hand. Action can test the initial sense made as well as shape the environment for sensemaking. "What the world is without our enacting is never known since we fiddle with that world to understand it" (Weick pers. comm. cited in Klein et al., 2007, p. 122).

Sensemaking in a developing crisis can both be helpful and harmful as action can alter the environment in unexpected ways. Crises and unexpected events are situations difficult to comprehend, and the situation may require people to take action with incomplete information (Maitlis & Christianson, 2014). Enactment is central in Weick's analysis of a Union Carbide gas leak that occurred in Bhopal in 1984. Early action may determine the trajectory of the crisis, "Had they not acted or had they acted differently, they would face a different set of problems, opportunities and constraints" (Weick, 1988, p. 309). Enactment is especially difficult in complex systems where changes in one part have less predictable effect on other parts, there may be a delay in the effects of action and small actions can result in big and surprising effects (Maitlis & Christianson, 2014).

The Outcome of the Sensemaking Process

The outcome of the sensemaking process is "a more ordered environment from which further cues can be drawn" (Maitlis & Christianson, 2014, p. 67). The specific sense made is seen as a springboard for the actions people take to attempt to restore an interrupted activity. However, the sense made does not need to be an accurate account of the situation at hand. According to Weick "perceptual accuracy is grounded in models of rational decision-making" (Weick, 2005, p. 415). Sensemaking is not about discovering the truth and achieving a correct understanding, it is about "continuing redrafting of an emergent story" and it is "driven by plausibility rather than accuracy" (Weick, 1995, p. 55). As such, the endpoint for sensemaking is not a full comprehension of the situation or system at hand, it is a dynamic process occurring in a dynamic, changing environment (Klein et al., 2007). The sensemaker only needs a plausible explanation or narrative sufficient enough to continue their activity (Weick, 1995): "To deal with ambiguity, interdependent people search for meaning, settle for plausibility, and move on" (Weick et al., 2005, p. 419).

ASPECTS OF SENSEMAKING

There are different fundamental assumptions about the sensemaking concept found in the literature. The temporal orientation has been a subject for debate as well as whether sensemaking is primarily an individual cognitive process or a social construction of intersubjective meaning where language is the locus of sensemaking (Maitlis & Christianson, 2014).

Sensemaking and Temporal Orientation

Weick (1995) listed *retrospective* as one of the seven distinct properties of sensemaking. Sensemaking rationalizes what people have done as they look back on action that has already taken place (Maitlis & Christianson, 2014; Weick, 1995). According to Weick people can know what they are doing only after they have done it. "The creation of meaning is an attentional process, but it is attention to that which has already occurred" (Weick, 1995, p. 26). Changes or cues in the environment are noticed when looking back over previous experience and seeing a pattern (Weick, 2005). As part of retrospective sensemaking, forward looking sensemaking has been explained as "future perfect" thinking where a future event is imagined and made sense of as if it had already occurred. However, in recent years, researchers have argued that sensemaking can also be prospective or future oriented (Gephart, Topal, & Zhang, 2011; Klein, Wiggins, & Dominguez, 2010; Rosness, Evjemo, Haavik, & Wærø, 2016) or be seen as drawing on all three dimensions (past, present and future) of sensemaking (Maitlis & Christianson, 2014).

Sensemaking and Language

Over time Weick has developed the notion of sensemaking in a way that gradually removed it from its cognitivist origins into a social constructivist perspective (Sandberg & Tsoukas, 2015). In this perspective, sensemaking is understood as being more fundamentally concerned with language (Maitlis & Christianson, 2014; Weick et al., 2005). The focus on language or linguistic factors has increased over the last two decades (Sandberg & Tsoukas, 2015). Language is a central part of organizational life as most social contact is mediated through talk and conversations. "Situations, organizations, and environments are talked into existence" (Weick et al., 2005, p. 409) and turning the flow of organizational circumstances into words and categories is central in sensemaking (Weick et al., 2005). Some scholars especially highlight narratives as the primary site from where experiences are made meaningful. Narratives are used to define individual and collective identities, and there may be several different narratives existing in an organization which contributes to people interpreting differently experiences they have in common (Brown, Stacey, & Nandhakumar, 2008; Maitlis & Christianson, 2014). Although the focus on language is connected to understanding sensemaking as the construction of intersubjective meaning rather than primarily as an individual cognitive process (Maitlis & Christianson, 2014), sensemaking can be understood as both an individual and a social process. According to Weick (1995) "sensemaking is grounded in both individual and social activity", and it might not even be possible to separate the two.

FACTORS INFLUENCING SENSEMAKING

As "people can make sense of anything" (Weick, 1995, p. 49), there is an infinite number of factors that can influence sensemaking. In this section, some of the central factors from the sensemaking literature is reviewed; emotions, embodied sensations, social context, identity, technology and meaningfulness through work (Maitlis & Christianson, 2014; Maitlis & Sonenshein, 2010; Sandberg & Tsoukas, 2015; Weick, 1995).

Sensemaking and Expectations

Sensemaking has often been described as a response to a surprise – a failure of expectations (Klein et al., 2007). Expectations can be both enabling or constraining for sensemaking (Weick, 1995). The discrepancy between expectations and reality must be of a certain magnitude or importance to cause people to wonder what is going on and trigger sensemaking (Maitlis & Christianson, 2014).

It can either be an unexpected event or the non-occurrence of an expected event. The experience of how significant a discrepancy feels is highly subjective; it can depend on the "impact on individual, social, or organizational identity … and personal or strategic goals" (Maitlis & Christianson, 2014, p 70). It can also vary from moment to moment depending on emotions and identity construction (Weick, 1995).

In Weick's (1993) analysis of the Mann Gulch fire where 13 firefighters died, the firefighters expected a "10:00 fire", which meant it would be relatively easy to manage and be under control by 10:00 the next morning. This image stuck with them and prevented them from making sense of new cues as they emerged. Expectations were also an important part of the individual-level analysis of a friendly fire incident by Snook (2000). The F-15 fighter pilots had not been informed about the friendly helicopters when they entered what was designated as a "combat zone". Due to range, angle and speed of the fighters, the visual stimulus was ambiguous. As they flew close to the friendly helicopters a second time to confirm the sighting, they saw what they expected to see – the enemy.

Sensemaking and Emotions

Extensive research has found that the interplay between emotions and cognition influence who we are, what we do and the decisions we make (Norman, 2019). Emotions were initially ignored in sensemaking studies but have gradually been expanding in the recent years (Sandberg & Tsoukas, 2015). On both individual and collective levels, emotions have increasingly been understood to influence the sensemaking process, "whether sensemaking occurs, the form it takes, when it concludes, and what it accomplishes" (Maitlis & Christianson, 2014, p. 100).

Emotions in crisis are often strong and negative like anxiety fear, panic and desperation. The arousal these emotions trigger in the autonomous nervous system can consume cognitive information processing capacity, which in turn reduces the number of cues that can be noticed and become triggers for sensemaking (Maitlis & Sonenshein, 2010). As seen in the Mann Gulch incident when people are put under life-threatening pressure, they return to well-learned, habituated ways of responding, like flight (Weick, 1993). Positive felt emotions may "broaden individuals' scope of attention and their thought–action repertoires" (Maitlis & Sonenshein, 2010, p. 568). This should lead to a sensemaking process that can contribute to positive outcomes, averting crisis and accidents. However, overly positive emotions may cause people to be overly optimistic and overlook important cues and misinterpret the situation (Maitlis & Sonenshein, 2010). Hence, moderately intense emotions, strong enough to be noticed but not to distract and consume cognitive resources, seem to support sensemaking (Maitlis & Sonenshein, 2010).

Embodied Sensemaking

As sensemaking has been conceptualized as a deliberate process confined to specific episodes, research on sensemaking has mainly concerned the cognitive or linguistic sphere. However, over the recent years, focus on embodied sensemaking has emerged (Maitlis & Christianson, 2014). This research is connected to cognitive science and the related embodied cognition, where cognition, body, and context are viewed as three interrelated concepts that are in constant interaction with each other (Fahim & Rezanejad, 2014). Cunliffe and Coupland (2012) argued that "embodiment is an integral part of sensemaking" (Cunliffe & Coupland, 2012, p. 64) and that we make sense of our lives and ourselves through embodied interpretations of our ongoing everyday interactions and experiences. They theorized the process as "embodied narrative sensemaking". Through an analysis of rugby players, they demonstrated how the players made sense of their surroundings and experiences in sensory as well as cognitive ways; "sensemaking is not necessarily an information-processing activity but draws on an intuitive and informed feeling in his body – he senses the lines of force, the distance, his adversaries' positions on the field, and his critics off the field" (Cunliffe & Coupland, 2012, p. 77). They argue that we cannot separate our bodies from the context, in addition to the cognitive sphere "organizing also operates on a sensory level through sensory knowing and bodily sensations" (Cunliffe & Coupland, 2012, p. 83).

Embodied sensemaking is interesting in a maritime context where navigating a ship involves working in a highly dynamic environment. The form of tacit knowledge needed to maneuver a ship has been referred to as ship sense (Prison, Dahlman, & Lundh, 2013). Ship sense is presumed to play an important role in the dynamic interaction between the ship and the navigator. The navigator must handle the ship's distinctive maneuverability and the navigation instruments available, as well as account for the dynamic factors such as wind, waves, current and visibility that affect each other and the ship. When sailing in open sea with strong winds and high sea-state, the autopilot may be deliberately disengaged in order to steer the ship manually, and the more implicit knowledge to "get a feel for" the ship's movement becomes important. Both visual and other senses are engaged to feel the heaving motions of the vessel in the sea. Ship sense is needed to know when to take action, like slowing down or slightly altering course in relation to the direction of the oncoming waves (Prison et al., 2013), thus it is vital for the safety at sea.

Sensemaking Is Social

A lot of peoples' activities in organizations are concerned with collective efforts to make sense. Weick (1995) describes sensemaking as a social process where people actively shape each other's meanings. Sensemaking is never solitary as peoples' internal constructions or thoughts are created through interaction with others. In organizations "decisions are made either in the presence of others or with the knowledge they will have to be implemented, or understood, or approved by others" (Weick, 1995, p. 39). Sensemaking can thus be seen as unfolding between individuals as intersubjective meaning is constructed through a joint process of building understanding together (Maitlis & Christianson, 2014).

However, shared meaning is difficult to attain. People can share experiences although the sense made of it may differ significantly. For organizations, it is not even necessary that people share meanings to be able to coordinate action. It is sufficient to have minimal shared understanding or equivalent meanings (Brown et al., 2008;

Weick, 1995). Brown et al. (2008) were interested in why people interpret shared experiences differently. They explored the shared and discrepant sensemaking of members of a work team and argued that "although sensemaking is inherently social, it is fundamentally tied to processes of individual identity generation and maintenance" (Brown et al., 2008, p. 1037).

The social aspect of sensemaking is also understood by the sensemaking-related construct *sensegiving*, defined as "attempting to influence the sensemaking and meaning construction of others toward a preferred redefinition of organizational reality" (Gioia & Chittipeddi, 1991, p. 442). Organizational members may try to shape the sensemaking of others. Studies have shown that organizational leaders attempting to strategically shape the sensemaking of other organizational members do not necessarily succeed. Organizational members are not passive recipients of meaning; they engage in their own sensemaking and may actively resist the effort from leaders or alter the meanings conveyed to them (Maitlis & Christianson, 2014).

Sensemaking and Identity

Weick (1995) described sensemaking as being "grounded in identity construction" and that sensemaking begins with a self-conscious sensemaker. He argued that identities are constructed out of the process of interaction. "People learn about their identities by projecting them into an environment and observing the consequences" (Weick, 1995, p 23). Identity is thus not constant, as people experience a changing sense of self as they shift among interactions and try to decide which self is appropriate in the current situation (Weick, 1995). When the situation is ambiguous or confusing, sensemaking often occurs in ways that respond to people's identity needs (Weick, 2005). Sensemaking is part of maintaining a consistent, positive self-conception: "What the situation means is defined by who I become while dealing with it or what or who I represent" (Weick, 1995, p. 24). However, the direction of causality goes both ways: identity influences sensemaking but sensemaking also influences the definition of self.

The importance of identity for sensemaking becomes especially evident in organizational crises or change, when identity might be threatened (Maitlis & Sonenshein, 2010). A threatened identity may constrain action, as seen in Weick's (1993) analysis of the Mann Gulch fire. The foreman realized the severity of their situation and told the retreating crew to throw away their tools; however, without their tools they would turn "from a team of firefighters to a group of endangered individuals who were running from a fire without their tools" (Maitlis & Sonenshein, 2010, p. 563). Identity was also a contributing factor in the Westray mine disaster analyzed by Wicks (2001). Wicks found that institutionalization of a harmful mindset of invulnerability, e.g. they identified themselves as "real men", "going where few men would dare to go" (Wicks, 2001, p. 681), blinded them from seeing and preventing the risks in their work.

Sensemaking and Technology

Sensemaking has been described as influenced by technology, particularly information and communication technologies; however, there are relatively few studies on this topic (Bisio, Bye, & Hurlen, 2019; Sandberg & Tsoukas, 2015). Organizational sensemaking is influenced by the medium of communication where people in organizations interact or the introduction of new technology triggers sensemaking about the technology itself or sensemaking related to professional identity (Sandberg & Tsoukas, 2015). As such, technology sensemaking has been treated as a subset of organizational sensemaking, focusing on sensemaking of the technological phenomenon in organizations rather than addressing how technological materiality influence sensemaking (Mesgari & Okoli, 2019).

There are sensemaking research strands mainly concerned with information seeking and the use of information technology. Sensemaking in the field of human–computer interaction (HCI) is concerned with tools for retrieving and visualizing information, how people make sense of complex sets of information and their ability to create and shape external representations of knowledge (Russell, Stefik, Pirolli, & Card, 1993). In Library and Information Science (LIS), the central sensemaking activities are information seeking, processing, creating, and using (Dervin, 1998). Today web-based tools have enabled people to seek and access large amounts of information, thus, the LIS and HCI communities have seen the need to start converging on projects "to help people make sense of the information resources now available" (Russell, Convertino, Kittur, Pirolli, & Watkins, 2018, p 3). Although sensemaking in organizations, like sensemaking on the bridge of a vessel, also includes information seeking and the use of information technology, these research strands do fully consider the context; the many different technological applications as well as the broader sociotechnical work environment.

How technology is influencing sharp-end operator's sensemaking can, for instance, be observed in the maritime sector. There has been a steady increase in digitalized products, applications and services introduced to this domain. The role and tasks of navigators have gone from navigating the vessel by means of manual control to increasingly having the role as managers of automated systems (Lützhöft, Grech, & Porathe, 2011). The navigators work has changed to increasingly become more and more dependent on *representations* of the outside world, making sense of an increasingly digitalized context (Danielsen & Lamvik, 2019).

Despite the increase in digitalized products, advanced automated systems and sensors on ships introduced to increase safety, there is still a high number of accidents at sea. Although shipping is becoming safer every year, in terms of the number of ships lost (Porathe, Hoem, Rødseth, Fjørtoft, & Johnsen, 2018), the European Maritime Safety Agency reported 3174 casualties and incidents in 2018 alone (EMSA, 2019).

Already in the mid-1980s, scholars described the challenges emerging in the work cooperation between people and technology (Bainbridge, 1983; Morgan Jr, Glickman, Woodard, Blaiwes, and Salas, 1986). Morgan et al. (1986) found that the interaction between individuals in a navy bridge team was partly determined by interaction with machines and machine procedures which left too little room for communication and cooperation between the team members. They argued that standardized performance of tasks can weaken the mechanisms that create the dynamics and flexibility presumed to strengthen a team's capacity to handle uncertainty and ambiguity – the very core situations that trigger sensemaking.

There are many examples where the interaction with electronic navigation equipment contributes to incidents and accidents (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013; Nilsen et al., 2017). The grounding of Royal Majesty earlier in this chapter is one example. Another example is the grounding of the Spain-registered bulk carrier *Muros* in 2016, as it was on passage between Teesport, UK, and Rochefort, France (MAIB, 2017). Although the route was planned and monitored using the vessel's Electronic Chart Display and Information System (ECDIS), the "system and procedural safeguards intended to prevent grounding were either overlooked, disabled or ignored" (MAIB, 2017, p. 20). For example, the track over Haisborough Sands was not planned or checked in an appropriate scale chart and the audible alarm and guard zone was disabled. The report states that "The ECDIS on board Muros had not been used as expected by the regulators or equipment manufacturers" (MAIB, 2017, p. 22). The latter sentence demonstrates a gap between how regulators and equipment manufacturers imagine work on board a maritime vessel is performed and how the seafarers actually go about solving their daily tasks. As the design of maritime technology often lack usability (Lützhöft & Vu, 2018), it hampers rather than help the navigator's sensemaking.

Despite today's extensive knowledge about how design of technology influence work performance and safety, the human–technology interaction problems persist (Strauch, 2017). Part of the challenge in the maritime sector is the many stakeholders and processes involved in the design of a ship's bridge, like regulations, shipowners, classification companies, designers and equipment manufacturers (Johnsen, Kilskar, & Danielsen, 2019; Jones, 2009; Lützhöft & Vu, 2018; Meck, Strohschneider, & Brüggemann, 2009; Merwe, 2016).

Sensemaking and Meaningfulness through Work

The increasing digitalization and automation of work is a general trend in our society. In the maritime sector, the development from a being a navigating navigator to a monitoring operator of automated systems may have unintended consequences. Introduction of new technology, automated systems and increasing proceduralization of work are seen by experienced seafarers as "marginalisation of professional competence, skills and judgements" (Kongsvik, Haavik, Bye, & Almklov, 2020). Work is a central human activity and meaningful work is a fundamental human need (Yeoman, 2014). Does it make sense to have a job where you are reduced to a set of eyes and ears, where a particular sensory input should trigger the use of a particular procedure? What makes work meaningful? Sensemaking is also the tool for which people experience their work as meaningful. Individual's perceptions of the significance of their work, experiencing a sense of purpose through their work efforts, are contributing to the experience of meaningful work (Rosso, Dekas, & Wrzesniewski, 2010). In turn, the meaning of work influences work motivation, behavior and performance (Rosso, Dekas, & Wrzesniewski, 2010) which are all crucial for safety in organizations (Gregory & Shanahan, 2017). The increasing automation of the workplace not only causes problems like human out-of-the-loop (Endsley & Kiris, 1995), automation surprise (Sarter, Woods, & Billings, 1997) and other issues concerning human-automation collaboration, it is a safety issue, as well as an ethical issue of designing meaningful work for people.

SENSEMAKING IN SAFETY-CRITICAL SITUATIONS

The term safety-critical situation denotes situations that, if they go wrong, have a large potential for causing harm to people, property or the environment. In the organization literature, the term "crisis" is also commonly used. Weick describes crises as "low probability/high consequence events that threaten the most fundamental goals of an organization" (Weick, 1988, p. 305). Events like this place strong demands on sensemaking as they are often "characterized by ambiguity of cause, effect, and means of resolution" (Maitlis & Sonenshein, 2010, p. 554). Several examples of sensemaking in these situations have been given throughout this chapter.

The studies of sensemaking in crises have been on both sensemaking as it unfolds during a crisis and how sense is made of crises after they happened (Maitlis & Christianson, 2014). The latter often draws on public inquiry reports and other documents that "have constructed an account of what happened, why it happened, and who was responsible" (Maitlis & Sonenshein, 2010, p. 554). Public inquiries can say something about the shared sensemaking process after a crisis and they may enable organizational learning (Brown, 2004, 2005; Maitlis & Sonenshein, 2010).

Research on sensemaking during crisis has included a range of sectors, from the space sector (Dunbar & Garud, 2009; Stein, 2004) and the air force (Snook, 2000) to mining (Wicks, 2001), climbing (Kayes, 2004) and entertainment events (Vendelo and Rerup, 2009). Weick analyzed the Bhopal accident (Weick, 1988, 2010), the Tenerife air disaster (Weick, 1990), the Mann Gulch fire (Weick, 1993) and the medical disasters of Bristol Royal Infirmary (Weick & Sutcliffe, 2003). Maitlis and Sonenshein (2010) found that the two central themes underlying sensemaking in crisis and change conditions are *shared meanings* and *emotions*. The criticality of shared meanings can be illustrated by a recent example of breakdown in team sensemaking.

Breakdown in Team Sensemaking

The social aspect of sensemaking was discussed earlier in this chapter. Klein et al. (2010) discussed the social aspect as team sensemaking, defined as "the process by which a team manages and coordinates its efforts to explain the current situation and to anticipate future situations, typically under uncertain or ambiguous conditions" (Klein et al., 2010, p. 304). Klein describes it as a macrocognitive function as it is the team rather than individuals that perform the sensemaking. A successful outcome of the team sensemaking process is a collective understanding of the situation which accommodates decision-making. Klein et al. (2010) points out that team sensemaking is not new or different type of sensemaking, it is about "the coordination of the team members as they seek data, synthesise the data and disseminate inferences" (Klein et al., 2010, p. 304). Sensemaking at the team level requires additional coordination and is more difficult to accomplish than individual sensemaking. According to Klein et al. (2010), breakdown in team sensemaking may more often contribute to accidents than sensemaking at the individual level as "Most failures can be traced to a breakdown in team sensemaking where critical cues were ignored and the teams failed to synthesise the existing information". The latter sentence may be a good description of what happened on the bridge of the frigate *HNoMS Helge Ingstad* before it collided with the tanker *Sola TS* in Hjeltefjorden on November 8, 2018 (AIBN, 2019). The comprehensive report from the accident investigation board takes into account a broad set of factors contributing to the accident, like organizational factors, leadership, teamwork, training and technology, on the frigate and the other involved actors *Sola TS* and the Fedje VTS (AIBN, 2019). But as a case of breakdown in team sensemaking, it is interesting to take a look at what happened on the bridge of *HNoMS Helge Ingstad* minutes before the collision.

On the bridge of *HNoMS Helge Ingstad*, the structure of team sensemaking was hierarchical (Klein et al., 2010). In such a structure, the data should flow from different sources to a common node, in this case the officer of the watch (OOW), who puts the pieces together and directs the search for new data. The OOWs role was being responsible for conveying a clear and authorative picture of the situation (AIBN, 2019). To use Kleins' vocabulary, the OOW was the *data synthesizer*, which is a difficult task as the relevant information resides in different places.

During the watch handover sometime between 03:36 and 03:53, the OOW about to be relieved and the oncoming OOW observed an object (the tanker *Sola TS*) at the Sture Terminal starboard of the frigate's course line. It was observed both visually and on the radar display, however shown as an Automatic Identification System (AIS) signal without speed vector. During discussion between the two OOWs, they formed a clear perception (selected a frame) that the "object" was stationary near the shore. According to the data/frame theory of sensemaking (Klein et al., 2007) when a frame is selected it is used to guide further information seeking. During the handover, the first opportunity to gather further data was missed as they did not use the AIS to obtain more information about the "object". The relieving OOW's mental model was from this point very stable and the subsequent data-seeking and actions were based on his selected frame of reference.

Since the "object" was understood as stationary, it was not tracked by any of the radars; hence the bridge system did not generate any alarms to indicate that the vessel was on collision course with *Sola TS*. The "object" was primarily observed visually, and when *Sola TS* first started maneuvering out from the quay, this was done so slowly that it was difficult to perceive any movement from the bridge on *HNoMS Helge Ingstad*. Further visual observations by the bridge crew did not change the impression of the "object". None of the bridge team members saw the navigation lights on *Sola TS*; they only observed the strong deck lights. When the OOW saw that a little distance had appeared between the shore and the "object" on the radar, this cue was explained by assuming that the distance between the shore and the "object" on the radar screen was due to the frigate having come closer to the point which the "object" lay alongside.

The information the OOW received from the rest of the bridge team gave no indication that the "object" posed any risk to the voyage. The team's capacity to monitor the traffic situation was reduced due to a temporary unmanned starboard lookout position. In addition, the OOW and the bridge team were focusing on training activities and on the three vessels approaching in the opposite direction on the port side of

HNoMS Helge Ingstad. These vessels had been observed visually and tracked in the bridge system. Of those present, only the helmsman had identified the lights ahead on starboard side as belonging to a moving vessel. However, he did not disseminate this observation; he assumed that the OOW and the rest of the bridge team were aware of it being a vessel, since it should be observable on both AIS and radar. A minute before the collision, the pilot on board *Sola TS* made a direct call on VHF requesting *HNoMS Helge Ingstad* to alter course to starboard. The OOWs understanding was that there was not enough room to pass on the shore side of the “object” and assumed that the call was from one of the three northbound vessels approaching on port side. He responded by saying that they could not turn to starboard. By the time the OOW understood that the “object” giving off light was moving and on direct course to collide it was too late, and at 04:01:15, *HNoMS Helge Ingstad* collided with the tanker *Sola TS* (AIBN, 2019).

In hindsight it is easy to see that the cues and the weak signals of danger were there: the AIS signal, the radar echo, information on VHF and the visual information. However, at the time the selected mental frame of the OOW and the rest of the bridge team were used to guide information seeking. According to the data/frame theory of sensemaking (Klein et al., 2007), a surprise or an inadequacy in an existing frame will lead individuals to either actively obtain more relevant data to improve the frame, replace the frame with a more relevant one, construct a new frame or preserve the frame by explaining away or distorting the data. In this case the frame was preserved, and it directed expectations and what counted as data. The one team member that had made sense of the visual information was not able to share this information with the team and as such the team was “less sensitive to the weak signals than the most sensitive of their individual members” (Klein et al., 2010).

Adaptive Sensemaking

As we have seen, sensemaking can be both helpful and harmful in safety-critical situations. Maitlis and Sonenshein (2010) argue that adaptive sensemaking is necessary for sensemaking to be helpful especially in crisis. Adaptive sensemaking is enabled when emotions are moderately intense, not too negative but not too positive either. Emotions can provide valuable information to a sensemaker and should be intense enough to be noticed. However, the capacity for anxiety toleration is important for the ability to make sense of a situation (Stein, 2004).

According to Maitlis and Sonenshein (2010), another enabler of adaptive sensemaking is the two processes of *updating* and *doubting*. Updating has to do with gathering new information and revising interpretations while doubt is a reminder of constantly generating new understandings. A finite sense of a situation is never made as things are always changing (Maitlis & Sonenshein, 2010).

Adaptive sensemaking is related to improvisation. The ability to improvise has been connected to resilience (Weick & Sutcliffe, 2015). Skill in improvisation, as well as having the flexibility to use it, increases the potential actions available in people’s repertoire, meaning they can act on a greater variety of situations and surprises as well as broaden the range of cues that can be noticed (Ibid). The connection between sensemaking and resilience has been made by several scholars, in the sense that sensemaking creates resilience but also that sources of resilience help to make sense of the situation (Kilskar, Danielsen, & Johnsen, 2020).

CONCLUSION

This chapter reviewed sensemaking literature and defined sensemaking as “a process, prompted by violated expectations, that involves attending to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn” (Maitlis & Christianson, 2014, p. 67). The cognitive sensemaking process of creation, interpretation and enactment is described, highlighting that sensemaking is about partly creating the environment or situation to make sense of (Weick, 1995). Sensemaking is most often described as being triggered by ambiguous or surprising events influenced by expectations, emotions, embodied sensations, technology, the social context for sensemaking as well as identity. Safety-critical situations or crisis are especially demanding for sensemaking. Sensemaking should be adaptive to be helpful in these situations (Maitlis & Sonenshein, 2010).

In the context of sociotechnical systems, the sharp end operators, like navigators, are confronted with dynamic evolving situations and complex stimuli. According to Klein et al. (2007), sensemaking contributes to our understanding of human behavior at a macrocognitive scale needed to understand and design complex cognitive systems. As such it should be a useful perspective for both accident analysis and for the future design of safety-critical systems.

There are several areas where future research could develop the sensemaking concept or perspective further (Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2015). In line with Sandberg and Tsoukas (2015), this review found that there are relatively few studies investigating how technologies influence sensemaking, especially how the design of technology can hamper or support sensemaking in high-risk industries, like the maritime sector. The design of technology is part of a general trend with increasing digitalization and automation of work. An interesting direction for future sensemaking research would be to investigate how meaningful work can be designed in this context and how meaningfulness relates to resilience and safety.

REFERENCES

AIBN. (2019). *Report on the collision on 8 November 2018 between the frigate HNoMS Helge Ingstad and the oil tanker Sola TS outside the Sture terminal in the Hjeltefjord in Hordaland county.* Accident Investigation Board Norway

Bainbridge, L. (1983). Ironies of automation. Automatica*,* 19(6), 775–779.

Bisio, R., Bye, A., & Hurlen, L. (2019). Human machine interface for supporting sensemaking in critical situations, a literature review. *Paper presented at the European Safety and Reliability Conference, Hannover, Germany.*

Brown, A. D. (2004). Authoritative sensemaking in a public inquiry report. *Organization Studies, 25*(1), 95–112. doi:10.1177/0170840604038182

Brown, A. D. (2005). Making sense of the collapse of Barings Bank. *Human Relations, 58*(-12), 1579–1604. doi:10.1177/0018726705061433

Brown, A. D., Stacey, P., & Nandhakumar, J. (2008). Making sense of sensemaking narratives. *Human Relations, 61*(8), 1035–1062. doi:10.1177/0018726708094858

Chauvin, C., Lardjane, S., Morel, G., Clostermann, J.-P., & Langard, B. (2013). Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *Accident; Analysis and Prevention, 59*, 26–37.

Cunliffe, A., & Coupland, C. (2012). From hero to villain to hero: Making experience sensible through embodied narrative sensemaking. *Human Relations, 65*(1), 63–88.

Danielsen, B.-E., & Lamvik, G. (2019). Making sense of bridge design: how seamanship may challenge technology-as-designed. *Paper presented at the Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany.*

Dekker, S. W. (2015). The danger of losing situation awareness. *Cognition, Technology & Work, 17*(2), 159–161.

Dervin, B. (1998). Sense-making theory and practice: an overview of user interests in knowledge seeking and use. *Journal of Knowledge Management, 2*(2), 36–46.

Dunbar, R. L. M., & Garud, R. (2009). Distributed knowledge and indeterminate meaning: The case of the Columbia shuttle flight. *Organization Studies, 30*(4), 397–421. doi:10.1177/0170840608101142.

EMSA. (2019). *European maritime safety agency annual overview of marine casualties and incidents 2019.* Retrieved from http://www.emsa.europa.eu/emsa-documents/latest/item/3734-annual-overview-of-marine-casualties-and-incidents-2019.html

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*(1), 32–64.

Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors, 37*(2), 381–394.

Fahim, M., & Rezanejad, A. (2014). An introduction to embodied cognition. *International Journal of Language and Linguistics, 2*(4), 283–289.

Gephart, R. P., Jr., Topal, C., & Zhang, Z. (2011). Future-oriented sensemaking: temporalities and institutional legitimation. In *Process, Sensemaking, and Organizing*. Oxford University Press.

Gioia, D. A., & Chittipeddi, K. (1991). Sensemaking and sensegiving in strategic change initiation. *Strategic Management Journal, 12*(6), 433–448. doi:10.1002/smj.4250120604.

Gregory, D., & Shanahan, P. (2017). *Being Human in Safety-Critical Organisations*. Norwich, UK: TSO.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience Engineering: Concepts and Precepts*. Abingdon: Ashgate Publishing Ltd.

Johnsen, S. O., Kilskar, S. S., & Danielsen, B.-E. (2019). Improvements in rules and regulations to support sensemaking in safety-critical maritime operations. *Paper presented at the Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany.*

Jones, B. S. (2009). Unpacking the blunt end–changing our view of organizational accidents. Paper presented at the Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009.

Kayes, D. C. (2004). The 1996 Mount Everest climbing disaster: The breakdown of learning in teams. *Human Relations, 57*(10), 1263–1284. doi:10.1177/0018726704048355

Kilskar, S. S., Danielsen, B.-E., & Johnsen, S. O. (2020). Sensemaking in critical situations and in relation to resilience—A review. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B Mechanical Engineering, 6*(1).

Klein, G., Phillips, J. K., Rall, E. L., & Peluso, D. A. (2007). A data-frame theory of sensemaking. *Paper presented at the Expertise Out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making.*

Klein, G., Wiggins, S., & Dominguez, C. O. (2010). Team sensemaking. *Theoretical Issues in Ergonomics Science, 11*(4), 304–320. doi:10.1080/14639221003729177

Kongsvik, T., Haavik, T., Bye, R., & Almklov, P. (2020). Re-boxing seamanship: From individual to systemic capabilities. *Safety Science, 130*, 104871.

Lützhöft, M., Grech, M. R., & Porathe, T. (2011). Information environment, fatigue, and culture in the maritime domain. *Reviews of Human Factors and Ergonomics, 7*(1), 280–322.

Lützhöft, M., & Vu, V. D. (2018). Design for safety. In H. A.Oltedal and M. Lützhöft (Eds.), *Managing Maritime Safety*. New York: Routledge.

Lützhöft, M. H., & Dekker, S. W. A. (2002). On your watch: Automation on the bridge. *Journal of Navigation, 55*(1), 83–96. doi:10.1017/S0373463301001588

MAIB. (2017). *Report on the investigation of the grounding of Muros Haisborough Sand North Sea 3 December 2016*. (22/2017). Marine Accident Investigation Branch UK

Maitlis, S. (2005). The social processes of organizational sensemaking. *Academy of Management Journal, 48*(1), 21–49. doi:10.5465/AMJ.2005.15993111

Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: Taking stock and moving forward. *The Academy of Management Annals, 8*(1), 57–125.

Maitlis, S., & Sonenshein, S. (2010). Sensemaking in crisis and change: Inspiration and insights from weick (1988). *Journal of Management Studies, 47*(3), 551–580. doi:10.1111/j.1467–6486.2010.00908.x

Meck, U., Strohschneider, S., & Brüggemann, U. (2009). Interaction design in ship building: An investigation into the integration of the user perspective into ship bridge design. *Journal of Maritime Research, 6*(1), 15–32.

Merwe, F. V. D. (2016). *Human-centred design of alert management systems on the bridge*. Retrieved from https://www.sdir.no/sjofart/ulykker-og-sikkerhet/sikkerhetsutredninger-og-rapporter/human-centred-design-of-alert-management-systems-on-the-bridge/

Mesgari, M., & Okoli, C. (2019). Critical review of organisation-technology sensemaking: Towards technology materiality, discovery, and action. European Journal of Information Systems, 28(2), 205–232.

Morgan, B. B. Jr, Glickman, A. S., Woodard, E. A., Blaiwes, A. S., & Salas, E. (1986). *Measurement of team behaviors in a navy environment*. Human Factor Division, Naval Training Systems Center, Department of The Navy Battelle Columbus Labs Research Triangle Park, NC.

Nilsen, M., Almklov, P.G., Haugen, S., & Bye, R.J. (2017). A discussion of risk influencing factors for maritime accidents based on investigation reports. *Paper presented at the ESREL, Glasgow, Scotland*.

Norman, E. (2019). *Affekt og kognisjon*. Oslo: Universitetsforlaget.

Porathe, T., Hoem, Å., Rødseth, Ø., Fjørtoft, K., & Johnsen, S. O. (2018). At least as safe as manned shipping? Autonomous shipping, safety and "human error". In Haugen (Ed.), *ESREL European Safety and Reliability Conference* (pp. 417–425). London: Taylor & Francis Group.

Prison, J., Dahlman, J., & Lundh, M. (2013). Ship sense-striving for harmony in ship manoeuvring. *WMU Journal of Maritime Affairs, 12*(1), 115–127.

Rosness, R., Evjemo, T. E., Haavik, T., & Wærø, I. (2016). Prospective sensemaking in the operating theatre. *Cognition, Technology and Work, 18*(1), 53–69. doi:10.1007/s10111-015-0346-y

Rosso, B. D., Dekas, K. H., & Wrzesniewski, A. (2010). On the meaning of work: A theoretical integration and review. *Research in Organizational Behavior, 30*, 91–127.

Russell, D. M., Convertino, G., Kittur, A., Pirolli, P., & Watkins, E. A. (2018). Sensemaking in a Senseless World: 2018 Workshop Abstract. *Paper presented at the Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*.

Russell, D. M., Stefik, M. J., Pirolli, P., & Card, S. K. (1993). The cost structure of sensemaking. *Paper presented at the Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems.*

Sandberg, J., & Tsoukas, H. (2015). Making sense of the sensemaking perspective: Its constituents, limitations, and opportunities for further development. *Journal of Organizational Behavior, 36*, S6-S32. doi:10.1002/job.1937

Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises. *Handbook of Human Factors and Ergonomics, 2*, 1926–1943.

Snook, S. A. (2000). *Friendly fire: The accidental shootdown of U.S. Black Hawks over Northern Iraq*. Princeton, NJ: Princeton University Press.

Stein, M. (2004). The critical period of disasters: Insights from sense-making and psychoanalytic theory. *Human Relations, 57*(10), 1243–1261. doi:10.1177/0018726704048354

Strauch, B. (2017). Ironies of automation: Still unresolved after all these years. IEEE Transactions on Human-Machine Systems, *48*(5), 419–433. doi:10.1109/THMS.2017.2732506

Vendelo, M. T., & Rerup, C. (2009). Weak cues and attentional triangulation: The Pearl Jam concert accident at Roskilde Festival. *Paper presented at the Academy of Management Annual Meeting, Chicago.*

Weick, K. E. (1988). Enacted sensemaking in crisis situations. *Journal of Management Studies, 25*(4), 305–317.

Weick, K. E. (1990). The vulnerable system: An analysis of the Tenerife air disaster. *Journal of Management, 16*(3), 571–593. doi:10.1177/014920639001600304

Weick, K. E. (1993). The collapse of sensemaking in organizations: The Mann Gulch disaster. *Administrative Science Quarterly*, *38*(4), 628–652.

Weick, K. E. (1995). *Sensemaking in Organizations*. Thousand Oaks, California: SAGE.

Weick, K. E. (2005). Organizing and failures of imagination. *International Public Management Journal, 8*(3), 425–438. doi:10.1080/10967490500439883

Weick, K. E. (2010). Reflections on enacted sensemaking in the Bhopal disaster. *Journal of Management Studies, 47*(3), 537–550. doi:10.1111/j.1467–6486.2010.00900.x

Weick, K. E., & Sutcliffe, K. M. (2003). Hospitals as cultures of entrapment: A reanalysis of the Bristol Royal Infirmary. *California Management Review*, *45*(2), 73. doi:10.2307/41166166

Weick, K. E., & Sutcliffe, K. M. (2015). *Managing the Unexpected: Sustained Performance in a Complex World*. New Jersey: John Wiley & Sons Inc.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organization Science, 16*(4), 409–421. doi:10.1287/orsc.1050.0133

Wicks, D. (2001). Institutionalized mindsets of invulnerability: Differentiated institutional fields and the antecedents of organizational crisis. *Organization Studies*, *22*(4), 659–692. doi:10.1177/0170840601224005

Yeoman, R. (2014). Conceptualising meaningful work as a fundamental human need. *Journal of Business Ethics, 125*(2), 235–251.

Paper II

Still Unresolved After All These Years: Human-Technology Interaction in the Maritime Domain

Brit-Eli Danielsen[1(✉)], Margareta Lützhöft[2], and Thomas Porathe[1]

[1] Department of Design, NTNU, Kolbjørn Hejes vei 2b, 7491 Trondheim, Norway
brit-eli.danielsen@samforsk.no

[2] Department of Maritime Studies, HVL, Bjørnsons Gate 45, 5528 Haugesund, Norway

Abstract. Over the last decades there has been a steady increase in digitalized products, applications and services introduced to ship's bridges with the intent to reduce workload and increase safety. However, new technology come with unexpected effects. The current study involves data collected from field trips on board five ships and semi-structured interviews with 21 seafarers. The results show that the human-technology interaction on ship bridges still is a challenge for the seafarers. However, the seafarers see it as part of their professional role to manage and adapt to the equipment or system they have at hand to get the job done. In this paper this ability to handle and make sense of technology is analysed through the notion of seamanship. To find ways to reduce the gap between technology-as-used and technology-as-designed future research should be directed towards the many stakeholders involved in ship bridge design.

Keywords: Human-technology interaction · Maritime domain · Ship bridge design · Seamanship · Sensemaking

1 Introduction

Over the last decades there has been a steady increase in digitalized products, applications and services introduced to ship's bridges with the intent to reduce workload and increase safety. However, new technology may come with unexpected effects, as Bainbridge pointed out already in the 1980's [1]. Technology and automation does not simply replace human work, it also changes the tasks it was meant to support and creates new possibilities and forms of "human error" [2, 3].

An accident in Singapore Strait in 2017 may serve as an illustration. A warship was overtaking a tanker when the warship had a perceived loss of steering. Onboard the warship bridge steering could be controlled from four Integrated Bridge and Navigation Systems (IBNS) as well as one in the emergency aft steering compartment. During transfer of the propulsion control from one bridge station to another, the steering was also accidently included. The helmsman declared he had no steering and the commanding officer ordered manual emergency steering to be taken over by the aft emergency steering compartment. The ship had two steering emergency-override-to-manual buttons

N. Stanton (Ed.): AHFE 2021, LNNS 270, pp. 463–470, 2021.
https://doi.org/10.1007/978-3-030-80012-3_53

(called the “big red button” by Navy crewmembers), one on the central steering console on the bridge and one in the aft emergency steering compartment. Pushing the button would immediately transfer steering control to the station where the button was pushed. However, the bridge crew though that by pressing the bridge “big red button”, steering was sent to the emergency steering compartment in the aft. So, when the commanding officer ordered steering to be taken over by the aft compartment, the aft crew pushed their button and gained control. Almost simultaneously the helmsman pushed the bridge “big red button” thinking he had sent the control to the aft, while in reality retaking control to his bridge console. Hence, the aft crew who thought they had control, did not and the helmsman thinking he had no control stopped trying to steer. Meanwhile, the vessel unintentionally turned to port into the path of the tanker and collided. The design of the IBNS was identified as a contributing factor to the accident [4].

The maritime sector is diverse and consist of many stakeholders that in some way influence ship bridge design. In this paper we look at the sharp end, how seafarers handle and make sense of technology on the bridge through the notion of seamanship.

The paper is structured as follows: in the next section, we present the theoretical foundation for the analysis, Sect. 3 outlines the methodological approach for the study. The results and discussion are presented in Sect. 4, followed by the conclusions in Sect. 5.

2 Theoretical Foundation

This section presents the theoretical foundations for the analysis, sensemaking and seamanship.

2.1 Sensemaking

The concept of sensemaking is influential in organization studies. Sensemaking is the transient process through which people assign meaning to issues, events or to their environment [5]. Sensemaking is triggered by *cues* that are actively extracted from peoples lived experience. The cues are noticed based on previous experience or existing cognitive frames. The cues are “seeds from which people develop a larger sense of what may be occurring” [5]. The cues are interpreted, and action is taken. The actions create a slightly different or new environment to continue to make sense of, a process known as enactment [5, 6]. This is an ongoing cycle where “people construct provisional understandings that they continuously enact and modify” [6].

Sensemaking is often described as triggered when people confront events or issues that are somehow surprising, confusing or violate expectations [5, 6]. However, sensemaking also occurs non-episodically during routine work. This is a form of mundane or *immanent* sensemaking where “people go on doing the things they routinely do without deliberately thinking about how they do them.” [7]. Sandberg and Tsoukas [7] connects immanent sensemaking to absorbed coping, something especially found amongst experts that are “as one” with their work, continuously acting in response to their sense of the situation.

Sensemaking is both an individual process going on in peoples’ head as well as a social process where people actively shape each other’s meanings [5]. Weick [5] argues that even individual sensemaking is influenced by the actual or implied presence of other organizational members.

As “people can make sense of anything” [5] there is an infinite number of factors that can influence sensemaking. *Technology* is one factor that has been found to trigger sensemaking about the technology itself, how to respond and engage with it as well as influence how sense is made of professional relationships and professional identity [7]. *Identity* is another central factor influencing sensemaking. People will often attempt to make sense of events in ways that respond to their need of maintaining a consistent, positive self-conception [8].

2.2 Seamanship

The professional culture among seafarers is denoted *seamanship*. This is a notion without a specified or agreed-upon definition. The term is used in several different areas, from textbooks and maritime regulations, to accident investigations and in the media. These understandings are not necessarily consistent with how seafarers understand or use the term [9]. According to Knudsen [10] seamanship is “a blend of professional knowledge, professional pride, and experience-based common sense”, as well as having a social and ethical dimension.

Antonsen [11] conducted a survey on the meaning of good seamanship with 258 seafarers. The most frequent characteristic given was the ability to maintain social relations and community, followed by work performance, in this case referring to working safely and with high quality. Other responses included individual properties, such as being independent, responsible and reliable, and competence - mainly referring to practical sailing experience.

Good seamanship is mainly developed through experience. Traditionally, seafarers training from novice to expert has been based on practice and a learning process based on socialization [12]. The developed experience and knowledge form a basis for using *common sense* and exercising *good judgement* which are central aspects of seamanship [10, 13]. *Troubleshooting* is another part of this picture, and according to Lamvik [14] it is a necessary, expected and highly appreciated aspect of seamanship. To be able to find solutions and make do with whatever you have at hand is important when spare parts or other forms of help are miles or days away.

Professional identity is central to seamanship, for instance in the sense that it separates “real seafarers” from those who are not, mainly the people in onshore organisations [9]. Professional identity is dynamic, and the traditional notion of seamanship has probably changed over the last decades due to technology development and proceduralisation [13].

3 Method

This study has a qualitative approach as the interest is in the seafarer’s view of the design of technology they work with on the bridge. The main topic for the data collection concerned the informants experience and opinions about the technology available mainly on the ship bridges they currently worked on, but they would also referred to previous experiences from other ships they had worked on. The questions were open-ended allowing the informants to speak freely about different aspects of their work on the bridge. The questions included how design of technology hamper or support their daily tasks, what kind of influence seafarers have on design and equipment available, as well as their take on the notion of seamanship.

3.1 Procedure

Data was collected onboard five ships, including observation and interviews with a total of 21 officers. An overview of the data collection and methods is given in Table 1. One researcher visited two offshore supply vessels while they were sailing on the Norwegian continental shelf. The ships were built in 2014 and 2016. Both vessels had four officers onboard that participated in the study. Two researchers performed shorter visits onboard three passenger ships, built in 1983, 1993 and 1996. Semi-structured interviews were performed with two officers on each passenger ship. A focus group interview was performed between lectures, with six coastal vessel officers, participating in a course at a Norwegian education facility. Two researchers performed a semi-structured interview with a master mariner and lecturer in nautical studies.

Table 1. Overview of methods and data collection performed.

Location	Method performed	Approx time (hrs)	Informants
Two offshore supply vessels	Observation Informal unstructured and semi-structured interviews	100	8 officers
Three passenger ships	Observation Semi-structured interview	4	6 officers
Onshore	Focus group interview	1	6 officers
Onshore	Individual semi-structured interview	2	1 officer
Total: 5 ships			Total: 21 officers

3.2 Data Management and Analysis

The audio recorded interviews were transcribed verbatim. The transcriptions and field notes were read several times, followed by coding of the data material with the help of NVivo software. Coding reduced the data by systematically examining the texts line by line and assigning a descriptive code for each segment. The generated codes were grouped into categories that were subsequently reviewed and organized. Two of the resulting themes are presented and discussed in chapter four. All quotes are translated from Norwegian. The data collection and management has been approved by NSD – Norwegian centre for research data.

4 Results and Discussion

This section will discuss two themes developed from the data that was found to be related to sensemaking, seamanship and technology on the bridge; 1) Seamanship as seafarers see and 2) Adaptation of, and adaptation to, bridge design.

4.1 Seamanship as Seafarers See It

The informants describe seamanship much in the same way as previous research have reported. They emphasize individual capabilities where experience is crucial, in the sense that education may be a foundation for seamanship, but it is mainly developed over time through experience. They also highlight performing work properly, thinking ahead, as well as continuously performing your own safety assessments. Social relations are described as important both internally on the ship, but also involves acting considerately and politely towards other vessels and people encountered at sea.

A recurring theme also in our data is to use *common sense* and think for yourself, as in using your own *good judgement*. The informants describe their sensemaking as trusting your own competence and experience in the form of seamanship to be able to notice the relevant cues in the environment and continuously make sense of the situation at hand. Seamanship in this sense was described by one informant as to "recognize situations where you know alarm bells should be going off in your head, that's something you acquire over time". The specificity of each situation requires situated solutions and was specifically described as 'not necessarily doing things by the book'.

When seamanship was discussed in relation to working with technology on board the informants described it as the ability to assess the whole situation and not only the reality as presented on screens: 'that you actually pay attention to what is happening outside and around you and not being busy with 300 screens overburdened with information and alarms'. Several informants mentioned that they thought newcomers pay too much attention to screens and that looking outside the windows is something they have to learn. To look outside is important, not only to assess the whole situation, but the screens may also take too much focus by presenting information that is not seen as important or necessary for work execution. Another part of seamanship expressed was the ability to sort out the important information from the abundance of information available on the bridge. Although working with information technology is an important part of the job, part of developing seamanship is to balance the attention between information presented on screens and other types of information available in the work environment. The ability to handle technology by adapting to it was very clearly expressed by one informant as "to adapt to the system is seamanship in practice".

4.2 Adaptation of, and Adaptation to, Design

The technology available on the bridge triggers seafarers' sensemaking about the technology itself and how it can be used to accommodate their job. The technology also triggers sensemaking about "the others" - the people in land organizations that are responsible for designing and implementing the technology on board.

On board the older ship bridges we observed many examples of poor design. The informants interviewed on shore describe the same problems. Some are directly connected to human perception such as lacking the possibility to dim screens and other lights that impair their night vision, or too many alarms having similar sounds. Regarding usability, consoles are cluttered with little grouping of functions, too many buttons, whereof many not functioning, and buttons and levers are too small and cumbersome to work with. There are issues like poorly functioning touch screens, lengthy menus to navigate through and too much unnecessary info on screens. Poor ergonomics is evident as we observed officers climbing on consoles or standing on pallets to reach necessary equipment. These issues still exist despite the knowledge, guidelines and to some extent regulatory requirements on ergonomics and usability that are available today.

Alongside poor design another interesting finding was observed – adaptation of the technology. The adaptations include self-made covers for dimming screens, partly covering screens to cover unnecessary functions, covers over non-functioning buttons, pallets to stand on, lengthening of levers, written notes, and adding equipment like computer mouse. This *adaptation of design* may be seen as part of seafarers sensemaking of the technology at hand. When workplace design is poor, seafarers make it work through *adaptation of design.* We know that identity is a core factor influencing sensemaking. The professional identity as a seafarer involves the pride taken in doing a good job as well as being excellent at troubleshooting. The adaptations are seen as necessary to avoid making mistakes and get the job done in a safe and practical manner. "You do modifications because you know the bridge will not be replaced" as one informant puts it. This statement refers to the fact that modifications are necessary, but it also illustrates the belief that despite the seafarers' dissatisfaction, the equipment will not be changed. Being excellent at troubleshooting and finding creative solutions may in this sense be a double-edged sword. For "the others" – the people in land-organizations the equipment on board may seem to be working well, or at least well enough.

The poorly designed technology also triggered sensemaking about "the others" - those who design, develop, and install equipment on ship bridges. The descriptions of poor design were followed by frustration and the impression that the people on shore who make design decisions do not have the knowledge or understanding of what is needed on board, clearly illustrated by statements like 'It probably worked well in the office'.

The two offshore supply ships were equipped with a recently developed integrated bridge concept where the manufacturer had emphasized end-user involvement during the development. In general, the informants working here describe the bridge as "well arranged", "you have everything you need around you" and that after working with this bridge they could not imagine going back to a conventional bridge again. The visual impression of this bridge environment was very tidy, clutter-free and very few adaptations were observed. The crew appeared to have the necessary equipment readily available when they were seated in their main working position.

The concerns that *are* raised regarding the integrated bridges are mainly on a higher level, such as the integration makes it hard to understand, or gain control over, what is going on behind the screens. Another concern is that integrated bridges make the crew more dependent on the land-organizations. It is not possible for them to perform maintenance or small adaptations as everything must be programmed into the bridge system by the manufacturer. This comes with a cost and thereby often is not prioritized. This challenges the seafarers' independence, responsibility and competence, all central parts of seamanship.

One informant described the difference between the new integrated bridge he was currently working with and an old ship he had worked on previously. He explains that it took some time for him to "get used to" this bridge system. Although the old ship was analogue and cumbersome to work with it did not bother him at the time because he "was used to it". However, after getting used to the integrated bridge, he now prefers the new system. "Getting used to" reflects sensemaking both as a learning process as well as an adaptation process.

It is reasonable to assume that many of the things that do not work well and cannot be adapted could lead to new and possibly suboptimal ways of working. *Adaptation to design*, where seafarers adapt their work to the system is a more tacit and invisible response than the *adaptations of design.* However, as the quote "to adapt to the system is seamanship in practice" illustrates this is also part of the notion of seamanship.

There was no systematic feedback loop from seafarers to land-organizations regarding design found in our field studies. If there was a feedback loop, the adaptations that seafarers perform could function as clues for designers, engineers and implementers of design. However, the adaptations are mostly quite small, individual or specific solutions to daily encountered problems and fixing these things may not mean that the system improves as a whole. As one informant put it "I don't know what I want, I only what I don't want". As such, the adaptations should not be treated as direct design input, rather a sign that the overall system is not working. To improve design on a system level would require more thorough research like longitudinal ethnographic studies that could reveal adaptations to design as well as user needs on a system-level.

5 Conclusion

This study found that seafarers see it as part of their professional role to manage the equipment or systems on the bridge to get their job done in a safe and practical manner. The necessary adaptations they do may not be visible to stakeholders on land as there is no system in place for feedback from operations. Inadequate design is most vividly described and observed on older retrofitted bridges. Retrofitted bridges seem to some extent to develop randomly over time as equipment is replaced or added. The newer bridges have fewer physical adaptations and the design is more positively referred to by the crew. Still the technology development with layers of integrated systems are perceived as a cause for concern where they lose sight of the real world behind the screens.

There is a gap between those who design, develop, and install equipment on ship bridges and the end-users – the seafarers. This is a finding that resonate with similar research over decades. To reduce the gap between technology-as-designed and technology-in-use, future research should study the blunt end of design. If the interest and influence the many maritime stakeholders have in ship bridge design are revealed, it should be possible to find where in the design process human-centred design activities can be introduced.

Acknowledgments. This work is supported by the SMACS (Sensemaking in Safety-critical Situations) project financed by the Norwegian Research Council, Grant no. 267509.

References

1. Bainbridge, L.: Ironies of automation. Automatica **19**(6), 775–779 (1983)
2. Strauch, B.: Ironies of automation: still unresolved after all these years. IEEE Trans. Hum.-Mach. Syst. **48**, 419–433 (2017)
3. Lützhöft, M.: "The technology is great when it works": Maritime Technology and Human Integration on the Ship's Bridge. Linköping University Electronic Press (2004)
4. NTSB, Collision between US Navy Destroyer John S McCain and Tanker Alnic MC, Singapore Strait, 5 Miles Northeast of Horsburgh Lighthouse, August 21, 2017. National Transportation Safety Board (2019)
5. Weick, K.E.: Sensemaking in Organizations. Foundations for Organizational Science. Sage, Thousand Oaks (1995)
6. Maitlis, S., Christianson, M.: Sensemaking in organizations: taking stock and moving forward. Acad. Manag. Ann. **8**(1), 57–125 (2014)
7. Sandberg, J., Tsoukas, H.: Making sense of the sensemaking perspective: its constituents, limitations, and opportunities for further development. J. Organ. Behav. **36**, S6–S32 (2015)
8. Weick, K.E., Sutcliffe, K.M., Obstfeld, D.: Organizing and the process of sensemaking. Organ. Sci. **16**(4), 409–421 (2005)
9. Bye, R., Antonsen, S., Lamvik, G.: Godt sjømannskap - ferdigheter og yrkesidentitet. In: Antonsen, S., Kongsvik, T. (eds.) Sikkerhet i norske farvann. Gyldendal Norsk Forlag AS, Oslo (2015)
10. Knudsen, F.: Paperwork at the service of safety? Workers' reluctance against written procedures exemplified by the concept of 'seamanship.' Saf. Sci. **47**(2), 295–303 (2009)
11. Antonsen, S.: The relationship between culture and safety on offshore supply vessels. Saf. Sci. **47**(8), 1118–1128 (2009)
12. Bye, R.J., Aalberg, A.L.: Why do they violate the procedures?–an exploratory study within the maritime transportation industry. Saf. Sci. **123**, 104538 (2020)
13. Kongsvik, T., et al.: Re-boxing seamanship: from individual to systemic capabilities. Saf. Sci. **130**, 104871 (2020)
14. Lamvik, G., Wahl, A., Buvik, M.P.: Professional culture, work practice and reliable operations in shipping. Reliability, Risk and Safety. Taylor & Frances Group, London (2010)

Paper III

Advances in Transportation, Vol. 60, 2022, 714–722
https://doi.org/10.54941/ahfe1002509

The Contribution of Ship Bridge Design to Maritime Accidents

Brit-Eli Danielsen

Department of Design, Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

Shipping is an industry where accidents have potential catastrophic effect on humans, the environment or material assets. The design of bridge equipment and the bridge layout has a significant impact on the human-technology interaction on a ship's bridge, hence design is important for safety of navigation. This paper presents a review of 28 accident investigation reports from the last decade where design of ship bridge equipment or bridge layout has been identified as contributing factors. Six categories of design issues were identified: 1) Bridge layout; 2) Not using available electronic equipment; 3) Unexpected use of electronic equipment; 4) Mode confusion; 5) Lack of information about system status; 6) Trust in electronic equipment. The corresponding investigation boards' safety recommendations and the shipowners' responses, mainly concerned revising the safety management system, revising or introducing procedures and checklists, as well as crew training. These responses place the responsibility for an improved human-technology interaction on the human operator. The few recommendations and actions that concerned improving design of technology where local fixes that do not contribute to learning on organizational or system level.

Keywords: Ship bridge design, Human-technology interaction, Accident investigation

INTRODUCTION

Shipping is an industry where organizational accidents occur. Reason (1997) describes organizational accidents as events that can have a catastrophic effect on humans, the environment or material assets. Further, organizational accidents occur within modern complex technologies, and they have multiple causes, involving many people at different levels in their organizations (Reason, 1997). Applying a systemic view on maritime accidents is not common, rather it is frequently reported that around 80% of maritime accidents are caused by human error. However, Wròbel (2021) could not find evidence for what he denotes the *80% myth*. Navigating a ship is a complex task that involves close interaction between the navigators and the technology and artefacts available on the ship's bridge. The design of the bridge equipment and the bridge layout has a significant impact on this interaction (Oltedal & Lützhöft, 2018). This is recognized by the International Maritime Organization (IMO) through the SOLAS V/15 regulation that requires human factors considerations in ship bridge design (IMO, 2002). However, lack of usability in the design of ship bridges and ship bridge equipment is a persistent challenge in the maritime industry (Costa & Lützhöft, 2014; Millar, 1980). This paper presents a review of 28 accident investigation reports from the last decade where design of ship bridge equipment or bridge layout has been identified as contributing factors. The objective of this review is to identify what kind of design issues the investigators recognize, as well as how these design issues have been followed up through the investigation boards' safety recommendations and the shipowners' response.

MARITIME ACCIDENT INVESTIGATION

Flag states are responsible for carrying out maritime accident investigations of accidents and incidents involving ships flying its flag or accidents occurring within its flag state territory (IMO, 2008). Human and organizational factors are included in the IMO guidelines to assist in the implementation of the Casualty Investigation Code (IMO, 2013). The accident investigation can be carried out by commissions or accident investigation boards within the flag state. The objectives of the investigations are to determine the accidents circumstances and causes, and to learn and prevent future accidents.

Studies of accident investigation reports have revealed design issues to be contributing factors to accidents. For example, Puisa (2018) analyzed accidents and incidents with passenger ships and found one of the prominent issues to be incomplete hazard analysis during design. Especially design issues that involve interactions between technology and people are either overlooked or not communicated to the operator (Puisa, 2018). Inadequate bridge design was also found to be one of the underlying factors in Sandhåland's (2015) study of accident reports from collisions between attendant vessels and offshore facilities in the North Sea.

In 2021, the Danish and the UK Maritime Accident Investigation Boards published a report from a study regarding the use of Electronic Chart Display and Information System (ECDIS). The study was issued due to the many investigations of groundings where a mismatch had been found between the way seafarers used ECDIS and the intention in performance standards and system design (MAIB & DMAIB, 2021). One of the reported challenges are difficulties in using some of the ECDIS safety features leading crew either to implement workarounds or ignoring the features. The report points towards structural flaws in the way new navigation technologies are designed and implemented and recommend that principles for human-centered design should be followed in the maritime industry (MAIB & DMAIB, 2021).

It is unquestionably valuable to study accidents in order to learn and to prevent future accidents. However, the causes found in an accident investigation reflects the underlying accident models used by the investigators, known as the 'What-You-Look-For-Is-What-You-Find' principle (Lundberg et al., 2009). This is followed by the 'What-You-Find-Is-What-You-Fix' principle, where the identified causes are turned into specific problems that can be resolved by implementing a solution (Lundberg et al., 2009). Maritime accident investigations are based on sequential accident causation models and tend to focus on technical components and pay less attention to how human, technological and organizational factors interact in sociotechnical systems

(Schröder-Hinrichs et al., 2011). Hindsight bias is a problem in accident investigations (Dekker, 2002), and so without applying a systems approach to investigations the possibility for learning may be limited even in preventing a similar accident. When human error is found to be the cause, only local responses like procedures and training is required, which is an impediment to learning on organization or system levels (Woods et al., 2010).

METHOD

The accident investigation reports were obtained by searching through the publicly available reports issued by the Accident Investigation Board Norway (AIBN), the German Federal Bureau of Maritime Casualty Investigation (BSU), the Danish Maritime Accident Investigation Board (DMAIB) and the UKs Marine Accident Investigation Branch (MAIB). According to UNCTAD (2022) these are the countries with the largest merchant fleet in North and West Europe by country of beneficial ownership. The search was limited to accidents occurring in the period 2010-2020. The investigation reports that had identified and reported design issues as contributing factors to the accidents were included. An overview of the selected reports is given in Table 1.

The reported design issues, as well as the safety recommendations and the shipowner's response were identified in each investigation report and grouped according to their themes. The resulting themes are presented and discussed in the following sections.

RESULTS

Design Issues Identified in the Investigation Reports

The design issues described in the accident investigation reports was grouped into six themes. It should be noted that the investigations often found several of the categories contributing to the same accident, e.g., in the report regarding the *Commodore Clipper* grounding, both bridge layout and unexpected use of equipment was registered. Also, reports investigating collisions may have reported design issues on board both ships involved.

1. **Bridge layout** was a design issue reported for 13 ships (*MF Bognes, Steinbock, Stena Nautica, Victoria, Express 1, World Bora, Raba, Ice Rose, Arrow, Red Falcon, City of Rotterdam, Commodore Clipper, MV Finnarrow*). There were three ways bridge layout could be a contributing factor to the accidents: a) The bridge layout hindered access to operate or use equipment. For example, on board *Red Falcon* the Electronic Chart System (ECS) and radar placement were not compatible with the natural manoeuvring position during single person operation; b) The bridge layout hindered visual overview. For example, on *Steinbock* it was not possible to have an all-round view from the helm as the funnel covered a significant part of the view astern; c) The bridge was designed to accommodate several functions. For example, on board *Express 1* the bridge

Table 1. The accident investigation reports included in this study.

Name of vessel (s)	Year of Accident	Accident Type	Accident Investigation Board
MV Godafoss	2011	Grounding	AIBN
MF Godfjord	2015	Grounding	AIBN
MF Bognes	2016	Grounding	AIBN
Aurora Explorer	2018	Allision	AIBN
Steinbock and MV Minerva	2010	Collision	BSU
MV Beluga Revolution	2010	Grounding	BSU
Nils Holgersson and Urd	2012	Collision	BSU
MV Fransisca and MV RMS Bremen	2014	Collision	BSU
Wes Janine and Stenberg	2014	Collision	BSU
Pazifik	2018	Grounding	BSU
Stena Nautica	2014	Allision	DMAIB
Victoria	2017	Grounding	DMAIB
Express 1 and Baltic Condor	2019	Collision	DMAIB
World Bora and Raba	2019	Collision	DMAIB
Ice Rose and Kazanets	2020	Collision	DMAIB
MV Finnarrow	2013	Allision	MAIB
Ovit	2013	Grounding	MAIB
Commodore Clipper	2014	Grounding	MAIB
City of Rotterdam and Primula Seaways	2015	Collision	MAIB
Muros	2016	Grounding	MAIB
Royal Iris of the Mersey	2016	Grounding	MAIB
CMA CGM Vasco de Gama	2016	Grounding	MAIB
Celtic Hav	2018	Grounding	MAIB
Priscilla	2018	Grounding	MAIB
Red Falcon and Greylag	2018	Collision	MAIB
Seatruck Performance	2019	Grounding	MAIB
Kaami	2020	Grounding	MAIB
Arrow	2020	Grounding	MAIB

had been designed as a combination of bridge, office and rest room which was very disturbing for the navigators.

2. **Not using available electronic equipment** to assist in navigation was reported for 10 of the ships (*MV Godafoss, MF Bognes, Steinbock, MV Beluga Revolution, Wes Janine, Stenberg, Seatruck Performance, Priscilla, Cetica Hav, Royal Iris of the Mersey*). For example, it was reported that before *MV Godafoss* grounded the voyage was performed visually with hardly any use of available navigational aids. The reason for not using the ECDIS was that the master knew that the passage marked on the electronic chart system was not accurate enough to be used as a navigational aid in the applicable waters.
3. **Unexpected use of electronic equipment** was reported for eight of the ships (*MV Beluga Revolution, Kaami, Seatruck Performance, Priscilla, Muros, CMA CGM Vasco de Gama, Commodore Clipper, Ovit*). For *MV Beluga Revolution* the unexpected use concerned the GPS receiver,

echo sounder and ECS. All the other cases concern the use of ECDIS. One typical example of this was the grounding of *Muros* where the track was not planned or checked on an appropriate scale chart, audible alarms and the guard zone function were disabled, the use of 'standard' chart view limited the information displayed. The term 'unexpected use' is inspired by the following quote from the *Muros* investigation report: "The ECDIS on board *Muros* had not been used as expected by the regulators or equipment manufacturers." (MAIB, 2017).

4. **Mode confusion** contributed to three of the accidents (*MF Godfjord, Aurora Explorer, Nils Holgersson*). For example, to limit unwanted vibrations due to a incorrectly adjusted port drivelines propeller pitch on *Aurora Explorer*, it was decided to operate the vessel in combinator mode during docking, and in back-up mode to reach cruising speed between destinations. The most likely cause of the accident was forgetting to re-engage to combinator mode before arrival to dock. This caused the vessel to increase its speed ahead as the port side maneuver handle was pulled astern, and the vessel collided with the quay.
5. **Lack of information about system status.** Systems not providing information about the system status to the navigators was found to be contributing in two of the accidents (*MV Finnarrow, Stena Nautica*). For example, on board *Stena Nautica* the steering arrangement allowed the switch from one control station to another to be performed without the watchkeeping crew having full knowledge of the helm and rudder positions. The design of the centre hand steering wheel was such that its position was not clearly indicated, especially at night.
6. **Trust in electronic equipment.** Not verifying the position displayed on the chart with other means like radar or visual bearings was reported to be contributing to the collision between *MV Fransisca* and *MV RMS Bremen*. The investigation found there had been a GPS error. On both vessels the officer in charge relied on the positions displayed on the electronic chart and did not verify the satellite positions displayed with another system, such as radar or visual bearings. This is the opposite issue as those reported in category 2 where navigation was performed visually, and electronic aids were not used.

Electronic charts, ECDIS or ECS, were the equipment type most frequently occurring in the reported human-technology issues - they occurred in 14 of the investigation reports. Several of the reports have limited descriptions of the design issue. In some cases, it was reported that certain equipment has not been used, but the reason for not using it was not addressed. It should also be noted that typical for organisational accidents, the design issues were not the sole contributing factors found by the investigators. Other contributing factors were the cooperation between pilot and crew, bridge resource management (BRM), fatigue, manning and external factors (fog or other vessels in the vicinity).

Safety Recommendations

The safety recommendations issued by the accident investigation boards were in most cases directed to the shipowner or ship operator. Safety recommendations were in some cases also directed to harbor commissions, maritime and coastguard agencies, pilot associations, the Vessel Traffic Service (VTS) and coastal administrations. In ten of the reports no safety recommendations were issued due to actions already taken by the involved parties. In several reports the investigation issued by MAIB and DMAIB (2021) was the reason for not issuing further safety recommendations. 17 of the safety recommendations directed to shipowners or operators advised a revision of the safety management system (SMS), procedures or checklists. Four reports recommended ECDIS or BRM training. Five reports had safety recommendations addressing the design issues:

- The owner of the *Aurora Explorer* was recommended to carry out and document risk assessments of operational changes.
- The owner of the *City of Rotterdam* was recommended to inform the crew and pilots about the risk of spatial distortion occurring due to the unusual shape of the bridge, particularly when standing away from the centreline or a navigation station.
- The owner of *MV Finnarrow* was recommended to ensure the status of the fin stabilisers had sufficient procedural and visual checks to prevent them being left deployed when the vessel enters port.
- The owner of *Red Falcon* was recommended to review the method of determining the orientation of the vessel displayed on the ship's electronic chart system and to ensure that the system was not solely reliant on the operation of a toggle switch.
- The investigation report regarding the grounding of *Ovit* was the only report having a safety recommendation to an equipment manufacturer. They were advised to improve the management of safety critical information in their ECDIS system.

Shipowners' Response

The shipowner's actions taken after the accidents were reported in 25 of the 28 accident investigation reports. In most cases the response was a combination of several actions. The solution used in most cases (19 reports) were revising existing or introducing new procedures and checklists. Performing BRM training or ECDIS training was reported in 13 reports. Distributing a circular, report or safety bulletin about the accident was reported in 12 investigation reports. In eight cases the shipowners reported doing a change or upgrade of bridge equipment or bridge layout (in addition to training, circulars and procedures):

- *Arrow*: The ECS system was upgraded.
- *Aurora Explorer*: The setup of the manoeuvring system was changed and the pitch on the propeller was adjusted back to system supplier's recommendations.

- *City of Rotterdam*: A bow tip marker on the centreline immediately ahead of the centre bridge window was installed to provide a reference point from any position on the bridge. The length of the VHF handset wires was increased to enable the radios to be used from the forward centreline conning position. Notices warning of relative motion illusion was posted in several positions.
- *Commodore Clipper*: An ECDIS repeater display was fitted at the chief officer's position.
- *Express 1*: Equipment was moved, and workspaces re-arranged so only navigation is performed on the bridge.
- *Nils Holgersson*: The button for triggering the automated crash stop sequence was made bigger and apart from other buttons.
- *Red Falcon*: The positioning of the radar units was adjusted on all 'Raptor' class vessels so that they are more visible to the person conning the vessel from the side of the forward and aft manoeuvring consoles.
- *Stena Nautica*: The old hand steering wheel was placed on top of the new one. A counterweight was placed on the wheel to force it to neutral position and a fixing hook was added to keep wheel centred.

DISCUSSION

Human and organizational factors are part of the IMO guidelines for maritime accident investigations (IMO, 2013). Design of technology is an important part of the ship bridge sociotechnical system. As such, the identification of design issues in maritime accident investigations are an important step towards improving and managing this risks in the sociotechnical system. The question remains of what can be learned from these investigation reports. The review of the 28 reports in this study resulted in six categories of human-technology cooperation issues. These issues are consistent with design issues previously found in maritime as well as other high-risk industries (Oltedal & Lützhöft, 2018; Woods et al., 2010). For category 2 and 3, not using or unexpected use of electronic equipment, ECDIS was by far the most frequently occurring equipment. The recently published study report by MAIB and DMAIB (2021) regarding the use of ECDIS, pointed at several challenges faced by navigators due to the inadequate design of ECDIS. The report found that these challenges led the users to implement workarounds and a minimalist approach, seen in the investigation reports as non-use or unexpected use of equipment. The report by MAIB and DMAIB points towards structural flaws in the way new navigation technologies are designed and implemented and recommend that principles for human-centered design should be followed in the maritime industry. This conclusion is valid also for the other design issue categories identified in the investigation reports. The underlying common theme for all six categories is that those who design, purchase and install ship bridge equipment does not have a sufficient understanding of the navigator's work tasks and work context, i.e., the end-user needs.

The accident investigation boards' safety recommendations and the shipowners' response to the accidents were mainly revising the SMS, revising or introducing procedures and checklists, as well as crew training. These responses put the responsibility for an improved human-technology interaction on the human operator. The assumed solution is that the human should adapt better to the technology rather than adapting technology to better support the human.

Safety recommendations that addressed the identified design issue from the point of view that design of technology should be changed or reviewed, were found in five of the 28 investigation reports. Shipowners addressing the design issue by doing something with the design or bridge equipment was reported in eight of the investigation reports. However, both the safety recommendations and the actions by shipowners were local fixes to make sure the exact same accident will not happen again. For example, installing a bow tip marker on the centerline and posting notes to warn about the possibility of relative motion illusion on board the *City of Rotterdam*, or placing a counterweight on the wheel to force it into neutral position and adding a fixing hook to keep wheel centred on *Stena Nautica*. Such local fixes will not prevent other potential design flaws to combine with other events and create new accidents in the future. The only report explicitly recommending improving design was the *Ovit* investigation report, where the equipment manufacturer was recommended to improve their ECDIS design.

For the maritime industry to learn from accidents and improve future bridge design, it is important that design issues are not only identified by the investigators, but they should also be described and investigated in more detail. In addition, applying a systems approach to accident investigations may contribute to investigate beyond the cause 'human error' and recommend solutions and lessons learned on an organizational or system level. The lessons to be learned should be fed back in a useful way to the relevant stakeholders, like regulators, designers, purchasers and installers, so new designs can possibly become more human-centered. Human-centred design may add value for both seafarers and shipowners (Costa & Lützhöft, 2014) and design considerations should be part of managing risk in any company.

CONCLUSION

This paper reviewed maritime accident investigations where design issues have been identified as contributing factors. The design issues were categorised in six categories: 1) Bridge layout; 2) Not using available electronic equipment; 3) Unexpected use of electronic equipment; 4) Mode confusion; 5) Lack of information about system status; 6) Trust in electronic equipment. The investigation boards' safety recommendations and the shipowners' responses mainly concerned revising the SMS, revising or introducing procedures and checklists, as well as crew training. The few recommendations and actions that concerned improving design of technology were local fixes that do not contribute to learning on organizational or system level.

The increasing instrumentation and digitalization of ship bridges during the last decades has changed the work environment of navigators considerably. These relatively rapid changes in ship technology does not seem to have been accompanied with usability concerns at the same pace, and the operational consequences of new ship bridge design are thus being shouldered by the navigators.

ACKNOWLEDGMENT

This work is supported by the SMACS (Sensemaking in Safety-critical Situations) project financed by the Norwegian Research Council, Grant no. 267509.

REFERENCES

Costa, N., & Lützhöft, M. (2014). The values of ergonomics in ship design and operation. *Human Factors in Ship Design & Operation*, London, UK.

Dekker, S. (2002). *The Field Guide to Human Error Investigations*. Ashgate.

IMO. (2008). *Resolution MSC.255(84). Adoption of the Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code)*. International Maritime Organization.

IMO. (2013). *Guidelines to assist investigators in the implementation of the casualty investigation code (Resolution MSC.255(84))*. International Maritime Organization.

IMO. (2002). *The International Convention for Safety of Life at Sea (SOLAS) V/15*. International Maritime Organization.

Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-You-Look-For-Is-What-You-Find - The consequences of underlying accident models in eight accident investigation manuals. *Safety science*, 47(10), 1297–1311.

MAIB. (2017). *Report on the investigation of the grounding of Muros, Haisborough Sand North Sea 3 December 2016*. (22/2017). Marine Accident Investigation Branch, UK.

MAIB, & DMAIB. (2021). *Application and Usability of ECDIS. A MAIB and DMAIB collaborative study on ECDIS use from the perspective of practitioners*. Marine Accident Investigation Branch & Danish Maritime Accident Investigation Board. Retrieved from https://www.gov.uk/government/publications/application-and-usability-of-ecdis-safety-study

Millar, I. C. (1980). The need for a structured policy towards reducing human-factor errors in marine accidents. *Maritime Policy & Management*, 7(1), 9–15.

Oltedal, H. A., & Lützhöft, M. (2018). *Managing Maritime Safety*. Routledge.

Puisa, R., Lin, L., Bolbot, V. & Vassalos, D. (2018). Unravelling causal factors of maritime incidents and accidents. *Safety Science* 110, 124–141.

Reason, J. (1997). *Managing the risks of organizational accidents*. Ashgate Publishing.

Sandhåland, H., Oltedal, H. & Eid, J. (2015). Situation awareness in bridge operations – a study of collisions between attendant vessels and offshore facilities in the North Sea. *Safety Science*, 79, 277–285.

Schröder-Hinrichs, J. U., Baldauf, M., & Ghirxi, K. T. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. *Accident Analysis and Prevention*, 43, 1187–1196.

UNCTAD. (2022). *UNCTAD United Nations Conference on Trade and Development: Statistics*. UNCTAD. Retrieved from https://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx?sCS_ChosenLang=en

Woods, D. D., Dekker, S., Cook, R., Johannesen, L., & Sarter, N. (2010). *Behind human error* (2 ed.). Ashgate Publising Ltd.

Wròbel, K. (2021). Searching for the origins of the myth: 80% human error impact on maritime safety. *Reliability Engineering and System Safety* 216, 107942.

Paper IV

Cognition, Technology & Work
https://doi.org/10.1007/s10111-022-00700-8

ORIGINAL ARTICLE

"Seafarers should be navigating by the stars": barriers to usability in ship bridge design

Brit-Eli Danielsen[1] · Margareta Lützhöft[2] · Torgeir Kolstø Haavik[3] · Stig Ole Johnsen[4] · Thomas Porathe[1]

Received: 4 January 2022 / Accepted: 2 May 2022

Abstract

Navigating a ship is a complex task that requires close interaction between navigators and technology available on the ship's bridge. The quality of this interaction depends on human and organisational factors, but also on technological design. This is recognized by the International Maritime Organization (IMO) through the SOLAS V/15 regulation that requires human factor considerations in bridge design. The objective of this paper is to investigate how tensions between the main stakeholders' interests and perspectives in ship bridge design may influence the achievement of the goals set forth in the SOLAS V/15 regulation. This objective is explored through a qualitative study in the maritime industry, involving seafarers, shipowners, and equipment manufacturers. We find suboptimal ship bridge design usability to be connected to structural characteristics of the maritime sector, where different aims and perspectives between core stakeholders impairs alignment with respect to conception of work-as-done in the operative environment. We also find that profitability is a major driver for the blunt end stakeholders, for whom the relation between usability and profitability is perceived as a trade-off rather than of synergy. We conclude that there is a need to develop processes, enablers, and management tools to (1) update the understanding of the professional competence needed in the technology dense work environment on ship bridges today; (2) strengthen the maritime stakeholders' awareness of the advantages of human-centred design (HCD) which are both operator well-being and system performance; (3) enable implementation of HCD into existing design and development processes; (4) provide metrics for business cases enabling informed ergonomic investment decisions.

Keywords Ship bridge design · Human-centred design · Usability · Maritime human factors · Human–technology interaction · Work-as-imagined/work-as-done

1 Introduction

Shipping is a vital part of our society as about 90% of the worlds trade in goods and materials are transported by ships. Shipping is also a high-risk industry; ship incidents and accidents can have major consequences for human lives, the environment, as well as the economy. Fortunately, the maritime safety is improving; according to Allianz Global Corporate and Specialty (Allianz Global Corporate & Specialty 2021), the total loss of ships globally is steadily decreasing, down by 50% over the last decade, from 98 total losses in 2011 to 49 in 2020.[1] Although this is a positive development, there are still human lives lost at sea and the effort to improve safety in the maritime sector should continue. The European Maritime Safety Agency (EMSA) recorded 6210 injuries and 496 lives lost in the period 2014–2019 (European Maritime Safety Agency 2020). The fatalities were mainly reported to occur during collisions, which is one of the categories EMSA denotes as 'accidents of navigational nature' (European Maritime Safety Agency 2020).

Navigating a ship is a complex task that involves close interaction between the navigators and the technology and

The first part of the title is a quote from a shipowner informant, reflecting how seafarers are expected to bridge the usability gaps stemming from suboptimal technical design.

Brit-Eli Danielsen
brit.e.danielsen@ntnu.no

1 Department of Design, NTNU: Norwegian University of Science and Technology, Trondheim, Norway

2 Department of Maritime Studies, Western Norway University of Applied Sciences, Haugesund, Norway

3 NTNU Social Research, Trondheim, Norway

4 SINTEF Digital - Safety, Trondheim, Norway

1 Vessels over 100 GT.

Published online: 27 June 2022

artefacts available on the ship's bridge (da Conceição et al. 2017; Hutchins 1995). Ship bridge design has a significant impact on the cooperative work and its output (Lützhöft and Vu 2018). Still, when maritime accidents occur, the cause is often attributed to 'human error'. It has been estimated that 'human error' has been a contributing factor in 75–96% of marine incidents (Dhillon 2007; Rothblum 2000), thus portraying humans as a major problem in the maritime system. However, the contributing factors found in accident investigations reflect that the investigations are performed with an underlying set of assumptions about why accidents happen (Lundberg et al. 2009). Maritime accident investigations tend to pay less attention to how human, technological and organizational factors interact in sociotechnical systems (Schröder-Hinrichs et al. 2012), and such omissions may be an impediment to learning from the accidents (see, e.g., Marine Accident Investigation Branch 2017), as well as learning from that which works well.

Dekker (2005) has argued extensively against using 'human error' as an isolated cause of incidents and accidents. Among the arguments is the occurring empirical observation that human actions take place in material and technological contexts that afford and invite to ways of working that are not always considered in the design phase. While new technical solutions often get the credit for improved safety, but not the blame for the accidents that happen, Dekker and the field of resilience engineering calls for a more balanced view on both successes and failures in sociotechnical systems.

That design can contribute to 'human error' was seen in the collision between the *City of Rotterdam* and the *Primula Seaways* in the river Humber in 2015 (Marine Accident Investigation Branch 2017). The *City of Rotterdam* had an unconventional design with a hemispherical shape of the bow, intended to reduce wind resistance and provide better fuel economy. As a result, the window in the vessel's bridge tilted inwards at the top and only the front window on the centreline looked ahead, all the other windows framed a view off the centreline axis. In the situation leading up to the accident, the *City of Rotterdam* was on the port side of her intended track due to the wind and the tidal stream. The pilot intended to manoeuvre the ship further to starboard to pass the oncoming ship port to port, and while doing so he communicated with both the Humber Vessel Traffic Service and the *Primula Seaways* over very high frequency (VHF) radio. The VHF radio was located below a window on the starboard side, which was off the vessel's centreline axis. Looking out of this window the pilot experienced a relative motion illusion in which the vessel appeared to be heading in the direction he was looking. The pilot made course corrections and believed that the vessel was heading towards the starboard side of the navigation channel, but the heading was not altered significantly beyond the axis of the channel. Hence, the *City of Rotterdam* remained on the port side of the channel, and when this was realized it was too late to make the necessary course corrections. As a result, the ship collided with the inbound *Primula Seaways*, port bow to port bow. In the accident investigation report the Marine Accident Investigation Branch (MAIB) points out that although innovations in ship design have the potential to make positive contributions to safety, a stricter adherence to the ergonomic principles in SOLAS V/15 should have been applied in this case (Marine Accident Investigation Branch 2017). The accident investigation found that several pilots found piloting the vessel 'disconcerting' or 'uncomfortable' due to the design of the bridge. The report states that operating this ship for several years without navigational accidents was largely due to adaptations and coping strategies by the crew and pilots, such as placing a cord on the centreline window and a strategy of mainly standing behind the centreline window (Marine Accident Investigation Branch 2017). Still, both the pilot and the master of the *City of Rotterdam* received suspended sentences of 4 months in prison for their involvement in the collision.

The design effort in this case was done with fuel saving as a goal and the unintended consequences of the design on other parts of the work system were not understood by designers, shipowner, or the regulators. The concerns raised by pilots and crew and their adaptations to cope with the design could have been a cue for understanding that this design represented a vulnerability in the system. The blaming of sharp-end operators for such accidents shows that there are still improvements to be made in the understanding of the human element in the maritime industry (Hetherington et al. 2006).

The current study is part of a research project focusing on how sensemaking in the sharp end of maritime operations can be supported by human-centred design of safety–critical systems. Human-centred design aims at making systems usable and useful by focusing on the needs and requirements of the users (International Organization for Standardization 2010).

The International Maritime Organization (IMO) has in regulation V/15 in the international convention for the Safety of Life at Sea (SOLAS) implemented human factor considerations in its 'principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures' (International Maritime Organization 2002). However, lack of usability in the design of ship bridges and ship bridge equipment is a persistent challenge in the maritime industry (Costa and Lützhöft 2014; Lützhöft 2004; Millar 1980). The objective of this paper is to investigate whether differences in the main stakeholders' interest and influence on usability in ship bridge design, as well as their perspective on work and professional competence, may influence the achievement of the goals set forth in the

SOLAS V/15 regulation. This topic is explored through a qualitative study of the maritime sector involving seafarers, shipowners, and equipment manufacturers. The tensions between the main stakeholders' interests are implied by the quote in the paper title from an interview with a shipowner informant.

In the next two sections, we present the background information for the study. Our methodological approach is presented in Sect. 4, while the results are presented in Sect. 5. The findings are discussed in Sect. 6, followed by the conclusion of the study.

2 Background—design in regulation and practice

2.1 Ship bridge design

Design is the specification of an object intended to accomplish goals within a particular environment, as well as satisfying certain requirements and constraints (Ralph and Wand 2009). Design is also often used to describe the design object—the result of the specification in the form of a product, system, or process. The design of a ship's bridge is the sum of the design activities undertaken by equipment manufacturers for the different pieces of equipment, as well as the procurement and integration process, where the different pieces of equipment are put together on the bridge to form a complete ship bridge work environment. The use of the technology by seafarers can be seen as a secondary design process through their adaptation to and of technology to make it work in practice (Carroll 2004; Hovorka and Germonprez 2010).

2.2 Regulations guiding ship bridge design

The International Maritime Organization (IMO) is responsible for the international regulatory framework for the shipping industry. The IMO exercises this responsibility through a number of instruments, one of which is the International Convention for the Safety of Life at Sea (SOLAS). Ship bridge equipment is regulated through SOLAS Chapter V, Safety of Navigation. Regulation V/19 outlines the carriage requirements for navigational systems and equipment. Depending on the size of the ship, required equipment can include magnetic compass, nautical charts (electronic and/or paper), Global Navigation Systems (GNS) receiver, radar, echo sounder, speed and distance measuring devices. The equipment is subjected to type-approval as well as classification requirements by the classification societies, which ensures its conformity against the applicable standards.

Regulation V/15 concerns 'Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures'. SOLAS regulation V/15 is the only requirement addressing human–technology interaction. This regulation sets forth that:

> All decisions which are made for the purpose of applying the requirements of regulations 19, 22, 24, 25, 27 and 28 and which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge and bridge procedures* shall be taken with the aim of:

1. facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions,
2. promoting effective and safe bridge resource management,
3. enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays,
4. indicating the operational status of automated functions and integrated components, systems and/or sub-systems,
5. allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot,
6. preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot, and
7. minimizing the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action.

* Refer to Guidelines on ergonomic criteria for bridge equipment and layout (MSC/Circ.982). Performance standards for IBS (resolution MSC.64(67); annex 1); and for INS (resolution MSC.86(70); annex 3). (International Maritime Organization 2002).

Human factor considerations are implemented in this regulation, and it also points to a set of further guidelines and performance standards. Functional or goal-based regulations have the potential to require a certain standard while still allowing for innovations. However, these rather high-level functional goals are not easily translated into measurable goals for designers, auditors, and classification societies to use.

The maritime industry is global and highly competitive and the focus on cost and profitability (Størkersen et al.

2017) often makes companies concentrate on how to be auditable with the least effort (Almklov et al. 2014). Low prioritizing of usability in bridge design may be connected to a lack of routines and methods for performing cost-effect estimations of ergonomic investments in shipping (Österman and Rose 2015; Österman et al. 2010). However, the maritime industry is diverse and some parts of the sector, for instance the offshore sector in Norway, is known to go beyond compliance (Almklov and Lamvik 2018).

2.3 Stakeholders in ship bridge design

The ship design and construction processes are complex and involve many stakeholders: seafarers, shipowners, naval architects, classification societies, regulatory authorities, shipbuilders, equipment suppliers, ship managers/operators, unions, and insurers (Rumawas and Asbjørnslett 2014). In this paper the scope has been limited to three key stakeholders: seafarers, shipowners, and equipment manufacturers. The seafarers are the operators at the sharp end utilizing the ship bridge design and equipment to do their job. The work on the ship bridge can be described as a sociotechnical system in which humans, organisational structures and technology must interact to provide a successful system outcome (Walker et al. 2008). At the blunt end, shipowners are the stakeholders that invest their money in the ship; they may initiate shipbuilding and specify arrangements and equipment to be installed. They determine which flag state and which classification society is to be used and the operation management. The equipment manufacturers are also part of the blunt end. They have a significant impact on the ship bridge work environment as designers and developers of navigational and related ship bridge equipment. Research has underlined that for human-centred design to be successful in the shipping industry, the stakeholders' collaboration and the application of human factor knowledge and principles should be strengthened (Earthy and Sherwood Jones 2010; Mallam et al. 2017; van de Merwe 2016).

2.4 Human-centred design and usability in the maritime industry

A framework for performing human-centred design (HCD) is outlined in the ISO standard ISO9241-210 (International Organization for Standardization 2010). HCD methods, where end users are involved throughout the design and development process, generally contribute to usability and operational efficiency of organizations (International Organization for Standardization 2010). Usability is in this standard defined as the 'extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (International Organization for Standardization 2010).

That design of technical systems on ships would benefit from implementing human factor knowledge has been argued by scholars for decades (Lützhöft 2004; Millar 1980) and continues to be called for (Ahola et al. 2018; Costa and Lützhöft 2014; Danielsen et al. 2021; Gernez 2019; Mallam et al. 2015; Praetorius et al. 2015). Although seafarers are very good at adapting to their environment, e.g., by doing integration work (Lützhöft and Nyce 2008), at times the combination of incompatible technology and other situational factors exceed human abilities and the resulting 'human error' lead to an incident or accident (Lützhöft and Dekker 2002; Nilsen et al. 2016; Puisa et al. 2018). Dekker (2005) argue that humans contribute to safety provided they are assisted by their system. Previous research has found that it may be challenging for designers to develop an understanding of the end users and their work environment (Busby and Hibberd 2002). Field research to inform design in the maritime industries has rarely been performed, although Lurås and Nordby (2015) argue that field research is paramount for designers to gain detailed knowledge about the environment they design for. Different designers may have very different perceptions of the navigator's role in relation to the technical systems (Meck et al. 2009). Of the different approaches applied to improve ship bridge design, researchers have developed design guidelines and implementation tools to contribute to cross-vendor integration and consistent user interfaces (Nordby et al. 2019). Multidisciplinary design may be challenging due to the differing fundamental understanding and practices between classic engineering and human factor disciplines (Petersen 2012; Petersen et al. 2015) and it has been suggested to implement human-centred design knowledge into maritime design engineering education to bridge this gap (Abeysiriwardhane et al. 2016). There are examples of human-centred design processes being performed in the maritime industry (Bjørneseth 2021).

3 Maritime design and safety—from the blunt end to the sharp end

In his portrayal of accidents as a process developing from the blunt end to the sharp end, Reason (1997) distinguishes between active failures and latent conditions. In this theoretical model active failures occur due to sharp-end operator actions instantly impairing barriers, while latent conditions refer to decisions and actions taken by the blunt end—those removed from the direct control interface but who still affect the outcome, for instance regulators, manufacturers, and managers. Reason exemplifies latent conditions by manufacturing defects, maintenance failures, unworkable procedures, clumsy automation, and poor design. Latent

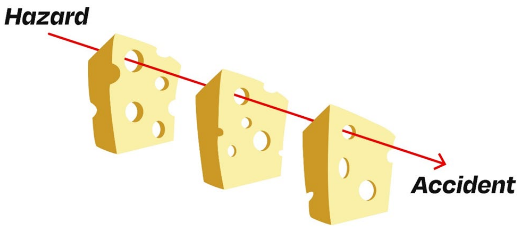


Fig. 1 Swiss cheese model redrawn from Reason (1997). The layers of defence (illustrated by cheese slices) may be physical, technological, organizational, or human applications. The holes in the barriers are created by active failures or latent conditions (Reason 1997)

conditions, such as the bridge design on board the *City of Rotterdam*, can be present for many years in the system before they combine with local circumstances and active failures to allow an accident trajectory to penetrate the many layers of defence (Fig. 1). The latent conditions can increase the likelihood of active failures (Reason 1997) which in the case of poor design are termed *design-induced errors* (Grech and Lützhöft 2016). Yet another way of understanding the sharp end—blunt end relationship is that blunt-end decision-makers are striving for cost efficiency and the sharp-end decision-makers are striving for local optimization of their work, the latter for instance seen as adaptations of design (Rasmussen 1997). This trade-off may according to Rasmussen (1997) cause operations to migrate towards the boundaries of safe performance. Common for these perspectives on accidents, as with the perspectives of Dekker (2005) is the acknowledgement that accidents in sociotechnical systems can seldom be traced back to human errors alone, as there is always an interplay with latent conditions represented by organisational and technological dispositions.

Perspectives, descriptions, and practices of work in the blunt end and the sharp end, respectively, have given rise to the representation of work as *work-as-imagined* and *work-as-done* (Dekker 2006; Hollnagel 2014, 2017). Previous work in our project has found that sensemaking and seamanship not inscribed in formal procedures are important factors in work-as-done on a ship's bridge (Danielsen 2021; Danielsen et al. 2021). Sensemaking is the process, where people actively pick up cues from their environment and develop a sense of what may be occurring, in a process of creating meaning (Weick 1995). It has mainly been described as a conscious process, which is triggered when certain issues, events or situations are either ambiguous, interrupt people's ongoing activity, or create uncertainty about how to act (Maitlis and Christianson 2014; Weick 1995). Professional identity influences sensemaking, which makes the notion of seamanship relevant. Seamanship is a comprehensive concept. Traditionally it has addressed individual characteristics and abilities of seafarers, where using your own good judgement based on knowledge and skills acquired through sailing experience is important (Knudsen 2009; Lamvik et al. 2010). With the increasing digitalization of systems on the ships' bridge the navigator's role has changed towards becoming system managers. Kongsvik et al. (2020) suggested the term *distributed maritime capabilities,* where knowledge and competence are not only seen as individual characteristics but being embedded in technology, procedures, regulations, and seafarers as a holistic system.

When an organization's management is planning and managing operations, alignment with onboard work practices is largely based on work-as-imagined. So are the technical design processes. The importance of designers of equipment and tools for work also having thought or imagination about how work is actually done or will be done in the future is reflected by SOLAS regulation V/15, ISO standard ISO9241-210 and the Resilience Engineering literature. It is challenging to predict how work is going to be done by others that are in a different time and place, often with incomplete information at hand (Hollnagel 2017). When work systems are designed according to work-as-imagined, informal work systems and adaptations may develop to manage local challenges. Informal ways of working may even be seen as a mark of expertise, fuelled by professional pride (Dekker 2006; Knudsen 2009). According to Dekker (2006), gradually increasing the gap between how a system is designed and how it is operated may be 'an important ingredient in the drift into failure' (Dekker 2006, p. 89).

4 Methods

The empirical foundation for this paper consists of qualitative interviews with seafarers, shipowners, and equipment manufacturers, in total 31 informants.

The data are divided into two sets, in the following referred to as the *Traditional Case* and the *Human-centred Design (HCD) Case*. The *Traditional Case* is data collected from several actors representing several sectors within the maritime industry. The findings from this case resonate with previous research (Abeysiriwardhane et al. 2016; Costa and Lützhöft 2014; Gernez 2019; Lützhöft 2004; Petersen 2012) and will in this paper represent the current design situation in the shipping industry. The *HCD Case* represent innovative initiatives, where human factors considerations have been implemented in ship bridge development and design. An overview of the informants in the *Traditional Case* and the *HCD Case* is shown in Tables 1 and 2, respectively. At the time of the study, all the seafarers worked as captains or deck officers. Equipment manufacturer informants worked as designers or engineers and shipowner informants had different roles in company management, that included being decision-makers concerning ship bridge design and

Table 1 Informants in the traditional case

Organization	Job titles	Persons interviewed
Seafarers	Deck officer/Captain	13
2 Equipment manufacturers	Vice President R&D/Senior Designer	2
4 Shipowner companies	Head of HSEQ and Human Factors/Electro Automation Engineer/Marine and HSEQ Manager/Vice president newbuilding	4
Total		19

Table 2 Informants in the HCD case

Organization	Job titles	Persons interviewed
Seafarers	Deck officer/Captain	8
1 Equipment manufacturer	Principal engineer HF and maritime HMI/Service engineer and Project Manager/Salesperson	3
1 Shipowner company	Senior Marine Advisor	1
Total		12

equipment in the company's fleet. All interviews were semi-structured (Kvale 1996), lasted for about 1 h and were conducted by one or two researchers. In the interviews, we asked the informants about their interest in and influence on ship bridge design, usability of ship bridge design, equipment preferences and priorities, and design related to performance and safety. The interviews took place in the informant's workplace or remotely using a web conferencing tool. In both cases, onboard visits and observations complement the interview data. Data collection details for each case are provided in the next subsections.

4.1 The traditional case

The *Traditional Case* includes semi-structured interviews with six deck officers on board three Norwegian passenger ships. This data set also includes a focus group interview with six high-speed coastal vessel deck officers, performed at a Norwegian education facility, and one interview with a lecturer in nautical studies with previous sailing experience as deck officer and captain on chemical tankers and bulk tankers. Further, the *Traditional Case* includes two semi-structured interviews with two designers/developers working in two Norwegian equipment manufacturer companies operating in the international market. We also interviewed four representatives from four international shipowner companies, with fleets consisting of bulk-carriers, oil- and gas-tankers and cruise ships. In total these four shipowner companies own about 600 ships operating around the globe. Two of the shipowner informants worked in a Norwegian department, while the other two were situated in UK and Singapore.

4.2 The HCD case

The *HCD Case* concerns a newly designed integrated ship bridge that intended to focus on usability through a design process connected to an externally financed research project. We interviewed three representatives from the equipment manufacturer responsible for development, design, and sales of this bridge. They worked in the Norwegian office of an international company. We performed observations and semi-structured interviews with eight deck officers working on board the first two ships to have this bridge installed. These were offshore supply vessels sailing on the Norwegian continental shelf. We also performed an interview with a representative from the Norwegian shipowner company owning the two ships visited.

4.3 Analysis

The resulting data material consisted of audio-recorded interviews and field notes. The audio recorded interviews were transcribed verbatim. The transcriptions are the source of the quotes in Sect. 5.

The data were analysed by means of thematic analysis (Braun and Clark 2008), which allows for identification of themes across the data in a systematic and theoretically flexible manner. First the data were divided into the *Traditional Case* and the *HCD Case* and further into the three groups seafarers, equipment manufacturers, and shipowners. The data from the seafarer group included observations, field notes, interviews and focus group interviews that were all coded together. Using NVivo, the data were subjected to

Table 3 Coding of data resulted in the following main themes for each stakeholder group

Informant group	Main theme
Traditional case seafarers	Design issues Adaptations No design influence Seamanship
Traditional case shipowners	No design feedback from operations Profitability as driver Usability responsibility
Traditional case equipment manufacturers	Barriers towards including end-users Customer requirements
HCD case seafarers	Design accommodates work Design influence
HCD case shipowner	Usability is an investment Involvement in design decisions Design feedback from seafarers
HCD case equipment manufacturers	Involving end-users in the design process Challenges with HCD process

open coding, which broke down the material to smaller sections assigned with descriptive labels (codes). After the initial coding the next step included comparing, refining, and clustering codes into themes. The resulting themes from each group are presented in Table 3. The initial coding was performed by the first author. The reliability of the study is strengthened by several researchers being involved in both the data collection, analysis, and writing.

4.4 Method discussion

This study investigates ship bridge design from the different informants' perspectives, thus qualitative interviews were the main data collection method (Kvale 1996). It is not possible to know whether the informants were telling the truth or if they were adjusting their accounts to what they think the researcher or company management would like to hear. However, the topics raised in this study were not of a personal or sensitive nature. The informants seemed to find the topic interesting and willingly shared their experiences and opinions.

A focus group interview was part of the *Traditional Case* data. There are several reasons for using the focus group interview method. From a pragmatic point of view a focus group provide data from several informants in a short period of time. Another advantage of this method is that the informants can discuss and challenge each other's views which may lead to more realistic accounts of what people think than is the case in one-to-one interviews (Bryman 2016). The limitation of the focus group interview method is the possibility for group effects. This may lead to only socially acceptable opinions to emerge or that some informants dominate the discussion, while others are reluctant to talk. It is not possible to know to which extent group effects influenced the focus group interview performed. However, we perceived the discussions to be fluid and although some participants spoke more than others, all interviewees contributed during the discussions. The themes raised for discussion in the focus group interview were inspired by the findings during previous field trips and interviews and the method allowed to explore the findings in more detail.

5 Results

In this section we present the findings from the *Traditional Case* (5.1) and the *HCD Case* (5.2) broken down in subsections covering the three stakeholder groups of this study: seafarers, shipowners, and equipment manufacturers.

5.1 The traditional case

The results from this case are presented in six Sects. 5.1.1–5.1.6. The first two sections reflect the seafarers' perspectives, the next two relate to shipowners, while the last two sections convey the views of the equipment manufacturers in the study.

5.1.1 Seafarers handle design issues by adaptations

Seafarers work environment on traditional ship bridges contain a variety of design issues. The seafarers handle this by adaptation *to* and adaptation *of* design.

On board the traditional ship bridges we observed many examples of design and equipment that did not accommodate the seafarers' work optimally. The seafarers we interviewed describe the same situation. The design issues included lacking the possibility to dim screens and other lights that impair night vision, and many alarms, often with similar sounds, making it difficult to distinguish them from each other. The consoles had little or no grouping of functions, they were cluttered with buttons and levers of which many did not function, and many buttons and levers were small and cumbersome to work with. Different equipment has been provided by multiple vendors with different design and interaction philosophies. There were issues like poorly functioning touch screens, lengthy menus to navigate through and an abundance of information on screens, much of which the seafarers found to be

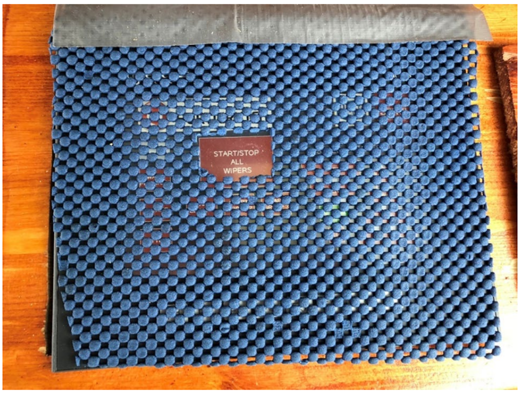


Fig. 2 Example of adaptation of technology by seafarers. All the available alternatives for managing window wipers except the one they need (start/stop all wipers) has been covered

unnecessary for their work. Poor physical ergonomics was evident as we observed officers climbing on consoles or standing on a pallet to reach necessary equipment. Some of these issues may seem like annoying or impractical details, however, as many seemingly small details add up, they create a demanding work environment. One seafarer expressed frustration over cumbersome equipment not fit for the maritime context:

> 'It probably worked well in the office'

The quote points to the gap between those who design, develop, and purchase equipment and the users of the equipment.

We observed how seafarers made physical adaptations to manage these issues. The adaptations included self-made dimming of screens, partly covering screens to quickly find the useful ones (see example in Fig. 2), covering non-functioning buttons, pallets to stand on, lengthening of levers, written notes, and added equipment, like a computer mouse.

Conversely, it is reasonable to assume that things that cannot be managed by adaptation leads to seafarers adapting their way of working in new and possibly suboptimal ways. This is a less visible response than adapting of design, but this dimension was described by one of the seafarers:

> 'Humans adapt to the system. That's seamanship in practice.'

In this quote the seafarer connects seamanship to the human–technology interaction on the bridge. To be able to handle available equipment is part of the skills and knowledge expected by seafarers. Another informant found seamanship to be important for information handling:

> 'The point is you have a lot of information available; you need to have a method for sorting out the information that is important (…) often when you are in a really difficult situation you see the difference good seamanship makes.'

5.1.2 Seafarers lack influence on ship bridge design

The seafarers in the *Traditional Case* express their influence on ship bridge design as being little or none. For a new build, a captain may be invited near the end of the process, where he or she, for instance, can give his/her opinion on the placement of equipment in the consoles. However, one person's preferences may not create an optimal working environment for navigators in general:

> 'What you are allowed as a captain in the building phase is to say something about where that panel is going, usually one of two options, can it fit here, no it must be like this, and so it goes. The next captain must put up with this and adapt accordingly.'

The seafarer is here making an important point regarding end-user involvement in design. Asking one user about his or her opinion of a particular matter may seem like a quick and reasonable approach; however, this approach does not address the needs of the whole user group.

Several examples were given of seafarers being invited by the shipowners to express their opinions, but their input was subsequently disregarded. The shipowners' reasons for this would be connected to cost, space limitations, or quality of equipment. For instance, a shipowner company issued a survey amongst the navigators regarding the choice of new Electronic Chart Display and Information System (ECDIS) on their ships. The shipowner found the ECDIS brand chosen by the navigators to be too expensive and invested in another one. From this experience the seafarer concluded:

> 'I think that survey they did was only to look good on paper.'

Changes or additions in bridge equipment can be introduced without involving seafarers or evaluating the impact on bridge design and ergonomics. There was a strong focus on fuel-saving on board all ships visited, and in one of the ships a fuel-meter monitor was placed in the bridge console right in front of the main working position. It had no function regarding the manoeuvring of the ship. It did not have dimming functionality and had a self-made cover so as not to impair night vision. A picture of this fuel meter was shown to the participants during the focus-group interview. One of the participants commented:

> 'The shipowner is probably satisfied as the OOW (Officer on Watch) will have a constant reminder about fuel consumption (…) If you isolate it, it probably looks like a very good initiative to reduce fuel consumption, without seeing what it brings about for the ergonomics or design of the panel.'

5.1.3 Shipowners balance design requirements and costs

Usability in itself is not on the Traditional Case shipowners' table. For a shipowner to invest more in bridge equipment than required by regulations a convincing business case must be shown. Building a ship is a considerable investment. The shipowners emphasize that the decision to buy a ship is taken on a high level in the company, where the focus is on big picture issues of a ship's construction and specifications, such as cargo-carrying capacity, available number of beds, speed, efficiency, i.e., the factors that are important for a profitable investment:

> 'Why would you spend more money than you need to on the bridge?'

One *Traditional Case* shipowner describes the purchasing process like this:

> 'For us as a bulk ship carrier owner we don't have specific requirements, very general, same as other bulk carriers over the world (…) We might go to the shipyard and check with them, ok we have investment, we would like to buy six new vessels, the shipyard would give us specification of their project, some of the shipyards they have a design, a new project, they build 12 numbers of similar ships. So, this is the spec, do you want this type of ship? How much?'

In these cases, the yard has full responsibility for designing and building the ship, including the ship's bridge, and buying a package with several identical ships is cost saving. If the shipowner has specific requirements, it will incur additional costs. An important point for shipowners is the service agreement with the supplier; they prefer fast and good service available around the globe to avoid delays in operations.

Regulations to assure a minimum standard and equal conditions of competition seems to be appreciated by the shipowners. One of the informants argued that if anything regarding ship bridge requirements needs to change it should be pushed through regulations and requirements:

> 'Should we push the requirements? I think that is where we must go. As soon as you have new guidelines, and those guidelines are explicit and proper requirements that must be followed, then the equipment manufacturers and shipowners will follow, that is only natural.'

On the other hand, the shipowners seem to feel confident that safety of navigation is taken care of by today's design requirements in standards and regulations, so in their view there is no need to use resources beyond that:

> 'as long as you follow the rules and requirements you are safe'

To consider changing bridge equipment in their fleet, the most important factor for shipowners is value for money:

> 'unless the business case is unprecedented, that is you get so much better navigation that you don't have any navigational incidents, you do save money on not having incidents. You also have to consider the training of personnel in using the new equipment and we are talking about 15,000 seafarers (…) that is a lot of money, the business case has to be very strong."

In this case, it seems the risk of an accident must be eliminated before investing in bridge equipment is valued as a good business case. Another shipowner representative described the attitude in the shipping community in general as 'you comply with the rules, then the residual risk you insure'.

5.1.4 Shipowners' view on the human–technology interaction on the bridge

The *Traditional Case* shipowners do not include seafarers in design decisions, and they view the human–technology interaction on the bridge to be the responsibility of equipment manufacturers and seafarers.

The *Traditional Case* shipowners do not find it very useful to include seafarers in decisions regarding bridge design or choice of equipment. They find different seafarers have different opinions and they may prefer equipment that needs repairs very often or is difficult to maintain—factors that are important for the shipowner:

> 'You get a lot of ambiguous response that is difficult to deal with.'

One of the shipowners argued that although seafarers often must deal with bad design, if standards and requirements for the safety of navigation have been met, the work environment is good enough. He thought the focus should rather be on the seafarer's competence in using the equipment:

> ‘a captain should be able to navigate just by the stars right (…) the seafarers should be competent, that’s where things should be improved’

The quote implies that things may need to improve, but from shipowners view the technology is irrelevant as seafarers should have the skills to even navigate without it. Although the informant may have exaggerated to emphasize his point, it is an example of the view that investing in ship bridge design is not connected to navigation performance, hence it should not affect safety or profitability either.

From the shipowners’ point of view the responsibility for usability in ship bridge design lies somewhere else:

> ‘It is the equipment manufacturers that have the responsibility to deliver safe equipment that is easy to use, and of course the maritime institutions have a responsibility to educate the people, so they are capable of handling it’

In addition, this shipowner pointed out that any additional cost that comes with a human-centred design process should be carried by the equipment manufacturers and not lead to increased cost for the shipowners.

5.1.5 Equipment manufacturers inclusion of seafarers in the design process

The equipment manufacturers do have an interest in end-user needs; however, there are several factors limiting their inclusion of seafarers in the design process.

The equipment manufacturers express that it is important to develop user-friendly equipment based on user needs, but simultaneously they must focus on profitability as part of a competitive market. The equipment manufacturer informants have the impression that it is common to find poorly designed ship bridges and ship bridge equipment in the maritime industry today. This impression originates from their own observations, or through sales personnel or service engineers:

> ‘I have a background as a service engineer, I have worked a lot with ships and bridge equipment on board ships. With that I have picked up a lot of frustration from users, particularly captains.’

The equipment manufacturers in our sample do not have a systematic process for involving end users in their design and development processes, but seafarers are asked about their opinions and to test prototypes of specific items and solutions. Two of the companies are located close to training facilities and regularly use instructors with seafaring experience or seafarers visiting to attend courses. There are also examples of good cooperation with shipowners, where the shipowner dedicates crew to participate in testing.

Designers express they would like to spend more time on board, to follow up during building and installation to make sure it is in line with the original design. They would also like to have more feedback from end users after their products have been in use for some time:

> ‘We have technical personnel that in a way do that, we who have the user-centred design part, we sort of don’t have any tasks like fixing a system, at least not that anyone sees. We see the need for that, we should do more’

The designers experience that access to ships is limited due to cost and visits are difficult to plan (e.g., due to weather conditions). Ships may not have the capacity for additional people on board, hence technical personnel needed to do repairs and maintenance are prioritized.

However, the equipment manufacturers’ perception of the end users can also be ambivalent as they find some of the seafarers being very conservative and negative towards new solutions. From the designer’s view

> ‘the users don’t necessarily understand what they need’

The individual user will have his/her own experiences and preferences in mind, and for the designers it can be a challenge to balance negative user input to a particular solution and the more general understanding they develop of the users’ needs.

5.1.6 The equipment manufacturers’ customer is not the end-user

The equipment manufacturers must meet customer requirements which may differ from end-user requirements. To sell their products equipment manufacturers must meet customer requirements and expectations. The customer is either a shipyard or a shipowner, not the seafarers and the customer requirements may be different from user preferences. Ship bridge equipment may be sold directly to the shipyard, where the equipment manufacturers mainly compete on price. None of the equipment manufacturers in our sample are in the lowest price category of equipment. They try to compete on quality and usability and must convince shipowners that investing in their equipment is worth the additional cost. This means that they are not able to reach the shipowners who in their own words ‘buy ships directly from the yard like you buy a car’. Their target customer group are the shipowners who are ‘very close to the yards and demand to get what they want’.

However, the equipment manufacturers experienced that shipowners do not always consider the seafarers' preferences:

> 'The owner wanted the conservative solution, the users wanted the table solution (…) in the end the shipowner decides, not the ones using it. (…) he then overruled it although all the users wanted ergonomic solutions'

To meet customers' requests the original design may have to be adapted or changed. Ships with different operations may have different needs and the products need to be adjusted accordingly. Other times, designers find the change requests stem from the shipowners own, sometimes conservative, ideas concerning what a ship's bridge should look like. The equipment manufacturers experienced that these adjustments could compromise the usability or the original design philosophy.

5.2 The HCD case

The results from this case are presented in three Sects. 5.2.1–5.2.3. The first section reflects the seafarers' perspectives, the next relate to the shipowner, while the last sections convey the views of the equipment manufacturer in this case.

5.2.1 Seafarers experience of user-friendly ship bridge design

On board the two offshore supply ships from the *HCD Case*, the seafarers generally describe the new integrated bridge in positive terms. They refer to it as 'well arranged' and 'user-friendly', and several of the solutions are described as practical and time saving. The seafarers seem to have the necessary equipment readily available when they are seated in their main working position. In the words of one seafarer, they appreciate not having to 'run around to localize switches'.

As opposed to the *Traditional Case*, the visual impression of this bridge environment is tidy, clutter-free and with few adaptations of design. As opposed to the many home-made covers to dim lights on the older ships we visited, the only home-made cover on this bridge was found covering a blue light on a handle base.

One example of a design that accommodates work practice was a display adapted to the Dynamic Positioning checklist, a manual checklist which must be completed several times a day. The information in this checklist is usually found by searching through several screens and menus, while this solution presented all the information for the checklist on a single display, a solution the seafarers appreciated. Another example of design appreciated by the seafarers are the thruster handles. The seafarers emphasized they were big enough and give feedback when put in neutral position. These are features that not all handlers necessarily have. The design thus seemed to have managed to consider both physical and cognitive ergonomics.

The captain on board one of the ships was present at the yard when the ship was completed and several of his suggestions were implemented in cooperation with the equipment manufacturer and the shipowner. He was aware of the trade-offs made when the bridge was installed in terms of space and technical solutions and felt ownership towards the ship and the ship's bridge. He claims that

> 'None of us would like to sail with a conventional bridge again, with all the buttons in the consoles.'

Most issues regarding ship bridge design that seafarers in the *HCD Case* brought up were on a higher level, for example that the integration can make it hard to understand what is going on behind the screens. Integrated bridges also make seafarers more dependent on land organizations, e.g., for performing maintenance, as everything must be programmed into the bridge system by the manufacturer.

5.2.2 Shipowner taking responsibility for ship bridge design

The HCD Case shipowner express an interest in usability and in being involved on a detailed level concerning the bridge equipment in their fleet.

The representative from the shipowner company in the *HCD Case* has previous sailing experience as a captain. The informant express that this company has an explicit interest in crew well-being and considers bridge design and equipment to be part of that. According to their own judgement they spend more resources on bridge equipment than most.

> 'I think we gain on that. We have used resources on it, but throughout the ship's lifetime people on board have much better workdays – as such, it is worth it'

This is a relatively small company and according to our informant the seafarers can pick up the phone and call the responsible person in the shipowner's office to give feedback at any time. The seafarers' opinions have consequences:

> 'the crew were very dissatisfied with that, so we carried the cost for exchanging them'

As opposed to the shipowners in the *Traditional Case*, this informant does not emphasize cost or regulations as priorities when purchasing new equipment:

> 'of course, it means something that the quality is excellent, but the most important thing is the people, the users that are on board and using the equipment, that we know they are content'

To some extent, this shipowner has direct contact with equipment manufacturers and expresses clear opinions on the usability of the equipment. He claims that some manufacturers do not have knowledge about how the equipment is going to be used:

> 'typical touch-screen with a very small screen, and in bad weather you are supposed to hit five choices and my fingers are covering half the screen (…) There is a lot of that – they don't know what it is going to be used for (…) something could clearly be done there'

This shipowner also has close contact with the yards when building a new ship to ensure their specifications are met, especially specifications that go beyond minimum requirements.

> 'It has type-approval, that's what the yards hide behind, it is approved according to existing regulations and then you have to take the cost of finding something else if you haven't done a good enough job of describing what you want in the specifications.'

The *HCD Case* shipowner is also concerned with compliance but still ensures usability of ship bridge equipment by following up equipment manufacturers and shipyards during new-build processes.

5.2.3 Equipment manufacturer performing an HCD process

The equipment manufacturer in the *HCD Case* performed an extensive human-centred design process when developing their integrated bridge concept. A human factors specialist was part of the project team. The result seemed to successfully accommodate user needs. The informants emphasized the involvement of seafarers throughout the design process with the intention of understanding their work, their needs, and to develop a holistic ship bridge design. A central idea was according to a designer:

> 'Enhance safety through lowering the operators' cognitive workload, make it simple by cleaning up the consoles and only place operation critical equipment near the operator'.

Several human factor methods were used, including observation on board ships and in simulators, interviews, eye-tracking, and several iterations of testing prototypes from low to high fidelity. The aim was a high-end product that does not compete on price but on functionality and user-friendliness.

The human factors specialist on the project team was an important driver for involving the end-users by applying human factors methods. The engineer involved in the development project emphasized practical and technical aspects of the design.

> 'Clearly we (the engineers) focus on the technical aspects of the products. The HF specialist has a different background than the rest of us (…) he sees the more theoretical (aspects)'.

The designers and developers experienced that seafarers highly appreciated the opportunity to influence the design and development of bridge equipment. An important realisation was that the seafarers' needs can be different from what the designers imagine:

> 'For me it might be very logical to click 14 times to get into a menu, while a user would like a shortcut, like pressing a button to immediately get to what he needs. It is hard for us technicians to know what the user needs at any time. I can think of something but when you get out in real life it might be the complete opposite.'

A challenge that added time and cost to the design and development process was achieving the necessary certificates required by maritime regulations. The new design challenged the type-approval standards and several rounds with the classification society was necessary. Some of the design solutions had to be changed to acquire approval and the designers found some of the changes to deteriorate usability.

The initial target market was the offshore sector. According to a salesperson in this company, the offshore market is a segment, where, to sell their product, they must convince the navigators:

> 'If the navigators don't believe in it, you can't sell it to the shipowner either.'

Hence, aiming the promotion at navigators is part of their sales strategy. In this part of the maritime industry, it seems that 'the customer' includes the end user. When expanding to other sectors in the industry the original design had to be modified, both due to other operational needs, but according to the designers due to the request by conservative shipowners.

The HCD design process was made possible through an externally funded research project. The informants believed that such an extensive design and development process would not have been performed without the additional funding. It was a challenge to gain an understanding of the additional time and cost required both within the company and in the market. Although receiving positive feedback from seafarers, it has been difficult to get a significant position in the market.

Table 4 Summary of the main findings from the two cases

Stakeholder group	Findings traditional case	Findings HCD case
Seafarers	Consequences of poor design are handled by seafarers through adaptations Seafarers have no influence on ship bridge design	The ship bridge is found to accommodate work well Seafarers have some influence on design decisions
Shipowners	Ship building is high level investment, and shipowners have focus on ship specifications ensuring the investment, not on ship bridge design Ship bridge design investment is only interesting to shipowners if proved as good business case Shipowners' perspective is that compliance to regulation ensures safety Usability is seen by shipowners as the responsibility of equipment manufacturers Shipowners' perspective is that competent seafarers should be able to handle the equipment	The shipowner finds it worth spending resources on usable ship bridge equipment and crew well-being The shipowner accommodates seafarer feedback, and the feedback has consequences The shipowner is involved in ship bridge design through conscious choice of equipment and contact with shipyard
Equipment manufacturers	Equipment manufacturers haves an interest in developing usable equipment However, trade-offs must be made: It is difficult for equipment manufacturers to get access to ships and crews End users' involvement in design process adds time/cost Equipment manufacturers experience that customer requests may differ from end-user preferences	The equipment manufacturer performed an extensive human-centred design process with involvement of seafarers throughout the process The process was possible due to external funding Challenges encountered by equipment manufacturers Standards and regulations do not accommodate innovative solutions To gain an understanding of the additional time and cost required in development phase both within their own company and for the customer

6 Discussion

Humans are important for managing the risk of accidents in complex systems (Rasmussen 1997; Reason 1997) and humans are both restricted and supported by design of technology (Lützhöft and Vu 2018). That usability supports operator sensemaking is recognized by the IMO through the SOLAS V/15 regulation. However, in this study, as well as in earlier research, we have found that lack of usability in ship bridge design is still common in the maritime industry (Ahola et al. 2018; Costa and Lützhöft 2014; Gernez 2019; Mallam et al. 2015; Praetorius et al. 2015). We set out to investigate how tensions between the main stakeholders' interests, and between their views on maritime competence and the role of design, may influence the achievement of the goals set forth in the SOLAS V/15 regulation. The previous section outlined our findings from two different case contexts, one reflecting traditional approach to ship bridge design, and one representing innovative approach paying more attention to usability issues. A summary of the main findings is provided in Table 4. In the following we discuss central themes arising from the seafarers', shipowners', and equipment manufacturers' differing work experiences, requirements, and understanding of ship bridge design, usability, and each other's roles.

6.1 Usability or profitability guiding ship bridge design

Shipowners are the stakeholder that has the last word in deciding what kind of equipment and investments that will be made on their ships' bridges. In the *HCD Case* the shipowner perspective is that usability in ship bridge design is one of the factors ensuring crew well-being and safety, which is an investment the company will benefit from in the long run. This differs from the *Traditional Case* shipowner's mindset, where profitability goals limit their interest in ship bridge equipment to compliance with regulations, and otherwise constitute a profitable investment in a ship. For *Traditional Case* shipowners to be willing to invest in bridge design they must be convinced that it is a good business case. However, to show that usability can also be profitable is a well-known challenge for the human factors discipline (Dul et al. 2012). Since shipping is lacking routines and methods for performing cost-effect estimations of ergonomic investments (Österman and Rose 2015; Österman et al. 2010) more development work is needed to develop processes that manage the trade-off between explicit costs and hard-to-measure gains, such as safety and usability. Although performing HCD requires additional time and cost in the development phase, it has been shown to have positive effects on usability (Lützhöft and Vu 2018; Petersen 2012).

Compared to shipowners, equipment manufacturers are working with a different set of drivers. They do express an interest in including end users in their development processes; however, they must also limit cost on design and development, and they must accommodate the customer requests (which may be different from user requests). One of the challenges for the *HCD Case* manufacturer was to gain an understanding of the additional time and cost such development process required, both from customers and within their own company. It is our judgement, however, that for future HCD processes the cost will be lower if methods and routines are established. We also see that a set of processes and enablers are needed to manage blunt-end and sharp-end feedback and to enable the use of HCD, which at face value may look like a low return investment to the equipment manufacturers.

A picture is emerging where blunt-end decision-makers, such as shipowners and equipment manufacturers, strive for cost efficiency, while the seafarers in the sharp-end strive for local optimization of their work. These findings resonate with previous research over decades addressing lack of usability in ship bridge design (Abeysiriwardhane et al. 2016; Costa and Lützhöft 2014; Gernez 2019; Lützhöft 2004; Millar 1980; Petersen 2012). This study finds that the different stakeholder groups have different perspectives, different drivers and priorities concerning design of technology on the ship's bridge. The *HCD Case* show that a HCD processes is possible to perform in the maritime industry and that it requires the involvement of all three stakeholder groups.

HCD can improve safety (International Organization for Standardization 2010) by reducing the number of accidents. However, the competitive character of the maritime industry forces all actors to focus on maximizing profit and to reduce the number of possible future accidents involve metrics that are hard to value in economic terms. There are, however, other positive effects of HCD but they are equally difficult to value in terms of cost. User friendly equipment may prevent mistakes and injuries, but also reduce stress, which in turn can reduce sick leave, reduce the need for training, and enhance crew well-being and motivation (Costa and Lützhöft 2014), all factors that have a cost attached. However, it is well known that traditional risk analyses and cost-effectiveness analyses performed in connection with evaluating human centred design are characterised by huge uncertainties, and conservative decision makers will find few guarantees in those analyses that investments will pay off. Even though a price tag cannot be applied to HCD, the relation between usability and profitability can be perceived as synergy rather than trade-off.

6.2 The gap between work-as-imagined and work-as-done

The design issues described in Sect. 5.1.1 hamper the bridge's ability to 'facilitating the tasks to be performed', 'enabling (…) convenient and continuous access to essential information which is presented in a clear and unambiguous manner' and 'preventing or minimizing excessive or unnecessary work', which according to SOLAS V/15 is part of what the bridge '*shall'* aim to do (International Maritime Organization 2002). The seafarers appear as the stakeholders with highest interest in usability, which is understandable as usability has direct impact on their daily work. However, seafarers in the *Traditional Case* have little or no influence on ship bridge design, whether it is new builds or retrofitted bridges. The design issues and the adaptations on board are not visible to the blunt end of the organisation as there is no feedback system from operations in place. Seafarers make things work by their adaptation *to* and *of* design, and from management on shore the design may seem to work well enough. The resulting gap between work-as-imagined and work-as-done is thus not recognised by those in position to bridge it.

This gap in information exchange between the sharp and the blunt end is confirmed by the *Traditional Case* shipowners that have limited contact with seafarers. Seafarers may be part of a different division within the company or employed by a completely different company. An illustration of this gap can be found in the following statement by one *Traditional Case* shipowner: 'Seafarers 'should be able to navigate just by the stars'. This statement can be interpreted as a lacking acknowledgement of the maritime developments that have taken place over the last decades, and the consequently changes in seamanship, or more concrete, the nature of seafarers' professional competence as portrayed by Kongsvik et al. (2020). The importance of traditional maritime competencies has been challenged and to some degree replaced by the increased instrumentation on modern ships, making the system operator aspect of seamanship increasingly important. These relatively rapid changes in ship technology have not been accompanied with the same usability concerns and customizations as ship design developments that has taken place over centuries, and that has gone hand in hand with the development of maritime professions. Thus, seafarers tend to be shouldering the operational consequences of ship bridge design processes, where they have not themselves been included in the loop.

Adding to the gap is the shipowners' opinion that usability is the responsibility of regulators and equipment manufacturers. However, minimum compliance with regulations does not ensure usability. To the contrary, a narrow focus on compliance may lead shipowners and system manufacturers to lose sight of the contextual adaptations needed for resilient performance, and the fact that well-functional socio-technical systems are always characterised by the technology being adapted to the humans, and not vice-versa (Hollnagel 2016). Taking this into account would imply an appreciation of the *intention* of the SOLAS V/15 regulation, despite the difficulties of interpreting its letter in terms of measurable goals for designers, auditors, and classification societies.

The gap between equipment manufacturers and seafarers stems from limited involvement to ships and seafarers and the need to accommodate the shipowners' requirements, that may be different from user requirements, and sometimes at the expense of these. Including seafarers in the design process is sometimes challenging when seafarers are negative towards new ideas and design solutions. Both equipment manufacturers and shipowners experience that the input they receive from seafarers is not always useful, suggesting there may be a need for a different approach to end-user involvement, where a mapping of the seafarers' needs goes beyond asking a few individuals about their opinion.

What can we learn from the *HCD case*? We find the gap between the blunt and the sharp end to be smaller in the *HCD Case* than in the traditional case. The ship bridge design seemed to be more aligned with work-as-done in this case and the seafarers experienced having some influence on both the equipment manufacturer and the shipowner during the design and installation process. The shipowner in the *HCD Case* expressed usability and crew well-being as important aspects that ship bridge equipment should accommodate. This shipowner has regular contact with seafarers and their input has consequences for decisions and prioritizations. This shipowner does not place the responsibility for usability somewhere else in the maritime industry, rather they make conscious choices when purchasing equipment and following up the shipyard. This shipowner company was smaller than the ones in the *Traditional Case* which may partly explain the shorter distance between management and seafarers. There may be several reasons for going beyond minimum compliance; from our data it seems the shipowners' mindset or perspectives differs between the *HCD Case* and the *Traditional Case*. This may be connected to the *HCD Case* shipowner having a previous seafarer in a key position and as such an understanding of seamanship in-house. For equipment manufacturers the main difference between the *Traditional Case* and *the HCD Case* is the extensive research and development process performed in the latter. The development process was made possible due to an externally funded research project, so this example might not fit in usual development budgets. Nevertheless, this example shows that the use of a human-centred design process, where the end users are involved in all stages contributes to usability and equipment that supports work-as-done.

Exchange of knowledge between the core stakeholders about the actual performance of operations is necessary for work-as-imagined to resemble work-as-done. The gap between the blunt and the sharp end is hindering information exchange and can thus be seen as a barrier towards usability in ship bridge design. According to Dekker (2006) the gap should be made visible to be able to learn and adapt. With this article we attempt to contribute to that.

6.2.1 Limitations

The findings and generalisability of this study must be seen in light of some limitations. There is a limited number of informants from each stakeholder group. However, the richness of the data collected did allow for an analysis that identified patterns across the stakeholder groups and novel inferences to be made concerning the barriers towards usability in ship bridge design.

A second limitation is that all sectors within the maritime industry, e.g., general cargo and container ships are not covered in this study. Considering that 72% of the world fleet's carrying capacity is carried by bulk carriers and oil tankers (UNCTAD 2022) the data selection does represent a significant part of the sector.

Third, the study has a preponderance of Norwegian informants, and the findings may thus first and foremost reflect a situation specific for the Norwegian maritime sector. Considering the international nature of the maritime industry, where the stakeholders operate, compete, and are regulated internationally, the conclusions drawn may still have broad relevance and should be further investigated to find whether they resonate with the maritime industry in general.

7 Conclusions

The objective of this paper was to investigate how tensions between the main stakeholders' interests and perspectives in ship bridge design may influence the achievement of the goals set forth in the SOLAS V/15 regulation. This topic was explored through a qualitative study in the maritime industry, involving seafarers, shipowners, and equipment manufacturers. We found that although the importance of usability in ship bridge design has been argued for by researchers for decades (Millar 1980), it is a topic that needs continuous attention. Minimum compliance does not ensure usability and the intentions of IMO's SOLAS regulation V/15 are not met in the maritime industry today. We find the lack of usability to be connected to structural aspects of the maritime sector, where there is a gap between the core stakeholders hindering the exchange of knowledge about work-as-done in operative environments. We also found that profitability is a major driver for the blunt-end stakeholders for whom the relation between usability and profitability is perceived as a trade-off rather than a potential for synergy. We conclude that there is a need to develop processes, enablers, and management tools to

1. update the understanding of the professional competence needed in the technology dense work environment on ship bridges today,
2. strengthen the maritime stakeholders' awareness of the advantages of HCD which are both operator well-being and system performance (Dul et al. 2012),
3. enable implementation of HCD into existing design and development processes,
4. provide metrics for business cases enabling informed ergonomic investment decisions (Österman and Rose 2015).

SOLAS V/15 is applicable for *'All decisions which are made (….) which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge'*. In this paper, the decisions are made by shipowners and equipment manufacturers. Seafarers that have the most obvious interest in ship bridge design usability has low influence on these decisions. There are several other stakeholders in the maritime industry, for example shipbuilders, classification societies, regulatory authorities, and insurers, that can also influence ship bridge design in different ways. We suggest future research should investigate how the larger network of stakeholders relates to SOLAS V/15, whether there is a sense of distributed responsibility or a derogation from responsibility for the decisions affecting ship bridge design.

Funding Open access funding provided by NTNU Norwegian University of Science and Technology (incl St. Olavs Hospital - Trondheim University Hospital). This research was funded by the SMACS (Sensemaking in Safety-critical Situations) project financed by the Norwegian Research Council, Grant no. 267509. The project LASH FIRE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814975.

References

Abeysiriwardhane A, Lützhöft M, Petersen ES, Enshaei H (2016) Human-centred design knowledge into maritime engineering education; theoretical framework [Article]. Australas J Eng Educ 21(2):49–60. https://doi.org/10.1080/22054952.2017.1287038

A Bryman (2016) Social Research Methods, 5.ed. Oxford University Press, UK

Ahola M, Murto P, Mallam S (2018) When people are the mission of a ship: design and user research in the marine industry. Mar Des XIII:285–290

Allianz Global Corporate & Specialty (2021) Safety and shipping review 2021. An annual review of trends and developments in shipping losses and safety. Accessed 16 Dec 2021 https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2021.pdf

Almklov PG, Lamvik GM (2018) Taming a globalized industry: forces and counter forces influencing maritime safety. Mar Policy 96:175–183

Almklov PG, Rosness R, Størkersen K (2014) When safety science meets the practitioners: does safety science contribute to marginalization of practical knowledge? Saf Sci 67:25–36

Bjørneseth FB (2021) Unified bridge: design concepts and results. In: Johnsen SO, Porathe T (eds) Sensemaking in safety critical and complex situations: human factors and design. CRC Press, Boca Raton

Braun V, Clark V (2008) Using thematic analysis in psychology. Qual Res Psychol 3(2):77–101

Busby JS, Hibberd RE (2002) Mutual misconceptions between designers and operators of hazardous systems. Res Eng Des 13(3):132–138

Carroll J (2004) Completing design in use: closing the appropriation cycle. In: ECIS Proceedings 44

Costa N, Lützhöft M (2014) The values of ergonomics in ship design and operation. Human factors in ship design & operation. The Royal Institution of Naval Architects, London

da Conceição VP, Dahlman J, Navarro A (2017) What is maritime navigation? Unfolding the complexity of a sociotechnical system. Hum Factors Ergon Soc Annu Meet 61(1):267–271

Danielsen B-E (2021) Making sense of sensemaking in high-risk organizations. In: Johnsen SO, Porathe T (eds) Sensemaking in safety-critical and complex situations: human factors and design. CRC Press, Boca Raton

Danielsen B-E, Lützhöft M, Porathe T (2021) Still unresolved after all these years: human-technology interaction in the maritime domain. In: International conference on applied human factors and ergonomics, virtual conference

Dekker S (2005) Ten questions about human error: A new view of human factors and system safety. Lawrence Erlbaum Associates Inc., New Jersey

Dekker S (2006) Resilience engineering: chronicling the emergence of confused consensus. In: Hollnagel E, Woods DD, Levenson N (eds) Resilience engineering concepts and precepts. Ashgate Publishing Limited, Farnham

Dhillon BS (2007) Human reliability and error in transportation systems. Springer Science & Business Media, Berlin

Dul J, Bruder R, Buckle P, Carayon P, Falzon P, Marras WS, Wilson JR, van der Doelen B (2012) A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics 55(4):377–395

Earthy J, Sherwood Jones B (2010) Best practice for addressing human element issues in the shipping industry. In: International conference on human performance at sea (HPAS), Glasgow, UK

European Maritime Safety Agency (2020) Annual overview of marine casualties and incidents 2020. Accessed 16 Dec 2021

http://www.emsa.europa.eu/publications/item/4266-annual-overview-of-marine-casualties-and-incidents-2020.html
Gernez E (2019) Connecting ship operation and architecture in ship design processes. J Ship Prod Des 35(01):88–101
Grech MR, Lutzhoft M (2016) Challenges and opportunities in user centric shipping: developing a human centred design approach for navigation systems. In: 28th Australian computer–human interaction conference, OzCHI 2016
Hetherington C, Flin R, Mearns K (2006) Safety in shipping: the human element. J Saf Res 37(4):401–411
Hollnagel E (2014) Safety-I and Safety-II: the past and future of safety management. CRC Press, Boca Raton
Hollnagel E (2016) The nitty-gritty of human factors. In: Shorrock S, Williams C (eds) Human Factors and ergonomics in practice: improving system performance and human well-being in the real world. CRC Press, pp 45–64
Hollnagel E (2017) Can we ever imagine how work is done. Hindsight 25:10–13
Hovorka DS, Germonprez M (2010) Reflecting, tinkering, and tailoring: implications for theories of information system design. In: From CSCW to web 2.0: European developments in collaborative design, pp 135–149
Hutchins E (1995) Cognition in the wild. MIT Press, Cambridge
International Maritime Organization (2002) International convention for safety of life at sea (SOLAS) V/15. London: International Maritime Organization
International Organization for Standardization (2010) ISO 9241 ergonomics of human-system interaction: part 210 Human-centred design for interactive systems. Accessed 16 Dec 2021 www.standard.no
Knudsen F (2009) Paperwork at the service of safety? Workers' reluctance against written procedures exemplified by the concept of 'seamanship.' Saf Sci 47(2):295–303
Kongsvik T, Haavik T, Bye R, Almklov P (2020) Re-boxing seamanship: from individual to systemic capabilities. Saf Sci 130:104871
Kvale S (1996) Interviews: an introduction to qualitative research interviewing. Sage, Thousand Oaks
Lamvik G, Wahl A, Buvik M (2010) Professional culture, work practice and reliable operations in shipping. In: Reliability, risk and safety: theory and applications. European safety and reliability conference, Prague, Czech Republic
Lundberg J, Rollenhagen C, Hollnagel E (2009) What-you-look-for-is-what-you-find: the consequences of underlying accident models in eight accident investigation manuals. Saf Sci 47(10):1297–1311
Lurås S, Nordby K (2015) Shaping designers' sea sense: a guide for design-driven field research at sea. In: International conference on marine design 2015. Royal Institution of Naval Architects, pp 53–63
Lützhöft M (2004) The technology is great when it works: maritime technology and human integration on the ship's bridge. Linköping University, Linköping
Lützhöft M, Nyce JM (2008) Integration work on the ship's bridge. J Marit Res 2:59–74
Lützhöft M, Vu VD (2018) Design for safety. In: Oltedal HA, Lützhöft M (eds) Managing maritime safety. Routledge, New York
Lützhöft MH, Dekker SWA (2002) On your watch: automation on the bridge [article]. J Navig 55(1):83–96. https://doi.org/10.1017/S0373463301001588
Maitlis S, Christianson M (2014) Sensemaking in organizations: taking stock and moving forward. Acad Manag Ann 8(1):57–125
Mallam SC, Lundh M, MacKinnon SN (2017) Integrating participatory practices in ship design and construction. Ergon Des 25(2):4–11
Mallam SC, Lundh M, MacKinnon SN (2015) Integrating human factors and ergonomics in large-scale engineering projects: investigating a practical approach for ship design. Int J Ind Ergon 50:62–72
Marine Accident Investigation Branch (2017) Report on the investigation of the collision between the pure car carrier City of Rotterdam and the ro-ro freight ferry Primula Seaways, River Humber, United Kingdom, 3 December 2015
Meck U, Strohschneider S, Brüggemann U (2009) Interaction design in ship building: an investigation into the integration of the user perspective into ship bridge design. J Marit Res 6(1):15–32
Millar IC (1980) The need for a structured policy towards reducing human-factor errors in marine accidents. Marit Policy Manag 7(1):9–15
Nilsen M, Almklov PG, Haugen S, Bye RJ (2016) A discussion of risk influencing factors for maritime accidents based on investigation reports. ESREL, Glasgow
Nordby K, Gernez E, Mallam S (2019) OpenBridge: designing for consistency across user interfaces in multi-vendor ship bridges. In: Ergoship conference, Haugesund, Norway.
Österman C, Rose L (2015) Assessing financial impact of maritime ergonomics on company level: a case study. Marit Policy Manag 42(6):555–570
Österman C, Rose L, Osvalder A-L (2010) Exploring maritime ergonomics from a bottom line perspective. WMU J Marit Aff 9(2):153–168. https://doi.org/10.1007/bf03195172
Petersen ES (2012) Engineering usability. Chalmers University of Technology, Gothenburg
Petersen ES, Nyce JM, Lützhöft M (2015) Interacting with classic design engineering. Interact Comput 27(4):440–457.
Praetorius G, Kataria A, Petersen ES, Schröder-Hinrichs JU, Baldauf M, Kähler N (2015) Increased awareness for maritime human factors through e-learning in crew-centered design. Procedia Manuf 3:2824–2831
Puisa R, Lin L, Bolbot V, Vassalos D (2018) Unravelling causal factors of maritime incidents and accidents. Saf Sci 110:124–141
Ralph P, Wand Y (2009) A proposal for a formal definition of the design concept. In: Design requirements engineering: A ten-year perspective, pp 103–136, Springer, Berlin.
Rasmussen J (1997) Risk management in a dynamic society: a modelling problem. Saf Sci 27(2–3):183–213
Reason J (1997) Managing the risks of organizational accidents. Ashgate Publishing, Farnham
Rothblum AM (2000) Human error and marine safety. National Safety Council Congress and Expo, Orlando
Rumawas V, Asbjørnslett BE (2014) A content analysis of human factors in ships design. Int J Marit Eng 156:251–264
Schröder-Hinrichs J-U, Hollnagel E, Baldauf M (2012) From Titanic to Costa Concordia: a century of lessons not learned. WMU J Marit Aff 11:151–167
Størkersen KV, Antonsen S, Kongsvik T (2017) One size fits all? Safety management regulation of ship accidents and personal injuries. J Risk Res 20(9):1154–1172
UNCTAD (2022) UNCTAD Handbook of statistics 2021. UNCTAD. https://hbs.unctad.org/merchant-fleet/ Accessed 28 March 2022
van de Merwe F, Kähler N, Securius P (2016) Crew-centred design of ships: the CyClaDes project. Transp Res Arena 14:1611–1620
Walker GH, Stanton NA, Salmon PM, Jenkins DP (2008) A review of sociotechnical systems theory: a classic concept for new command and control paradigms. Theor Issues Ergon Sci 9(6):479–499
Weick KE (1995) Sensemaking in organizations. Sage, Thousand Oaks

Paper V

TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 16
Number 4
December 2022
DOI: 10.12716/1001.16.04.10

Somebody Else's Problem? Usability in Ship Bridge Design Seen from the Perspective of Different Maritime Actors

B.E. Danielsen & E.S. Petersen
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT: Navigation is a complex interaction between human, organizational, environmental, and technological factors on the ship's bridge. Today, ships bridges include a broad suite of equipment with both digital and analogue interfaces, covering a range of functions and purposes. Suboptimal usability in equipment and interface design as well as layout of the ships bridge has been reported by researchers for decades. This paper aims to contribute to our understanding of why there has been limited progression in usability in ship bridge design over the last decades, by investigating the stakeholders' different perspectives of their influence, interest and responsibility for usability in ship bridge design. The study is based on interviews with seafarers, shipowners, equipment manufacturers, shipyard, insurance companies, classification societies and a flag state. Usability in navigational equipment and systems on a ship's bridge is required by the International Maritime Organization (IMO) SOLAS Regulation V/15. We find that this goal-based requirement is challenging to follow up both in design, development, and survey work. To achieve usability in maritime equipment and bridge systems ideally requires the actively involvement of end-users throughout the design and development process. We find that the seafarers, the direct end-users, do not have a clear voice in the ship bridge and bridge equipment design and the associated purchasing processes. The other stakeholders appear to recognize the existing shortcomings, and some do show interest in improvements, but the responsibility for usability seem to be fragmented, and they see the potential solutions as being somebody else's problem. We conclude by suggesting both long-term and a short-term way forward for improving usability in ship bridge design.

1 INTRODUCTION

According to the International Maritime Organization "Shipping is perhaps the most international of all the world's great industries - and one of the most dangerous" [1]. The high-risk nature of the shipping industry is confirmed by the European Maritime Safety Agency (EMSA) that registered 6921 persons being injured and 550 persons losing their lives at sea in the period 2014-2020 [2]. 43% of all casualty events in this time period was what EMSA categorise as navigational casualties which includes collisions, contacts and grounding/strandings [2].

Navigation is a complex interaction between human, organizational, environmental, and technological factors on the ship's bridge [3-5]. The ship's bridge can thus be characterised as a sociotechnical system [6, 7] where the design of technology interact with, and thus influence, other parts of the system [8, 9]. Since the general introduction of computerized equipment in the 1970s, there has been a steady increase in electronic and digital products for maritime use, and today, ships bridges include a broad suite of equipment with both digital and analogue interfaces, covering a range of functions and purposes. There is rarely any consistent user interface design across these systems [10] and suboptimal usability in equipment and interface design has been reported by researchers for decades [11-16].

There may be several factors contributing to the current situation on the ship's bridge. One factor is the challenge of designers and developers of technical systems to foresee how factors like time and resource constraints, management pressure or motivation will influence real use at a different time and in a different place [17]. As a result, it is often seen that the human component of sociotechnical systems do not behave as designers expect, or plan for [18]. Technology being designed without appropriate information about the user or context of use is a concern as, for instance, a systems designed-in safety features may not function as expected. For example, when of the bulk carrier Muros grounded in 2016 the accident investigation identified the use of some of the safety features in the Electronic Chart Display and Information System (ECDIS) as a contributing factor to the accident. The investigation report states that "The ECDIS on board Muros had not been used as expected by the regulators or equipment manufacturers." [19]. It thus seems there were limitations in the regulators and equipment manufacturers knowledge about the end-users and the context of use; knowledge that is however crucial when designing for usability [20].

The importance of considering human factors has been recognised by the International Maritime Organization (IMO) through its human element vision [21]. IMO has also addressed ship bridge design through the SOLAS (Safety of Life at Sea) convention regulation V/15. Regulation 15 requires that ship bridge equipment and procedures inter alia shall aim to "facilitating the tasks to be performed (...) making full appraisal of the situation and in navigating the ship safely under all operational conditions", "promoting effective and safe bridge resource management", "enabling (...) convenient and continuous access to essential information which is presented in a clear and unambiguous manner", "preventing or minimizing excessive or unnecessary work, "minimizing the risk of human error".

The IMO instrument also outlines specific requirements for the equipment that ships shall have installed through SOLAS regulation V/19. For all the equipment in V/19, there are also IMO Performance Standards, providing descriptions of high-level functionality required in a particular instrument, and much more detailed IEC Test Standards, where the individual test clauses must be fulfilled to obtain the required type-approval.

Despite the maritime stakeholders' commitment to regulatory compliance, suboptimal usability – which we claim is an indicator of a design which to some degree is unfit for the purpose it is intended for, and thus can be termed 'poor design', seems to be a persistent challenge in the maritime industry. In Reason [22], poor design is the terminology used to describe a latent condition that can be present for many years in a system before it combines with local circumstances and active failures that may result in a maritime accident [23-27]. In practice, the impact of poor design is often mitigated by the ability of users to find creative ways to make systems work [11, 18]. Seafarers are no exception, and they make the bridge system work through both adapting to design and making adaptations of design [3, 28]. Adaptations to design is occurring when seafarers adapt their work strategy to cooperate with the technology. This has also been described as integration work [3]. Adaptations of design can be very visible in the form of self-made covers for dimming screens, covering non-functioning buttons, pallets to stand on, lengthening of levers, written notes etc. [28]. Although seafarers apply strategies to handle their work environment, poor design have the potential to lead to design induced errors [29].

To mitigate, considerable design and development efforts aiming to improve usability in ship bridge design have been performed [10, 30-34], also attempting to increase the understanding of the fundamental issues underlying the present situation The persistence of suboptimal usability has been connected to the multiple stakeholders being involved in the ship building and ship bridge design processes [35]. There may be differences in the level of knowledge of human factors and human-centred design posited by different stakeholders [36]. The stakeholders may represent different interests that are difficult to align during the design process [37] and communication and cooperation between the stakeholders may be challenging [38, 39].

Yet another factor is the competitiveness of the maritime industry, in which many organizations work on very small profit margins and thus prioritize short-term economic gains [7, 16]. As new ship development is driven by economics, human-factor interventions need to be justified in terms of their likely benefits exceeding their anticipated cost [7, 40]. However, there is a lack of knowledge about, and especially methods for, measuring the financial effects of ergonomics which could enable maritime companies to make well-informed ergonomic prioritizations [41] – in other words, developing a convincing business-case based purely on objective data is difficult.

This paper aims to contribute to our understanding of why there has been limited progression in usability in ship bridge design by investigating the issue from the perspectives of a broad set of stakeholders in the maritime industry. The study is based on interviews with seafarers, shipowners, equipment manufacturers, shipyard, insurance companies, classification societies and a flag state. We seek to find factors influencing the low prioritisation of usability in the maritime industry by investigating the stakeholders' different perspectives of their influence, interest and responsibility for usability in ship bridge design. We also suggest a way forward.

The paper is structured as follows: The next section will provide the theoretical background as well as information concerning the ship operation and purchasing process and the maritime design regulations. Section 3 explains the methodological approach, followed by the presentation of the findings in Section 4. The findings are discussed in Section 5, and Section 6 concludes the study.

2 BACKGROUND

2.1 *Key concepts*

Design has been defined in multiple ways. For example, Herbert Simon viewed design as a problem-solving activity that concerns devising "courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 55). Design and development of products and systems in the maritime (or any other) industry must adhere to regulations and stakeholder- or customer requests which constrain or define what the 'preferred situation' may be. Design processes are also limited by factors like time and cost. Thus a more specific definition of design is used: "a specification of an object, manifested by some agent, intended to accomplish goals, in a particular environment, using a set of primitive components, satisfying a set of requirements, subject to some constraints" [42]. In this paper ship bridge design refers to the design of the physical bridge including the equipment, systems and layout of consoles.

The human factors discipline is concerned with achieving two related outcomes of sociotechnical systems: human well-being and overall system performance [43]. It requires a conscious approach of applying human factors theory, principles, data, and methods to the design process to achieve these two outcomes [44]. An essential characteristic of a well-designed system or product is its usability. The ISO standard 9241:210 defines usability as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [20]. To achieve a goal with effectiveness refers to the accuracy and completeness with which users achieve the specified goals while efficiency refers to the resources used, which may be time, human effort, costs, materials, in relation to the results achieved. In this paper, the user is the people who operate the system and make use of the output of the system.

One approach to achieve usability – i.e., what we have chosen to define as 'good design' versus 'poor design', as discussed above - is the Human-centred design (HCD) process. The HCD process as outlined in the ISO standard 9241:210 "aims to make systems usable and useful by focusing on the users, their needs and requirements, and applying human factors/ergonomics, and usability knowledge and techniques" [20].The ISO standard outlines a framework for an iterative design process where the major activities are

- Understanding and specifying the context of use
- Specifying the user requirements
- Producing design solutions
- Evaluating the design

A key success-factor in human-centred design is the actively involvement of users throughout the design and development process [20, 45], recognizing that it is only the users that can provide a profound understanding of their needs and the context of use in which the design object is to function. The users can be involved in all the activities outlined in the HCD process, they are an important source for relevant data obtained through methods like for example observation, interviews, task analysis, the users can participate in design activities, or they can evaluate and test prototypes and design solutions.

In general, the benefits of usable systems are increased productivity, reduced errors, reduced training and support, improved user acceptance and enhanced reputation [20, 46]. Research in the maritime industry has found that usable systems benefit seafarers in terms of improved physical, psychological, and social well-being, higher motivation and job satisfaction, as well as improved performance [13, 43, 46, 47]. Cost-benefit trade-offs are in general a key consideration for adopting HCD methods [45]. Hence, it is important to note that usability may also benefit the shipowners through a safety gain arguably achieved through good design, as well as improved operational performance in terms of productivity, efficiency, quality, a better reputation for hiring and retaining personnel, reduced training and operating costs [46, 47].

2.2 *Maritime stakeholders*

Stakeholders may be individuals, groups or organizations "who have an interest (stake) and the potential to influence the actions and aims of an organization, project or policy direction" [48]. The stakeholders are thus identified in relation to a specific issue or project. The relation to the issue can also be described as "those who are affected by or who can affect a particular decision or actions" [49]. The purpose of collecting and analysing data about stakeholders is to develop an understanding of how decisions are taken in a particular context and to possibly identify opportunities for influencing the decision-making processes [48]. Maguire [46] recommends identifying a broad set of stakeholders as part of the HCD process, including recipients of output from the system, marketing staff, and purchasers, and to this end, Dul [43] identified four main stakeholder groups of system design:

- System actors: i.e., employees, product users, who are part of the system and who are directly or indirectly affected by its design and who, directly or indirectly, affect its performance.
- System experts: i.e., professionals such as engineers who contribute to the design of the system based on their specific professional backgrounds.
- System decision makers: i.e., decision makers (e.g., managers) about the (requirements for) the system design, the purchasing of the system, its implementation and use.
- System influencers: i.e., media, governments, standardisation organisations, regulators.

Seeing this in the maritime context, this industry comprise numerous actors that are either directly involved in the transport of goods or people, or in supporting areas of activities, inter alia: ship operators, shipowners, the crews, shipbuilders, design firms, equipment suppliers, brokers, agents, repairers, the IMO, flag states, coastal states, classification societies, insurance companies, , education/training providers, financiers, cargo owners as well as port/terminals [50].

2.3 *Maritime design considerations*

In the ship design process, different stakeholders can represent vastly different interests and their expectations towards the design solution may for such reasons not be aligned. Indeed, a lack of relevant information, ineffective collaboration, conflicts and trade-offs may result in an excessive addition of features to satisfy the expectations of all stakeholders as the design process unfolds [37] but such additional capabilities may not cause a premium on the charter rate that can justify the added cost and thus negatively affect business outcome [37]. Of particular interest to maritime design is the issue of system design where authority is distributed within and among several organisations with design decisions spread over time, has been described as "sequential attention to goals" [51]. The sequential attention leads to decisions to be taken without being aware of how they influence other decisions. Gernez [52] differentiate between two stakeholder groups involved in ship design: designers (ship designer, sub-contractors, shipyard) and the end-users (ship owner, ship manager, operator, and crew). The difficulties of sharing information between the technical expertise of the designers and the operational experience of the end-users, is a factor that may contribute to suboptimal or unsafe ship design solutions [52]. Part of this picture is that designers and developers tend to assume that their experiences are similar to the users' experiences so they can see themselves as fair representatives of the users they design for [53]. Both the interest in, and the power to influence human factors in the maritime industry is greatly differentiated between stakeholders [54], and to illustrate this issue, the human factors community have stronger relationships with system actors than with systems experts and decision makers, i.e., the stakeholders that have the power to influence system design [43]. Also, the competitive nature of the industry entails the relation between usability and profitability is perceived as a trade-off rather than synergy [55].

2.4 *Ship operation and purchasing process*

The shipping industry is international and "a ship can be owned in one country, operated from another country, and registered by a third country, and crew can hail from any country" [50]. The industry consists of different business sectors depending on the type of cargo being carried (bulk, tank, container or specialized cargo, to mention a few), whether it is providing services like port tugs and bunker ships, services running on fixed schedules like container lines, passenger and cruise ships, or whether it is organized as tramp. The different sectors may have differently organized economic models or organizational structures to compete for business. What the sectors do have in common is the highly competitive terms of its business [56]. An essential activity in shipping is thus to match the capacity to carry cargo or perform given services with the needs of customers, shippers or charterers. "This includes not only providing the right service at the right price, but also the buying, building, chartering-in and chartering-out of ships in anticipation of international, but also local and regional, market conditions."[56].

The shipping companies has access to a global labour force as the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) ensures basic requirements on an international level, and the STCW certificates of competence are internationally accepted. Crewing management can thus be outsourced, and shipowners have the possibility to optimize cost structures through replacing the crew, or parts of the crew, with workers from a different nationality. The recruitment period for seafarers may be limited to a single voyage or a contract for up to a year. Seafarers employed through a crewing agency mainly interact with the crewing agency despite that their contract of employment may be with the shipowner. (Walters & Bailey, 2013).

Shipowners can decide to expand their fleet by investing in second-hand ships or new ships, as well as through the use of outsourcing and chartering, which occurs frequently and makes a distinction between ownership and the operation of a ship [56]. Investing in a new ship can be done through buying a standard ship type developed and 'mass' produced by a yard. In this case the shipowner has little or no influence on choice of equipment on board. An alternative approach is to initialize a ship design process based on the shipowner specific needs in terms of market, cargo type, expected area of operation, and possible equipment preferences and hull or machinery constructional feature preferences. Shipowners may approach shipyards with a preliminary specification and general arrangement plan prepared by a ship design bureau, or shipyards may have their own in-house naval architect departments that can provide both design and, subsequently to an agreement between the parties, the production specifications and drawings of a ship, usually also including the 'maker's list'. In some detail, the maker's list is a list of suppliers negotiated and approved for delivery of equipment, machinery or services to a particular (series of) ship to be built, which forms an important part of the contract between the shipowner and the shipyard, considering that it sets a certain agreed standard and limits the potential purchasing choices for the shipyard. The main participants contributing to the ship design process are the shipowner, the shipyard, and the ship designer [57]. The suppliers of materials and equipment are selected through negotiations and the number of suppliers for a single ship may add up to 350 [57].

2.5 *Maritime design regulations*

The global nature of the shipping industry has led to regulations mainly being developed internationally through the International Maritime Organization (IMO). The international Convention for the Safety of Life at Sea (SOLAS) was incorporated by IMO when it was founded in 1958, and this convention continues to be the most important international maritime safety mechanism [58]. The SOLAS convention governs safety through 14 chapters that specify minimum standards for the construction, equipment and safe and secure operation of ships [59]. Chapter V, Safety of Navigation, identifies a number of navigation safety services which should be provided by Contracting Governments and include subjects like maintenance of meteorological services for ships, the ice patrol service, search and rescue services and routeing of ships.

However, SOLAS Chapter V also relates to equipment onboard ships conforming with the convention, which counts almost all ships in the global trading fleet. As such, SOLAS Chapter V Regulation 15 (V/15) sets forth "Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures" [60]. Important in the present context, these seven principles require a series of usability considerations to be considered in bridge design, bridge equipment and procedures. Regulation V/15 is a goal-based regulation (also referred to as function-based regulations) that sets forth objectives which the designed product or system shall achieve, however without offering a detailed description of how to achieve them. Detailed guidelines for physical ergonomic criteria for bridge equipment and layout is made available in the IMO MSC/Circular 982 [61].

The principles in Regulation V/15 are applicable for decisions made for the purpose of applying the requirements of several other regulations in Chapter V, including Regulation V/19 "Carriage requirements for shipborne navigational systems and equipment". Regulation V/19 outlines specific requirements for the equipment that ships shall have installed, for example compass, charts, ECDIS, radar, automatic identification system (AIS), echo sounder, speed measuring devices, track and heading control. For each of such instruments, and underlying /supporting Chapter V/19, IMO has issued Performance Standards for the devices in question. One-by-one, the Performance Standards outline, usually in rather high-level language, the functionalities, and qualities of the particular instruments, and thus serves the purpose of ensuring that seafarers are provided with the equipment and tools deemed needed to perform a particular task, independently of the manufacturer of the devices. However, due to the brevity and nature of the IMO Performance Standards, they are less usable as test standards to prove conformance, and for this purpose, the International Electrotechnical Committee (IEC) develops highly detailed test standards matching the IMO performance standards. In other words, the practice is so that manufacturers relate to the IEC Test Standards when they develop their instruments, and the IEC Test Standards in turn form the base for the issuing of Type Approval certificates of navigational instruments. This goes for any kind of requirements, i.e., also including requirements to ergonomics of equipment, where the combined requirements contained in the appropriate IEC Test Standard and the over-arching ergonomics requirements contained in IEC 60945 [62] and IEC 62288 [63] are to be fulfilled in entirety.

Ships flying the flag of a European Union (EU) country, or one of the European Free Trade Association (EFTA) countries, are further constrained to only install marine equipment marked with the EU Marine Equipment Directive (MED) mark of conformity, also known as the "wheel mark". The "wheel mark" is issued by notified bodies that verify the equipment is in compliance with all applicable standards for design and production, including the IEC Test Standards IEC60945 and IEC 62288, all together specifying the minimum performance requirements, methods of testing and required test results of particular devices.

There are several test methods outlined in IEC62288 that can be applied for validating the equipment's compliance: inspection of documented evidence, measurement, observation, and analytical evaluation. Of particular relevance for this paper, it is noted that this standard describes how testing according to the requirements of 'analytical evaluations' are to be performed:

"Analytical evaluations may be made by a relevant expert with the necessary education, skills and/or experience to make an informed and reliable judgement concerning the presentation of information, its appropriateness and usability. It is used for the evaluation of properties which can be judged only in the context of other information or knowledge which requires the tester to make an informed assessment of the likely performance of a typical user of the presentation." [63]. The appointment of "a relevant expert" is at the discretion of the notified body.

The flag state is responsible for national enforcement of the international maritime regulations. The Norwegian legislation directly addressing ship bridge design is found within Regulation 1157 2014-09-05 [64] where SOLAS Chapter V/15 is implemented. The flag state administrations are responsible for surveying and issuing certificates that confirm ships are designed, constructed, maintained, and managed in compliance with the IMO regulations for ships flying their flag, a task which the flag state administrations at their own discretion may delegate either to surveyors nominated for the purpose or to recognized organizations (ROs), to perform the inspections and surveys required to validate conformance.

3 METHODS

The empirical foundation for this paper consists of interviews with seafarers, shipowners, a shipyard, equipment manufacturers, a flag state, classification societies and insurance companies. In total, 42 informants have been interviewed in the period 2018-2021. An overview of the informants is presented in Table 1. The maritime sector consists of a vast array of possible stakeholders in ship bridge design. The stakeholders in this study were selected using a snowball sampling approach, initiated through the interviews with the end-users - the seafarers - and further developed through the subsequent interviews with informants from other stakeholder groups.

All seafarers, except one, worked as captains or deck officers in Norwegian companies at the time of the interviews. One seafarer was a lecturer in nautical studies with previous sailing experience as a captain. Semi-structured interviews were performed during field trips on board three passenger ships and two offshore supply vessels. The onboard visits allowed for observations that complement the interview data. In addition, a focus group interview with six high-speed coastal vessel deck officers was performed at a Norwegian education facility.

Table 1. Overview of informants in the study.

Stakeholder group	Job titles	No. of persons
Seafarers (working on passenger ships, high-speed coastal vessels, offshore supply vessels)	Deck officer/Captain	21
5 Shipowner companies (with fleets consisting of bulk-carriers, oil- and gas-tankers, cruise ships, offshore support vessels	Head of HSEQ & Human Factors/ Electro Automation Engineer/Marine and HSEQ Manager/Vice president newbuilding/ Senior Marine Advisor	5
3 Equipment manufacturer companies	Vice President R&D/Senior Designer/ Principal engineer HF and maritime HMI/ Service engineer and Project Manager/Salesperson	5
2 Classification societies	Head of Section/HF Consultant	4
1 Flag state (The Norwegian Maritime Administration)	Senior engineer/Senior Advisor	3
2 Marine insurance companies	Senior Loss Prevention Executive/ Loss Prevention Director/Vice President	3
1 Shipyard	Naval Architect	1
Total number of informants		42

Table 2. The findings from each stakeholder group in this study.

Stakeholder group	Influence & Interest
Seafarers	Design issues Takes responsibility for handling suboptimal usability through adaptations No/low design influence, high interest
Shipowners	Low interest, perceived influence varies from low to high Responsibility for usability sits somewhere else Profitability prioritised
Equipment manufacturers	High interest in involving end-users through HF methods Influence through design and development, however HCD processes are challenging (cost (profitability), regulations, customer requirements, barriers to including end-users)
Shipyard	Have influence but low interest (due to lack of awareness about HF and usability) Prioritize completing project within time/budget/contract specs (profitability)
Classification societies	SOLAS V/15 a «dormant» requirement HF not part of standard packet class Market competition forces minimum notations (profitability) High interest but influence through voluntary notations (chosen by shipowner)
Flag state	Interest and influence on conventional ship building is medium SOLAS V/15 not followed up through supervisory work No national requirements beyond international due to risk of ships flagging out (economic considerations) Industry have responsibility for challenging regulations
Insurance	Not responsible, low interest, low influence Work on behalf of shipowner Indirect influence through awareness campaigns (towards seafarers)

The interview with the other stakeholder groups took place in the informant's workplace or remotely using a web conferencing tool. The shipowner informants had different roles in company management, they were all decision-makers concerning ship bridge design and equipment. They were employed in shipowner companies with international operations, four which have their main office in Norway and one in UK. The shipyard informant was a naval architect that had worked for several years in a shipyard in Asia. The equipment manufacturer informants worked as designers or engineers in Norwegian companies or in a Norwegian department of an international company. The Flag state informants worked in relevant departments in the Norwegian Maritime Authority. The informants from the classification societies worked at either the company head office in Norway or in the head office in UK. The insurance companies operate internationally, and the informants worked either in the company head office in UK or in Norway.

All interviews were semi-structured [65], lasted for about one hour and were conducted by one or two researchers. In the interviews, we asked the informants about their role, their interest in and influence on ship bridge design and usability, and how they perceived other maritime actors' role, equipment preferences and priorities, and design related to performance and safety. The interviews consisted of open questions focusing on the informants' experiences and opinions and allowed the informants to talk freely about different aspects of the topics we introduced.

The data material consisted of field notes and audio-recorded interviews that were transcribed verbatim. The transcriptions are the source of the quotes in Section 4.

3.1 *Analysis*

Thematic analysis (Braun and Clark 2008) was initially used to analyse the data in this study. This method allows for identification of themes across the data in a systematic manner. The data material for each stakeholder group was first analysed separately. Initially the data from the three stakeholder groups seafarers, equipment manufacturers and shipowners were subjected to open coding, which broke down the material to smaller sections before comparing, refining, and clustering codes into themes. This work was published in[28, 55]. The topic of stakeholders' influence and interest in ship bridge design was then further developed through performing additional interviews with a shipyard, a flag state, classification societies and insurance companies. The additional data allowed for a re-analysis and comparison of findings across the seven stakeholder groups. The findings concerning interest and influence on ship bridge design for each stakeholder group are shown in Table 2.

The approach of generating knowledge about stakeholders' behaviour, inter-relations, interest and influence on a particular process or decision-making is known from the stakeholder analysis literature [48, 66]. This knowledge can be used to develop strategies for managing stakeholders of projects or organisation in order to facilitate the implementation of specific decisions or organisational objectives [48], however, in the present case, the knowledge generated focused on the informants perceived influence and interest in ship bridge design, with the ultimate aim of shredding light on existing factors that may hamper progress in this direction. Moreover, the resulting insights were used to suggest possible ways forward.

3.2 *Scientific quality*

Several measures have been applied to ensure the trustworthiness [67, 68] of the current study. The initial coding was performed by the first author. In addition to the authors of the current paper, five researchers with extensive experience from research within the maritime sector, human factors and safety, have been involved in both the data collection, analysis, and writing during the course of the research, which strengthens the credibility of the study. When performing interviews, one cannot be sure whether the informants are providing an accurate account of their experiences and thoughts or if their accounts are adjusted to what they think the researcher is interested in, or what others, like company management, would like to hear. However, the topics raised in this study were not of a personal or sensitive nature. The informants seemed to find the topic interesting and willingly shared their experiences and opinions. In addition, serving as a kind of triangulation, information obtained from previous interviews and observations was continuously discussed during subsequent interviews.

There are some factors relevant for the transferability to other contexts of the study. First, the data sample does not include all sectors within the maritime industry. The authors acknowledge that there is an extensive network of actors and stakeholders in the maritime industry in addition to the stakeholder groups included in this study. There is also a limited number of informants from each stakeholder group. However, the richness of the data collected has allowed for an analysis that identified patterns across the stakeholder groups concerning their perceived interest, influence and responsibility for usability in ship bridge equipment design. Second, the majority of informants in the study are Norwegian and the findings may first and foremost reflect a situation specific for the Norwegian and/or European maritime sector. Considering the international nature of the maritime industry where the stakeholders operate, compete, and are regulated internationally, the conclusions drawn may still have broad relevance. The results provide descriptions from which readers can make judgements relating to the transferability of results to other, specific contexts. Further research is needed to establish the relevance of the findings for specific maritime sectors, geographic areas, or the maritime industry in general.

4 RESULTS

In this section the findings from the interviews with the stakeholder groups seafarers, shipowners, shipyard, equipment manufacturer, flag state, classification societies and insurance companies are presented.

4.1 *Seafarers*

The navigators are the stakeholder that has the most obvious interest in ship bridge design. Navigating a ship requires management and interaction with many pieces of equipment. The function and design of individual equipment as well as how the equipment is physically organized to constitute the overall work environment have direct impact on seafarers' work tasks and work performance. In our fieldwork and interviews with seafarers we found many examples of suboptimal usability in ship bridge design and equipment. The frequent existence of suboptimal usability was also confirmed by the other stakeholder groups.

One example of equipment not fit for the context-of-use is the lack of possibility to dim screens during night-time, an issue that frequently came up during the interviews and field trips:

"That screen, you have it in front of you all the time, it cannot be dimmed properly so you lose your night vision while you are steering the ship. We used to cover it with a patch. In return we could not see the alarms from the propulsion system, we heard the alarm and had to lift the patch. When you are in a narrow fairway and a pilot is shouting at you, it starts beeping and you have to lift the patch and in addition lose your night vision"

The seafarers expressed frustration over systems and equipment that do not accommodate their tasks and the context. Still, they manage to do their job through creative ways of adapting to less successful designs, as also described in [28].

All in all, the seafarers describe they have little or no influence on ship bridge design. The seafarer's involvement in ship bridge design in a newbuilding is usually restricted to a captain being part of a site team or being allowed to give his opinion during the final assembly e.g., regarding placement of certain items in the consoles. The seafarers would like to have more influence, however finding ways to give feedback can be challenging. In our study we did not find any systematic feedback system in place and the seafarers may find it difficult to be heard, as this quote exemplifies:

"I have tried but got the message: 'thanks for the input but we have already paid for this solution'. Then designers, engineers and sales have related to classification, regulations, and authorities, then they deliver the order to

the yard, and on top is the owner that has paid for the solution already. When you as the end-user express what you would like to have the message is 'Sorry, you are half a year to late"

This quote also sums up who the seafarers think have influence on ship bridge design, designers, engineers, sales, class, regulations, authorities, shipyard and shipowner. Several seafarers pointed to the fact that many actors and competitors are involved, as contributing to the lack of usability.

4.2 *Shipowners*

Shipowners can be organized in different ways, it can be a company, a person or an investment fund owning ships. Shipowner companies can range from small family-run companies owning one or a few ships to multinational companies owning hundreds of ships. The different functions like ship management, technical management, purchasing, insurance and human resources may be departments within the company, or it may be outsourced to a third-party company.

The shipowners in our study span from describing their interest and influence in ship bridge design from being high to low. In the high end of this scale, the offshore support vessel company expressed an explicit interest in ship bridge design, not only to ensure safety and production but as part of ensuring crew well-being. During the ship building processes they described following up both on the equipment manufacturers and the yards closely to make sure the bridge design had the intended standard. Their own judgement was that they spent more resources than most shipowner companies on ship bridge design, but that it paid off in the form of good working conditions for the crew:

"I think we gain on that. We have spent resources on this, but throughout the ship's lifetime the everyday life of people on board is much better, that way it is worth it."

The other four companies in our study, ranged both their interest and perceived influence on usability in ship bridge design to be medium to low. They all emphasize that building a ship is a considerable investment, and shipowner management is focusing on big picture issues of a ship's construction and specifications, such as cargo carrying capacity, the number of passengers, speed, efficiency, i.e., the factors that are important for a profitable investment. For these owners it is important to keep the costs to a minimum and usability on the ships bridge is not worth an additional investment. The large bulk and oil tanker companies described buying ships more or less off-the-shelf. They also prefer buying several ships in a series with standard design as they find this decreasing investment cost and crew training cost.

One of the informants from these companies did think that they have some influence on bridge equipment through what they choose to buy and how much they are willing to invest:

"We do have some power, we build maybe 10 boats per year, and we are buying them, so we have the possibility to make requirements and invest more money if we want to. If we get in early, we can request to redesign the whole bridge without additional costs. So, the owners have a lot of power in this, we can drive things forward, but in almost all shipowner companies they now use equipment made in Asia"

Although this shipowner found they have some influence, the shipowner informants pointed to the regulators, shipyards and equipment manufacturers as the stakeholders with the main influence on ship bridge design. The informants expressed that safety of navigation is ensured by complying to regulations:

"…as long as you follow the rules and requirements you are safe"

The belief that safety is ensured by regulations may have influenced their interest in safety and ship bridge design. This was currently not a topic of specific interest for these shipowners:

"Of course, safety is always an important thing, but that is not where you feel it is urgent right now, after all, we do have relatively safe equipment already"

It was also emphasized that if there is a need to change anything it should be done through regulations as both equipment manufacturers and shipowners are forced to prioritize compliance:

"I think the easiest way to make changes is through regulations, because they will be followed by both the equipment manufacturers and shipowners"

When the shipowner signs a contract for the whole ship, the shipyard has the design responsibility. The shipyard chooses equipment suppliers depending on their negotiations and agreements with suppliers and if the shipowner would like a different supplier it will come with an additional cost, as explained by one informant:

"We had in the contract what they call a makers list, so you had to have at least three possible suppliers for the bridge equipment that the ship yard could choose and then we would get the specifications for the supply and either approve it, but if you wanted an alternative supply we had to pay the difference in the cost between the supplier we wanted and the supplier that the ship yard had chosen. (…) then we would say 'I'm sorry we are not going to pay the extra'"

Usability was perceived to be the responsibility of equipment manufactures and the equipment manufacturers should also bear the cost for developing usable equipment. The competitiveness of the maritime industry was emphasized, and one informant described themselves as 'the weak link in the food chain', thus other actors must take responsibility for the equipment on the bridge:

"Everybody is always turning towards the shipowners to pay more, but financially it must be very critical for the shipowners to do more. The shipowners might think that the equipment manufacturers have the responsibility to deliver safe equipment that is easy to use and of course the maritime institutions have a responsibility to educate people, so they are capable of handling the equipment"

In other words, as this quote additionally illustrates, the shipowners also pointed to the seafarers' training, competence and their responsibility for being able to handle the available equipment.

4.3 *Shipyard*

The shipyard is where new ships are being constructed or where service and maintenance repairs or conversions, modifications or upgrades of ships are performed. Most shipyards have a design department and an engineering department. Naval architects are important professionals in this context as they work with ship design at the conceptual and construction levels, as well as often being involved in project management.

The building time which consists of both the design phase and the building phase, is an important cost parameter for a shipyard. Depending on the market situation, ships like tankers and bulk carriers are increasingly built in larger series from a standard design to increase the production efficiency of the shipyard. After the first vessels in a series have been built and construction bugs have been ironed out, there is seldom much more to be done by the design and engineering departments, leading to a per-ship cost reduction and shortened delivery time. Shipping companies do not need to be involved during this type of building process. Neither is it usually being considered in any detail what particular kind of operations the ship will be used for, where should the ship sail, what kind of crew will operate it etc.; designs of this nature are aimed a world-wide, unrestricted trading.

Naval architecture is an engineering-based profession and according to our informant, ship operations or the human-factors needs of end-users are not part of their professional focus. The informant describes the ship design process being about going into the ship design spiral and try to complete the design fulfilling all main requirements within the given time. An alternative approach, experientially very often used as a starting point for a new design, is to use the drawings from an already approved (sister) ship.

Concerning the ships bridge, the naval architect designs the outline of the bridge and can also be involved during the detailed design at the shipyard. The equipment manufacturers may deliver finished consoles, or consoles can be designed and produced by the shipyard and their sub-suppliers, in which case the equipment suppliers deliver components and drawings. Bridge equipment may be bought as individual sub-systems or components, resulting in equipment coming from perhaps 5-10 different equipment manufacturers, which all may have different operating philosophies.

The informant is of the impression that usability and implementation of human factors considerations into design differs considerably between equipment manufacturers. However, the informant emphasize that a naval architect will not start a discussion with stakeholders regarding human-factors related end user needs. As long as there are no compulsory requirements regarding usability or human factors this is not on a naval architect’s agenda. According to the informant, although being aware of guidelines for implementing human factors in design, both from classification societies and standardization organizations, it is not clear who should be responsible for using them.

4.4 *Equipment manufacturers*

Equipment manufacturers are companies that make maritime equipment for ships, including specialist hardware, software, diesel and electrical propulsion systems, bridge equipment or DP systems. The equipment manufacturers in our study were either delivering a few specific pieces of bridge equipment or a whole range of bridge equipment, including consoles and integrated bridge solutions.

All equipment manufacturer informants in our study expressed high interest in usability and in involving seafarers in their design and development processes. However, there is a trade-off between this interest and time and cost considerations in the development processes. The price of their product is an all-important factor when competing in the maritime market.

Their influence is considerable in the sense that they design and develop the equipment and systems to be used on board. However, the informants depict several factors that limit this influence. Regulations are an important factor. The intention of regulations, to ensure a certain standard that contributes to safety, are perceived as positive. However, they also experience regulations, i.e., the IMO Performance Standards and the IEC equipment test standards described above, as being a hinder for innovation and restricting design solutions towards lower usability. As an example, one of the equipment manufacturers has ECDIS as the main part of their portfolio and ECDIS, like all other mandatory bridge systems required by SOLAS Regulation V/19, must comply with detailed regulations. In their opinion some of the requirements lead to solutions that create unnecessary challenges for the users:

“We would like to see that the experiences we have from being close to the user group would be taken into account. We see so many times that the standards have things that works directly opposite of the intention, it reduces safety although the intention has been the opposite”

Another factor limiting equipment manufacturer influence is the customer requirements. The customer is either representing the shipowner or the shipyard, not the end-user directly. The equipment manufactures experienced that shipowners can have their own subjective opinions regarding the bridge which may lead to altering the design in ways that designers think makes the bridge less usable.

“In the end the owner decides, not the people using it. He (the owner) overruled it even though all the users wanted the ergonomic solutions.”

It may be difficult to get a position in the market based on selling the concept of usability. The maritime market is focused on cost effectiveness and equipment developed through user-centered design process does not mainly compete on price, but in addition on intangible benefits like increased safety, efficiency, effectiveness and user satisfaction, which are difficult to quantify in a business case or purchase decision.

In addition, it may be a challenge to get access to seafarers and ships and none of the equipment manufacturers had any systematic way of collecting feedback from operations. The informants also described tensions within their company regarding time and cost spent on design and development processes:

"We would like to be more out (in the field) but it is challenging to achieve (…) we have technical personnel that does it, in a way we who have the user-centred design part we do not have any tasks or system to fix, at least not something that everybody sees. We do see the need for it."

4.5 *The Flag State*

The flag state is responsible for the enforcement of national and international maritime regulations on ships flying their flag. The Norwegian Maritime Authority (NMA) is subordinate to the Ministry of Trade, Industry and Fisheries and the Ministry of Climate and Environment. The Norwegian legislation directly addressing ship bridge design is found within Regulation 1157 2014-09-05 Navigation and navigational aids for ships and mobile offshore units, where SOLAS Chapter V and the IMO MSC circular 982 is implemented. However, the focus on regulation V/15 through supervisions seem to be limited:

"The intention to include it in the regulations, regulation 15 states the considerations that must be taken when designing and placing equipment on a bridge. The guideline (MSC circular 982) addresses these considerations but from there to being good at actually using it in our supervisory work is to go a bit far"

Concerning ships being built within existing regulations the flag state informants considered NMA's interest and influence to be medium. The influence is essentially through providing the framework conditions through regulations, including supervision and auditing to ensure compliance with legislation. The informants express being comfortable with having general regulations with minimum requirements, as that provide the same conditions of competition in some areas. The informants are of the opinion that prescriptive regulations may limit innovation; however, goal-based regulations are difficult to follow up:

"The issue with goal-based and function-based, the problem is its all good but when you have to measure something and set an acceptance criterion or standard for what should be allowed, you need to have some known factors to measure up against, so that everything does not become completely abstract"

The NMA is aware of existing challenges regarding design of ship bridges and bridge equipment. They point to the lack of standardisation considering a holistic view on the bridge work environment guiding how the different pieces of equipment should be placed together. Currently it is up to equipment manufacturers, yards, and shipowners to decide how this is done and the practice varies between ship types and within different segments in the industry. In general, the informants have the impression that HMI and human factors developments is not fully exploited in maritime sector, which can be connected to the strong focus on profitability. Still, it is important for the NMA that Norwegian requirements do not go beyond IMO regulations, due to the goal of ensuring predictable conditions for the industry and to reduce the risk of ships flagging out.

The NMA is responsible for bringing issues to the IMO, however, the NMA is of the opinion that the industry also has a responsibility for pushing regulations forward.

"I would like to see the industry challenge the regulations. As new equipment becomes available or new research that says something about which resolutions and colors are best, I would like to see that automatically forwarded. I am unsure if this is the case, you do get the impression that they are most concerned with staying within the regulations when building a vessel. I understand that they do, but someone has to take the fight."

4.6 *Classification Societies*

Classification societies are non-governmental business organizations that establish technical standards for the construction of ships. Based on plan approval and onboard inspections during the building period of a ship, they issue classification certificates that verify that the construction of a vessel complies with their standards; certificates that are maintained throughout the lifetime of the ship through renewed surveys. The class certificate is necessary for the shipowner to register the ship in a flag state and obtain marine insurance. The certificate of class will include class notations that signify which rule requirements are applicable for the assignment and retention of class. While the basic class notation is mandatory, other descriptive class notations are optional and can cover different aspects, for instance ship type, special structural or engine standards, or, depending on the ship type and the wishes of the owner, there are also notations regarding navigation and manoeuvring. In addition to delivering their own services, classification societies can also have a role as Recognised Organisation (RO), meaning the flag state has delegated the responsibility for inspection and supervision of the flag state rules to the classification society.

Bridge and bridge equipment is not part of classification unless the shipowner wants a specific, navigation-related voluntary notation. Following up SOLAS V/15 is not a priority for class societies:

"Regulation 15 says something about bridge design, but it is almost a dormant requirement in relation to SOLAS ships. There are not many requirements for it in relation to normal standard class or SOLAS ships, but some flags i.e., Germany and Norway have said that IMO circular 982 applies, that they are minimum requirements. So, when you build a main class ship according to SOLAS, the 982 also applies and then it is quite significant, however the follow-up I do not want to say much about"

The informants experience from the role as RO is that it is common for the flag to give exemptions from this part of the regulations. The informants think that traditionally class societies have focused on the technical solutions and not been concerned with operations. Also, the majority of surveyors from class societies have technical background and human factors knowledge is not part of their training. The class surveyors follow guidelines and checklists concerning technical systems and equipment and they often work under considerable time pressure.

All mandatory equipment required by SOLAS Chapter V/19 has type approval, and according to the informants, installation and placement are equipment manufacturer and shipowner responsibility. From class point of view the shipowner has the main influence on ship bridge design, illustrated by the following quote:

"We think it is entirely driven by the owner/operator. Every other player in the industry is just selling stuff or providing services. (…) the only ones putting money in in the end, either by buying stuff or by running stuff, is the owner/operators. Everyone else are passengers. (…) if the owner/operator is not interested and does not provide sufficient information and requirements, nothing is ever going to happen. That is a big problem, because increasingly owners are banks"

Class considers their interest in ensuring safety through bridge design as being high. However, their influence on ship bridge design is through selling and developing the optional navigation and maneuvering notations. These are adapted to different ship types and may include requirements for different working positions, what kind of equipment should be there, placement, visibility etc. The sales argument being put forward is that navigation notations will give lower insurance, meaning that although investment in design is higher cost is saved on lower insurance. One of the informants emphasize that through developing these notations they contribute to push the industry forward. If the shipowner chooses a high navigation notation their influence through this notation is high. However, this classification society recently had to develop a new notation that only have minimum requirements in addition to SOLAS. This notation was described as necessary due to the demand in the market for a simple notation that requires minimum investments. Providing such as notation is part of the competition with other classification societies that provide these types of notations.

4.7 *Insurance*

Insurance is the shipowner's protection against financial loss due to accidents and incidents. Marine insurance has two main areas: 1) hull and machinery that cover the risk of property damage and 2) Protection and Indemnity (P&I) insurance that cover open-ended risks, like third party liability for cargo, injuries to people or environmental damage. (The loss associated to not operating is still with the owner).

Insurance companies are impacted by ship bridge design in terms of claims due to navigational incidents and accidents. According to the insurance companies, although the ship accident rate is declining every year, the risk remains the same as the consequences are higher, the ships are larger, systems are more complex, and claims are larger. However, collisions and groundings do not lead to the largest claims:

"Pollution claims are high cost as you can imagine but not very frequent (…) but what we get they are very expensive so in terms like that collision claims, groundings, in real terms are not a huge problem, they are acceptable within insurance terms anyway."

The insurance company informants state that both their interest and influence in ship bridge design is low. They have no direct influence on shipowners regarding ship design or choice of bridge equipment. Especially the P&I club emphasized that they are working on the shipowner's behalf, they are brought in by the shipowner to protect him/her from the unexpected and interfering with the design of ships is not part of their responsibility.

According to the insurance companies it is a misconception in the industry that insurance premium can be influenced by the choice of ship bridge equipment. The insurance premium is calculated in a conservative way based on the historical number of claims. The reward in the form of lower insurance premium will only occur when no claims have been shown over time:

"Insurance is just gambling you know, insurance gamble that you are not going to have a claim and proceeds the premium (…) answer to the underwriters is: well if you do this claims will go down so you will clearly get less premium, but at the end of the day insurance is a market place, it's all down to if you have a lot of claims that you have to pay a lot of premium, that's the system."

One of the insurance companies stated that they would like to have more impact on safety and ship bridge design, especially the opportunity to connect insurance premium level to class notations but they claim that will not be agreed to by the underwriters.

The insurance companies do regard they have indirect influence through the awareness campaigns run by their loss prevention departments towards seafarers:

"We have had lots of awareness presentations on what we see in navigation accidents, including the use of systems, understanding of positioning. It is based on the requirements we see, to try to avoid seafarers making the same mistakes (…) and the problem is that our audience is the seafarers, the navigators and not the superintendent or the technical personnel in the shipping company".

5 DISCUSSION

5.1 *SOLAS V/15 – a 'dormant' requirement*

SOLAS V/15 requires that human factors' considerations are the basis for all decisions "which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge", i.e., in our interpretation, that the navigational equipment and systems must be usable; must be good design. Achieving usability requires however requires active involvement of end users throughout the design and development process [20, 45, 46]. In this study we find that the core regulation underpinning this demand, SOLAS V/15, is neither applied systematically in the design and development processes, nor is it having a significant position and impact during the ship design and purchasing processes, and nor is it an explicit, or even implicit, part of the survey work by the regulators.

The seafarers in our study have high interest in usability in ship bridge and equipment design as they are directly affected by it [49] through their daily work. However, they experience having little or no influence on ship bridge design or the selection of equipment, whether it is the design and development process or the purchasing process. With the widespread use of crewing agencies and short employment contracts [56] there are few possibilities for seafarers to interact with the shipowners or other stakeholders to give feedback from the use of ship bridge equipment. Even in organizations where owners' representatives – superintendents – are recruited among seafarers, and thus understand the end-user needs from their own practice, there is little impact to be observed. Speculatively, the underlying cause for this paradox could be that their freedom of action is tuned to the same agenda as most other members of a ship owning organization: ensuring compliance to rules, cost-neutrality (or cost-reduction), and timely delivery of the ship so that a return of investment can commence.

Seen from the perspective of the other stakeholders there are differing reasons for not involving seafarers in design and purchasing decisions. The equipment manufacturers in our sample expressed high interest in usability and in involving seafarers in the design and development process. However, they experienced that their access to ships and seafarers is limited. To involve seafarers arguably also adds time and cost to a development project which reduces the profitability margin, and since there does not seem to be an explicit market demand for usability, 'going the extra mile' could be considered as a luxury.

The purchasing process is another opportunity for involving seafarers in bridge design decisions and equipment selection, where seafarers' experience would be able to influence the choice of equipment towards instruments with superior usability. The ship purchasing process is however usually a negotiation between the shipyard and the owner/buyer, and these negotiations often revolves around the main characteristics of a newbuilt ship like speed, fuel consumption, capacity, delivery time, and cost. Usability is not on the table, apart from the implicit assumption that compliance to the IEC test standards provides usable systems. This was emphasized by some of the shipowner informants, that believed as long as you comply with regulations, the level of safety is good enough, and there is no reason to invest more time and money.

Based on the maritime actors focus on cost efficiency it would seem like a viable idea to connect insurance premium to the choice of ship bridge equipment. However, according to the insurance companies' informants, the insurance premium is conservatively calculated based on the historical number of claims. Despite running awareness campaigns directed towards seafarers on how to use equipment on the bridge, the state that they are in general neither interested nor involved in ship design processes.

Regulators can ensure compliance through their plan approvals and subsequent survey work. However, they seem to have conflicting relationships between balancing safety and economic considerations. The class societies express high interest in usability in ship bridge design but their only possibility to influence design is through voluntary navigation notations. Class societies are also part of the competitive maritime market and must provide 'cheap' notations that require minimum investments to compete for business. As such, they are in the main no driver for usability in the industry. One class society informant described SOLAS V/15 as a 'dormant requirement' not followed up by anyone in the industry: "It says something about bridge design in regulation 15, but it is almost a dormant requirement in relation to SOLAS ships".

The flag state is, as described, responsible for enforcing the international regulations on ships flying their flag. One example is Norway, where it is important for the NMA to ensure a level playing field also on a world-wide scale, i.e., predictable competitive and reasonable conditions for the shipping industry, and thus avoiding any additional national requirements that can enhance the risk of ships flagging out. SOLAS Regulation V/15 is, it transpires, not actively followed up within the NMAs supervisory work, and moreover, one of the flag state informants brought up the challenge of following up goal-based regulations: "you need to have some known factors to measure up against, so that everything does not become completely abstract". As opposed to the chain of prescriptive regulations and standard tests underpinning the implementation of SOLAS V/19 – IMO performance standards and IEC test standards, the goal-based requirements in SOLAS Regulation V/15 requires both specialized human factors and seafaring knowledge, as well as an out-of-the-ordinary effort from designers and surveyors to be implemented. So, while the benefit of goal-based regulations is the freedom in developing technical solutions to meet the goals, there seem to be a need for providing the required knowledge to follow up SOLAS Regulation V/15 in a form that can be understood and applied by the relevant actors.

5.2 *Usability – somebody else's problem?*

The stakeholders in our study varies in the expressed interest in ship bridge design, and represents a continuum that spans from 'high' when it comes to the seafaring end-users, all the way to 'low' when it comes to the shared tacit understanding by other stakeholders that is agreeable to consider SOLAS V/15 as dormant and settle for compliance to SOLAS V/19. The perceived possibility to influence ship bridge design was often seen in the context of responsibility for design and design processes. One common pattern is that stakeholders refer to the shipowners as responsible for the equipment on board their ships. Another pattern is the stakeholders referred to the regulators, or the regulations, as responsible for ensuring safety and as a major influence on usability. Maritime stakeholders are in general committed to regulatory compliance, as it is necessary to be allowed to operate. We wholeheartedly agree to the impact of maritime regulation and see the IMO instruments as essential for the safety of shipping. However, we do not immediately support that IMO is lacking behind when it comes to the institutionalization of maritime usability. On the contrary, we suggest that the IMO in this case have made the necessary provisions through SOLAS V/15; however, and much to be considered, what appears to be the less-than-vigilant enforcement of this regulation leaves usability up to the different maritime actors. The resulting fragmentation of responsibility for usability is evident, as the actors suggest – think - that the responsibility for usability sits somewhere else, as illustrated in Figure 1. The figure illustrates the fragmentation of perceived responsibility but also that the distribution of arrows is not symmetric, most arrows points towards shipowners. Most shipowners meant usability is the responsibility of shipyards, equipment manufacturers and regulations. They also pointed out the seafarers' responsibility for being able to handle the equipment. On the other hand, seafarers, equipment manufacturers, class societies, flag state and insurance companies are of the opinion that the shipowners are responsible for ensuring usability in ship bridge design. It is also interesting to note that the insurance informants believed shipowners are responsible for usability while their awareness campaigns are directed at seafarers and their use of equipment. In other words, the stakeholders believe responsibility for usability sits somewhere else - it is somebody else's problem.

Ideally, the knowledge from research and design efforts already undertaken would lead maritime stakeholders involved in ship bridge equipment design to understand the value of ergonomics and prioritize it, regardless of whether it is supported by mandatory rules and regulations. However, as usability arguably is associated with cost, we find it is unlikely that improved usability of bridge systems and equipment is something that will appear by itself within the world fleet, unless practice is changed, and – everything else equal – a more subjective drive for safer and cleaner oceans becomes a part of the decision-making fabric. This unfortunate notion also springs from the consideration of the difficulty of constructing a credible business case in favour of good bridge system usability, unless the cost of potential accidents is included – accidents, which however, in the eyes of the insurance companies, are 'not a huge problem, they are acceptable within insurance terms anyway'.

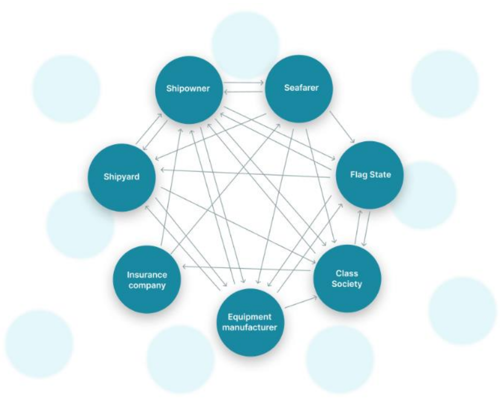


Figure 1. The allocation of responsibility for usability in ship bridge design, as perceived by the different stakeholders. The arrows pointing towards seafarers is about their responsibility for handling the equipment. The background circles indicate the existence of additional stakeholders, who may also have influence on usability in ship bridge design.

5.3 *A way forward?*

One could believe the closing statement above to be a kind of stalemate, at least unless a workable shortcut could be found. In the foregoing, the present situation arguably resulting in poor usability of bridge systems and equipment has been outlined. Stakeholders appear to recognize these shortcomings, appear to show an interest in improvements, but see a potential solution, or solutions, as somebody else's problem. Moreover, in spite of the provisions of SOLAS Regulation V/15, expectations apparently are that a change of rules is needed to make usability requirements more explicit than they already are, also considering IEC 60945 and IEC 62288, and from our data it seems that the industry is waiting for the IMO to initiate such a process.

Pursuing this line of thinking, it seems relatively clear to the authors that usability considerations relating to bridge design and the design of bridge equipment could be made more explicit, and that the provisions of SOLAS Regulation V/15 could be made more operational through descriptions of usability inspection methods, and the transfer of generic human factors knowledge to more technically-oriented stakeholders, i.e. tuned to the typical audience of maritime design engineers, marine superintendents, surveyors and plan approvers. We suggest that actions towards such a change are initiated, towards what we see as long-term improvements of maritime safety through improved usability and the associated reduction of errors and mishaps that often are attributed to humans. On the other hand, we also recognize that such actions, as well as the corresponding cultural adaptation that rather likely is also a component necessary for success of such a scheme, is a very far reaching, serious and time-consuming venture, ignores the need of a here-and-now return-of-investment (ROI), and all in all, such a scheme is possibly to the timescale of decades, rather than years.

With this in mind, our thinking keeps reverting to the position that the present regulations actually do seem to state what appears to be needed in way of usability requirements, especially considering the powerful wording of SOLAS Regulation V/15, but also the wording and the test regime included in IEC 60945, IEC 62288 and the individual equipment test standards which could suffice in many respects. On that basis, we ask ourselves, could there be a short-cut, a simpler, more expedite and less complicated way forward, without a major revision of rules, and a massive change of culture in the maritime industry? We have arrived at the conclusion that there could be such a solution. Our suggestion is that a shorter-term, potentially immediately effective approach, could possibly be brought about if end-users were to be much more clearly represented in the process of plan approval, system assessment and type approval of maritime instruments. As mentioned above, the present test methods often call for expert evaluation, but leaves the definition of experts open – but, if the norm for the definition of 'expert' was to include current seagoing experience and a relevant seafaring career, many of the 'pass' criteria in the various standards would not need explicit explanations. The term 'intuitive', which is seen in both IMO Performance Standards and IEC Test Standards would, for instance, take on a much more real meaning when evaluated by an experienced seafarer, as would – again as an example – the term 'logical grouping', which is also a usability heuristic that is used in the present rules and test standards. Considering that the relevant, present-day IEC Test

Standards call for the assessment of navigational instrument features and functions according to such terms, the evaluation of seafaring experts would probably be more to the point and several degrees more relevant for fellow seafarers than similar assessment made by any other discipline.

Taking a change of practice towards giving the seafarers a louder and clearer voice during type approval, plan approval and potentially onboard surveys, could possibly, and possibly even in a rather short time span, help building up a more comprehensive understanding of the actual context-of-use and perspective of the end-users, thus aiding bridge design and bridge equipment development. In the slightly longer run, such a pool of knowledge could also become a resource that design engineering could tap into to improve their products and services.

6 CONCLUSION

To achieve improved usability in maritime equipment and bridge systems ideally requires the actively involvement of end-users throughout the design and development process. Usability in navigational equipment and systems on a ship's bridge is required by the IMO SOLAS Regulation V/15 regulation. However, this is a goal-based requirement that is challenging to follow up both in design, development, and survey work, considering that the surveyors overwhelmingly have a technical background not having been trained in human factors, and – perhaps for this reason - the regulation is seen as a 'dormant requirement' by the maritime stakeholders. In this study, the usability in ship bridge design and bridge equipment is investigated from the perspective of different stakeholders in the maritime industry: seafarers, shipowners, equipment manufacturers, shipyard, insurance companies, classification societies and a flag state. From these sources, we find that the seafarers, the direct end-users, do not have a clear voice in the ship bridge and bridge equipment design and the associated purchasing processes. In other words, the stakeholder with highest interest in usability have what seems to be a low, or even the lowest, influence. Indeed, the other stakeholders appear to recognize these shortcomings, and some do show interest in improvements, but the responsibility for usability is fragmented, and they see the potential solutions as being somebody else's problem.

In our understanding of the wider picture, there seems to be a lack of incitement for prioritizing usability, since it is not strictly followed up through certification of bridge and bridge equipment designs, and neither is it perceived as cost-effective as usable equipment, which conceivably may have a higher investment cost, does not seem to result in lower insurance premiums or other tangible economic benefits. We suggest long-term improvements of usability can be made through making the usability considerations relating to bridge design and the design of bridge equipment in current regulations more visible and subject to more focused validation. In addition, we recommend that the transfer of generic human factors knowledge to more technically oriented stakeholders become a best practice, highlighting the importance of catering for end-user needs. We also argue that small steps to improve usability within a shorter time span can be taken, and to this end, we suggest that seafarers are included as 'experts' when 'expert evaluation' is required in the process of plan approval, system assessment and type-approval of maritime equipment. Such a practice can potentially be effective within a very short time span and within the current structure of the maritime sector and the present regulations governing the usability of bridge equipment and bridge design. From our vantage point, we believe that the perspective of the end-users, and an immediate and direct understanding of the context-of-use, can almost immediately be brought into the ship bridge design and equipment manufacturing processes without any change of rules, regulations or other practices.

REFERENCES

1. International Maritime Organization. Maritime Safety. 2022 30.01.2022]; Available from: https://www.imo.org/en/OurWork/Safety/Pages/default.aspx.
2. European Maritime Safety Agency, Annual overview of marine casualties and incidents 2021. 2021.
3. Lützhöft, M. and J.M. Nyce, Integration work on the ship's bridge. Journal of Maritime Research, 2008. 2: p. 59-74.
4. da Conceição, V.P., J. Dahlman, and A. Navarro. What is maritime navigation? Unfolding the complexity of a Sociotechnical System. in Human Factors and Ergonomics Society Annual Meeting. 2017.
5. Hutchins, E., Cognition in the Wild. 1995, Cambridge: MIT press.
6. Caranyon, P., Human factors of complex sociotechnical system. Applied Ergonomics, 2006. 37(4): p. 525-535.
7. Grech, M., T. Horberry, and T. Koester, Human factors in the maritime domain. 2008: CRC press.
8. Norman, D.A., The design of everyday things. Rev. and exp. ed. ed. 2013, New York: Basic Books.
9. Lützhöft, M. and V.D. Vu, Design for Safety, in Managing Maritime Safety, H.A. Oltedal and M. Lützhöft, Editors. 2018, Routledge: New York.
10. Nordby, K., S.C. Mallam, and M. Lützhöft, Open user interface architecture for digital multivendor ship bridge systems. WMU Journal of Maritime Affairs, 2019. 18: p. 297-318.
11. Lützhöft, M., "The technology is great when it works": Maritime Technology and Human Integration on the Ship's Bridge. 2004, Linköping University: Linköping.
12. Abeysiriwardhane, A., et al., Human-centred design knowledge into maritime engineering education; theoretical framework. Australasian Journal of Engineering Education, 2016. 21(2): p. 49-60.
13. Costa, N. and M. Lützhöft. The values of ergonomics in ship design and operation. in Human Factors in Ship Design & Operation. 2014. London, UK: The Royal Institution of Naval Architects.
14. Wilkinson, G.R., Wheelhouse and bridge design. Journal of Navigation, 1971. 24(3): p. 313-324.
15. Millar, I.C., The need for a structured policy towards reducing human-factor errors in marine accidents. Maritime Policy & Management, 1980. 7(1): p. 9-15.
16. Bhardwaj, S., et al., Technology introduction on ships: The tension between safety and economic rationality. Safety Science, 2019. 115: p. 329-338.
17. Hollnagel, E., D.D. Woods, and N. Leveson, Resilience Engineering : Concepts and Precepts. 2006, Abingdon: Ashgate Publishing Ltd.
18. Wilson, J.R., Fundamentals of systems ergonomics/human factors. Applied Ergonomics, 2014. 45: p. 5-13.

19. MAIB, Report on the investigation of the grounding of Muros Haisborough Sand North Sea 3 December 2016. 2017, Marine Accident Investigation Branch UK.
20. International Organization for Standardization, ISO 9241 Ergonomics of human-system interaction - Part 210 Human-centred design for interactive systems. 2010: www.standard.no.
21. International Maritime Organization, Resolution A.850(20) Human element vision, principles and goals for the organization ed. I.M. Organization. 1997, London: International Maritime Organization.
22. Reason, J., Managing the risks of organizational accidents. 1997, Aldershot: Ashgate Publishing.
23. MAIB and DMAIB, Application and Usability of ECDIS. A MAIB and DMAIB collaborative study on ECDIS use from the perspective of practitioners. 2021.
24. Danielsen, B.-E. The contribution of ship bridge design to maritime accidents. in AHFE. 2022. New York: Springer.
25. Chauvin, C., et al., Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. 2013. 59: p. 26-37.
26. Mallam, S.C., et al. The digitalization of navigation: examining the accident and aftermath of US navy destroyer John S. McCain. in Damaged Ship V. 2020. The Royal Institution of Naval Architects
27. Lützhöft, M.H. and S.W.A. Dekker, On your watch: Automation on the bridge. Journal of Navigation, 2002. 55(1): p. 83-96.
28. Danielsen, B.-E., M. Lützhöft, and T. Porathe. Still unresolved after all these years: human-technology interaction in the maritime domain. in International Conference on Applied Human Factors and Ergonomics. 2021. Virtual Conference: Springer, Cham.
29. Grech, M.R. and M. Lutzhoft. Challenges and opportunities in user centric shipping: Developing a human centred design approach for navigation systems. in 28th Australian Computer-Human Interaction Conference, OzCHI 2016. 2016. Association for Computing Machinery, Inc.
30. Costa, N.A., E. Holder, and S.N. MacKinnon, Implementing human centred design in the context of a graphical user interface redesign for ship manoeuvring. International Journal of Human - Computer Studies, 2017. 100: p. 55-65.
31. Petersen, E.S., K. Dittmann, and M. Lutzhoft. Making the phantom real: a case of applied maritime human factors. in 3rd International Symposium on Ship Operations, Management and Economics 2011. 2011.
32. Lurås, S., Systemic design in complex contexts : an enquiry through designing a ship's bridge. 2016, Oslo School of Architecture and Design: Oslo.
33. Javaux, D., et al., Model-based Adaptive Bridge Design in the Maritime Domain. The CASCADe Project. Procedia Manufacturing, 2015. 3: p. 4557-4564.
34. Bjørneseth, F.B., Unified Bridge - Design Concepts and Results, in Sensemaking in safety critical and complex situations: Human factors and design, S.O. Johnsen and T. Porathe, Editors. 2021, CRC Press.
35. Rumawas, V. and B.E. Asbjørnslett, A content analysis of human factors in ships design. The International Journal of Maritime Engineering, 2014. 156: p. 251-264.
36. Vu, V.D. and M. Lützhöft. Improving human-centred design application in the maritime industry - challenges and opportunities. in Human Factors. 2020. London, UK: The Royal Institution of Naval Architects.
37. Garcia, J.J., et al., Overspecified vessel design solutions in multi-stakeholder design problems. Research in Engineering Design, 2019. 30(4): p. 473-487.
38. Gernez, E., Connecting ship operation and architecture in ship design processes. Journal of Ship Production and Design, 2019. 35(01): p. 88-101.
39. Puisa, R., Lin, L., Bolbot, V., & Vassalos, D., Unravelling causal factors of maritime incidents and accidents. Safety science, 2018. 110: p. 124-141.
40. Mallam, S.C., M. Lundh, and S.N. MacKinnon, Integrating participatory practices in ship design and construction. Ergonomics in Design, 2017. 25(2): p. 4-11.
41. Österman, C. and L. Rose, Assessing financial impact of maritime ergonomics on company level: a case study. Maritime Policy & Management, 2015. 42(6): p. 555-570.
42. Ralph, P. and Y. Wand, A proposal for a formal definition of the design concept, in Design requirements engineering: A ten-year perspective. 2009, Springer: Berlin. p. 103-136.
43. Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W. S., Wilson, J.R., van der Doelen, B. , A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics, 2012. 55(4): p. 377-395.
44. International Ergonomics Association, Triennial Report of the International Ergonomics Association 2018-2021. 2021.
45. Gulliksen, J., et al., Key principles for user-centred systems design. Behaviour and Information Technology, 2003. 22(6): p. 397-409.
46. Maguire, M., Methods to support human-centred design. International Journal of Human-Computer Studies, 2001. 55: p. 587-634.
47. Österman, C., Beyond the ethic case: a value proposition of proactive human factors management. AMET Maritime Journal, 2013. 1: p. 14-41.
48. Brugha, R. and Z. Varvasovszky, Stakeholder analysis: a review. Health policy and planning, 2000. 15(3): p. 239-246.
49. Lelea, M.A., et al., Methodologies for stakeholder analysis-for application in transdisciplinary research projects focusing on actors in food supply chains. 2014: Witzenhausen, Germany.
50. Lützhöft, M., M.R. Grech, and T. Porathe, Information environment, fatigue, and culture in the maritime domain. Reviews of human factors ergonomics, 2011. 7(1): p. 280-322.
51. Edwards, K. and P.L. Jensen, Design of systems for productivity and well being. Applied Ergonomics, 2014. 45: p. 26-32.
52. Gernez, E., Nordby, K., Seim, Ø., Brett, P. O., & Hauge, R., Human-centered, collaborative, field-driven design—a case study, in Marine Design XIII, K. Lu, Editor. 2018, Taylor and Francis. p. 291-305.
53. Bader, G. and J.M. Nyce, When only the self is real: theory and practice in the development community. Journal of Computer Documentation, 1998. 22(1).
54. Österman, C., M. Ljung, and M. Lützhöft. Who Cares and Who Pays?: The Stakeholders of Maritime Human Factors. in Human Factors. 2009. Royal Institute of Naval Architects: Royal Institute of Naval Architects.
55. Danielsen, B.-E., et al., "Seafarers should be navigating by the stars": barriers to usability in ship bridge design. Cognition, Technology & Work, 2022.
56. Walters, D. and N. Bailey, Lives in Peril: Profit or Safety in the Global Maritime Industry? 2013, Hampshire, UK: Palgrave MacMillan.
57. Solesvik, M.Z. A collaborative design in shipbuilding: two case studies. in 5th IEEE International Conference on Industrial Informatics. 2007. IEEE.
58. Parsons, J. and C. Allen, The history of safety management, in Managing maritime safety, H.A. Oltedal and M. Lützhöft, Editors. 2018, Routledge.
59. International Maritime Organization. Safety of Life at Sea (SOLAS). 2022 30.01.2022]; Available from: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx.
60. International Maritime Organization, SOLAS Chapter V Regulation 15 Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures, ed. International Maritime Organization. 2002, London: International Maritime Organization.

61. International Maritime Organization, MSC Circ. 982. Guidelines on ergonomic criteria for bridge equipment and layout. 2000, International Maritime Organization.
62. International Electrotechnical Commission, IEC60945 Maritime navigation and radiocommunication equipment and systems- general requirements - methods of testing and required test results. 2002, International Electrotechnical Commission: www.standard.no.
63. International Electrotechnical Commission, IEC62288 Maritime navigation and radiocommunication equipment and systems - presentation of navigation-related information on shipborne navigational displays - general requirements, methods of testing and required test results. 2021, International Electrotechnical Commission: www.standard.no.
64. Norwegian Maritime Authority, Navigation and navigational aids for ships and mobile offshore units, in Regulations of 5 September 2014 No. 1157. 2014.
65. Kvale, S., Interviews: an introduction to qualitative research interviewing. 1996, Thousand Oaks, California: Sage.
66. Elias, A.A., R.Y. Cavana, and L.S. Jackson, Stakeholder analysis for R&D project management. R&D Management, 2002. 32(4): p. 301-310.
67. Lincoln, Y.S. and E. Guba, But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation, in Naturalistic evaluation: New directions for evaluation, D.D. Williams, Editor. 1986, Jossey-Bass: San Francisco.
68. Bryman, A., Social Research Methods. 5 ed. 2016, UK: Oxford University Press.

ISBN 978-82-326-7068-0 (printed ver.)
ISBN 978-82-326-7067-3 (electronic ver.)
ISSN 1503-8181 (printed ver.)
ISSN 2703-8084 (online ver.)

NTNU

Norwegian University of
Science and Technology