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ORIGINAL ARTICLE

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

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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.

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[1] Vessels over 100 GT.

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

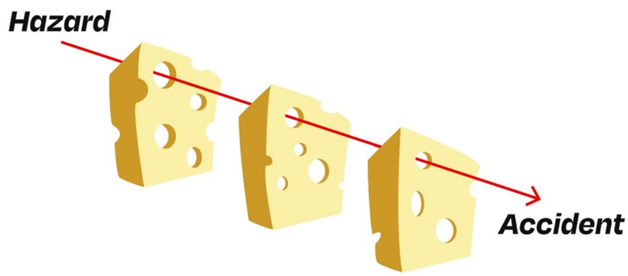

Fig. 1 Swiss cheese model redrawn from Reason (1997). The layers of defence (illustrated by cheese slices) may be physical, technological, organizational, or human applications. The holes in the barriers are created by active failures or latent conditions (Reason 1997)

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

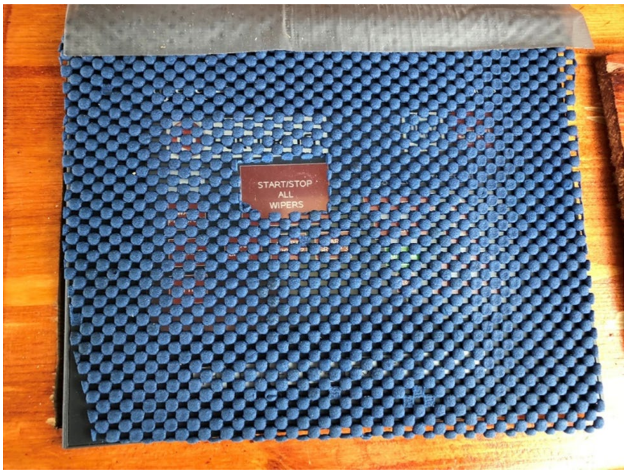

Fig. 2 Example of adaptation of technology by seafarers. All the available alternatives for managing window wipers except the one they need (start/stop all wipers) has been covered

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 sociotechnical 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.

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