THE IMPACT OF DIGITALIZATION ON MARITIME SAFETY AND THE WORK ENVIRONMENT OF THE CREW

(DIGITALISERINGENS PÅVERKAN PÅ SJÖSÄKERHET OCH BESÄTTNINGENS ARBETSMILJÖ)

Monica Lundh
Christina Palmén
Johannes Hüffmeier
Scott MacKinnon

PREFACE

This project was funded by The Swedish Transport Administration (Trafikverket), lead by Swedish Shipowners´ Association (Svensk Sjöfart) in cooperation with Chalmers University of Technology. The project ideas originated from representatives from the shipping industry and other stakeholders raising voices about problems associated with digitalization on board. This project was executed in close cooperation with industry representatives and stakeholders through the collection of data, discussions surrounding the findings and its relevance and the dissemination of results.

The project management would like to express their sincere gratitude for all the valuable input we have received from the participants.

Contact

Monica Lundh, Chalmers Technical University, monica.lundh@chalmers.se

Scott MacKinnon, Chalmers Technical University, scottm@chalmers.se

Christina Palmén, Svensk Sjöfart, christina.palmen@sweship.se

Johannes Hüffmeier, ForeSea, johannes.huffmeier@gmail.com

SUMMARY

The 4th Industrial Revolution has foreseen the direct and indirect disruptions within the shipping industry. The greatest manifestation is how technology has disrupted how work and its application to make work safer and more efficient and reduce the workload on operators and other stakeholders. The International Maritime Administration (IMO) has provided guidance to support the implementation of digital solutions and highlights several emergent problems. Among the issues are the risk of information overload, complex interfaces, and a risk of over reliance by the operator.

Apart from being regarded as a potential stressor in modern work life, digitalization also partly depends on a connectivity to internet, which exposes the system to risk of cyber-attacks and the emergence of ¨wicked problems". Recent research have also identified gaps highlighting that the exploitation of these new technologies is fragmented and, facing a ¨square peg into a round hole¨ barrier. The same research also identified a discrepancy between *Work as Imagened* (*WAI*) and *Work as Done* (*WAD*) which emphasize the need to understand how the operators use the technology before it is introduced onboard.

The purpose of this research was to identify the scope, nature and consequences of incidents and problems associated with the application of digitalization. Participant stakeholder groups within the shipping industry were interviewed and identified many of the problems associated with the digitalisation on board.

MAIN FINDINGS

Among the results, evidence was given of several areas in need of improvement e.g. systems being too complex, not fit for purposes, providing too much information, the crew need to "work around" and adjust work and procedures together with not having sufficient support when needing it, interference of programmers to update software during operation; the issue of ¨lack of support¨ was a consistently recurring theme.

The ¨support¨ problem has many dimensions such as the crew members don't understand (a) what went wrong (b) how it was fixed and (c) what can be learnt from the event. Furthermore, support to handle these issues were not always available 24/7 which in some cases disrupted the operation of the ship and/or prevented it from leaving port.

CONTENTS

INTRODUCTION

The 3rd industrial revolution started in the 1960s, catalyzed by the development of the semiconductors. This development was followed by the personal computer (1970s and ´80s) and the internet in the 1990s (Schwab, 2016). This development had a huge impact on work and personal life, the shipping industry no exception. Sweden took a leading position in the development of shipboard computer technology through Kockums Shipyard (Maritime Executive, nd). The Swedish Ship Research Foundation funded a project using a turbine tanker ordered by Sahlénrederierna AB. The vessel had a prototype installed of what later became the first worlds automatic telex. ASEA (today ABB) equipped the vessel with computerized navigation and steering control of the vessel, automation of the turbine machinery and control of the cargo handling process. This was the beginning of an era that would change the operation of vessels and impacted how work is done on board.

Schwab (2016) argues that the 4th Industrial Revolution (4th IR) (*also referred to as Industry 4.0 – IR 4.0*) is different in scale, scope and complexity compared to impacts of earlier industrial revolutions. He suggests that the emergence of technological evolutions (i.e. Artificial Intelligence (AI), Data Analytics, Cloud, Quantum and Edge Computing and the Internet of Things (IoT)) are profound and have created long-lasting impact. His prediction of how theses disruptive technologies, such as digitalization and automation into society will drive socio-economic change.

The disruptive technological evolution related to the 4th IR has had both a direct and indirect impact upon the shipping industry and its rise has been monikered as *Shipping 4.0*. Recent research (Aylward, 2022; Aiello et.al., 2020; Baum-Talmor and Kitada, 2022) have identified gaps highlighting that the exploitation of these new technologies is fragmented and, facing a ¨square peg into a round hole¨ barrier; attempts to use these technologies in a way that doesn't reflect the way *work as done* (WAD) should develop at the same pace as the technologists' understanding of *work as imagined* (WAI). While crew can exploit technologies to support or replace repetitive or cognitively complex tasks, these performance shaping technologies may, ironically, increase the performance gaps between WAI and WAD. Shipping 4.0 have attempted to manage the disruptive changes; it has also brought to light the emergence of ¨wicked problems¨.

While supporting the implementation of digital tools on board, the International Maritime Organization (IMO) published an e-Navigation strategy and is described in MSC 85/26 (IMO, n.d.). This circular address a vision of the future of navigation systems, vessel traffic information and aims at creating harmonized data and communication structures to address growing obstacles related to the safe and efficient operation of vessels. Complementing the e-Navigation strategy, the IMO initiated the Maritime Autonomous Surface Ship (MASS) scoping exercise between 2017 and 2021 which aimed at investigating how increasing levels automation (LOA) would impact safety, security, and the environment (IMO, 2021).

The purpose for introducing digitalization and Information and Communication Technology (ICT) in the shipping domain and on board has been to increase safety and efficiency, but it is also known that this development has not only had positive consequences but also a long list of negative ones and is regarded as a potential stressor in our modern working life (Tarafdar et.al. 2006). Furthermore, the digitalization and ICT technology also depend on a connectivity to internet, thus open up for the risk of unwanted hacking thus adding cyber security to the equation (Svilicic et.al 2019; Meland et,al. 2019). IMO has provided guidance to support the implementation of digital solutions and ICT and in this work noted that there are several problems related to this, which also is supported by other research (IMO 2006; Tarafdar et.al. 2006). Other results have also suggested that this technological development can be both counterproductive and ineffective or as Lützhöft (2004) elegantly phrased it; "technology is great when it works". Voices within the shipping industry has also raised awareness of problems associated with the digital equipment on board and asked for more knowledge of the challenges the crews are facing.

Purpose

The purpose of this project is to contribute to the understanding of the scope, nature and consequences of incidents and problems connected to digitalization called for by the industry, IMO and other research that the introduction of digitalization and ICT technology has brought on. The goal is to propose implementations of targeted measures and action plans that can support the shore and on-board organization and thus contribute to increased safety, efficiency and a better work environment.

Research questions

1. What problems occur?
2. How do you prevent and solve the problems occurring?
3. How frequent are these problems?
4. What targeted measures need to be developed?

Limitations

This study was performed in Scandinavia with Swedish speaking participants. Their answers has been translated by the researchers.

THEORY/BACKGROUND

The introduction of digitalization and ICT have meant major changes in our society and workplaces. How digitalization has changed the nature and efficiency of work life across different domains has been a focus of research for decades (Höivold, 1984; Bloor et. Al 2000; Lützhöft, 2004; Allvin et al, 2006; Lundh & Rydstedt, 2016; Cijan et.al. 2019; Ichimura et al 2022). The shipping industry has not been isolated from major technical and organizational changes which has had implications on crew performance and how Work is Done (WAI) (Lützhöft, 2004; Lundh & Rydstedt, 2016; Conceição et.al. 2017, Aylward, 2022). Research results describe a change in task performance, e.g. new tasks to perform, traditional tasks performed in different ways, seafarers adjusting to the management of new technologies and a demand for a different vocational skill sets and knowledge (Lundh & Rydstedt, 2016, World Maritime University 2019, Baum-Talmor and Kitada 2022). One distinct example is the historic development of navigational aids on the bridge (Conceição et.al. 2017) (Figure 1)

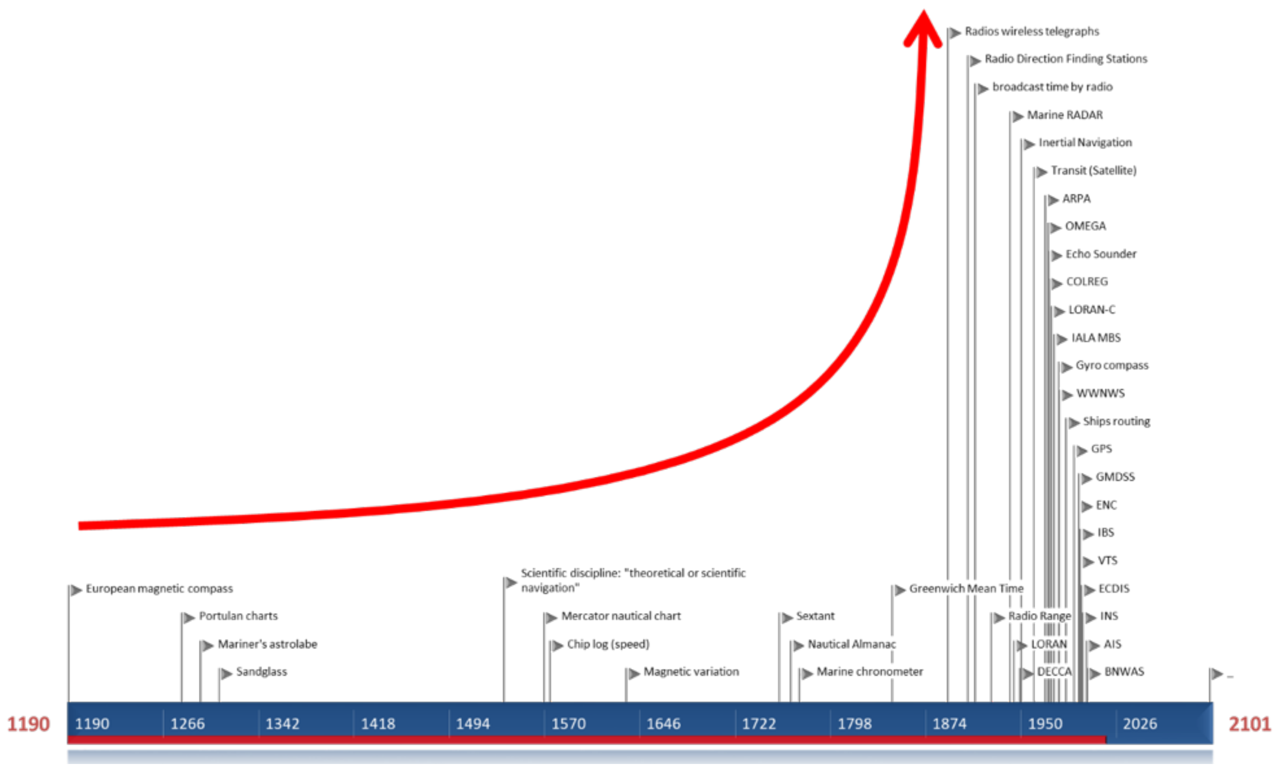

Figure 1 The development of navigational aids (Conceição et.al. 2017) (Used with permission from the authors)

Systems Approach

It is not only exploitation of new technologies that must be considered in large socio-technical systems, but also how these technologies change Society. Past IRs have done this in a very profound way; the invention of electricity, computers, and the internet, as examples. An emerging term, ¨Industry 5.0¨ refers to people working with robots (i.e. AI Agents) and smart machines (digitalisation). This construct provides a vison of industry that aims beyond efficiency, reinforcing the role and the contribution of industry to society. ¨It places the wellbeing of the worker at the centre of the process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet … It complements the existing "Industry 4.0" approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry (European Union, n.d.). Elements related to the future of industry are already part of the EU Commission's policy initiatives and relevant to this report includes (1) adopting a human-centric approach for digital technologies including artificial intelligence and (2) up-skilling and re-skilling European workers, both digital and non-technical skills.

Work as done versus work as imagined

How people perform their work is sometimes hard for an observer to fully understand. Design, job descriptions and checklists often rely on "Work as Imagined" (WAI) which is defined as an idealized way of performing tasks based on the belief of what should happen at work while the opposite, "Work as Done" (WAD) is what happens when tasks are performed, including workarounds of prescribed procedures to be able to cope with the complexity that the work environment has (Hollnagel, 2012).

Human Centered Design (HCD)

It is well known that a successful design of technical equipment builds on early involvement of the end user into the design process. This approach is described as an interactive design process making systems/technology more usable through the application of human factors/ergonomics knowledge and usability techniques (ISO, 2019). Despite decades of this type of research within the shipping domain, pointing out the necessity of this approach, many problems remain in maritime applications (Lützhöft 2004, Grech and Lützhöft 2016, Mallam et al. 2017, Costa 2018, Gernez 2019, Aylward 2022).

Additional technique is developed and added on to existing systems on board without a strategy to integrate these systems. This lack of strategy risk causes a lack of overview and more complex systems as a result (Aylward 2020, Aylward et al. 2020, MAIB 2021). To successfully design complex workplaces as e.g., a ship's bridge, a collaborative and holistic approach from a interdisciplinary team with the end user involved from start is a prerequisite (Lurås 2016, Aylward 2022).

Low-level automation

Other transportation and safety critical domains have visioned and adopted LOAs (and its concurrent contributions from digitalization technologies). While MASS has provided operational definitions for progressing levels of digitalization and automation, so have other maritime stakeholder groups (e.g. Lloyd's, 2016; NFAS, 2017; Bureau Veritas, 2019). While all can serve as benchmarking or standardization baselines, the variants in taxonomies and ontologies of LOAs will make cross-domain comparisons of human performance more challenging. Standardization would be an obvious approach to address these challenges (Patraiko, 2007).

Although the shipping industry is, at an increasing speed, moving towards highly automated systems on board and eventually autonomous operation we are not there yet. Globally, today's shipping is a mix of vessels operating at AL 0 without any autonomous functions to higher levels such as AL 4 where the human is in the loop but as an operator/supervisor. As more technology is being introduced and ships are subjected to retrofitting the situation onboard will be pushed up the scale ant thus changing how work is done onboard (Aylward, 2022). To successfully be able to build on the experiences made during this transition period, it is important to create an understanding how the introduction of new technology will affect the crew performance thus focusing on MASS 1 (Aylward, 2022).

Research on digitalization on board

Several EU-funded projects have investigated how the operators on onboard are affected by the introduction of e-Navigation and digitalization (Sea Traffic Management (STM) MonaLisa, MonaLisa 2.0, EfficienSea, EfficienSea II). To take this matter further, other projects have focused on future autonomous operation of vessels (Maritime Unmanned Navigation through Intelligence in Networks (MUNIN, 2016) and the European Defense Agency project Safety and Regulations for European Unmanned Maritime Systems (SARUMS). Putting this into reality, at the end of 2017, the China Daily reported the first so called "smart ship" completed its trial voyage (MarineLink, n.d.). It is said to be able to analyze real-time navigation and meteorological data, pick the best routes and will become "smarter" as it accumulates more data. Yare Birkaland is another example, the worlds' first autonomous fully electric container ship aiming at fully autonomous operation (Kongsberg, 2021).

This development has manifested itself in several other projects aiming at understanding the skills and knowledge future seafarers will have to gain to operate in this increasingly automated workplace. Human Maritime Autonomy (HUMANE) has aimed at investigating a series of alternative scenarios regarding use of autonomy and/or advanced ICT from the perspective of e.g. work organization, education/training and regulation (HUMANE, n.d.).

Another area of interests are decision support systems. NAVDEC or navigation decision supporting systems is said to be the first of its type (Pietrzykowski and Wołejsza 2016). The purpose of the system was to provide the navigator with plans that comply with COLREG. Other examples of decision support systems from more recent data are the work on Multi-ARPA (MARPA) and Advanced Intelligent Maneuvering (AIM) (Ozoga and Montewka, 2018;

Wärtsilä, n.d.). MARPA provides the navigator information on safe headings based on direct hazards for the Own Ship while AIM is developed to support the navigator in traffic situations and by suggesting different alternatives, building on Convention on the International Regulations for Preventing Collisions at Sea (COLREG) rules, to prevent collisions and near misses. Bainbridge (1983) wrote about the risk of unwanted and surprising consequences while adding new technology. This was confirmed by Aylward et.al (2022) who after having user tested AIM concluded that while the decision support system was appreciated by navigators, they also saw concerns with miss-placed trust, overreliance, and complacency.

It is not only the actual operation of the vessel that has changed, administrative duties and means of communication has through the access to internet onboard changed how work is done (Lundh & Rydstedt, 2016; Österman and Hult 2016). A more recent project investigated the possible benefits/improvements to shipboard safety and welfare (ADSinsight, 2022). The results indicated that the digital tools as seen by the seafarers have a positive impact on efficiency and personal safety. The concerns made by the participants pointed towards an increase of "new" risks such as cyber security issues. The report made recommendations how to improve the implementation of digitalization mentioning e.g. the tools are suited for on board use, involve the end users early, training and user manuals, ensuring the tools are properly tested before full rollout and ensure that cyber security risks are properly taken into consideration.

ForeSea

Data from incident reporting systems are used withing different safety critical organisation including the shipping industry to e.g. identify causes of different events and to generate an understanding of problems occurring (Hetherington et.al. 2006). ForeSea is an information system for accidents, near-accidents, and deviations whose primary purpose is to prevent marine accidents and improve maritime safety. The system is developed by the Swedish shipping industry in collaboration with maritime authorities. As of January 2016, the system is owned and financed by the Swedish Shipowners´ Association. Incidents are anonymously reported by ship owners and shared amongst the other ship owners.

To exemplify typical incidents onboard related to digitalisation, Appendix A contains result of searches in the incident report system ForeSea using search terms "computer", "software" and "power management system/ PMS" and those categorized with involving computers to exemplify certain typical digitalisation failures onboard impacting maritime safety. These can be seen as complementary to the main report, supporting the findings and give insights into details of typical occurrences onboard related to digitalisation.

METHODS

A mix of semi-structured interviews and focus groups was used in this project (Magaldi and Berler, 2020; Gerger Swartling, 2007).). The on line platform Zoom (https://zoom.us/) was used for the interviews and Microsoft Teams (https://www.microsoft.com/sv-se/microsoft-teams/log-in) for the focus groups. The recorded material was then transcribed verbatime and then analysed. All interviews were performed in Swedish and the results translated by the reseearchers.

Semi-structured interviews

The semi-structured intervies build on themes building on the research questions. In total 10 interviews were perfomed. Each interview lasted approximately 1 hour and was lead by one researcher. The themes were;

- What problems occur?
- How do you prevent and solve the problems occurring?
- How frequent are these problems?
- What targeted measures need to be developed?

Follow-up questions were prepared together with open questions like; “Could you tell me more?”, “Do you have any examples?”.

Focus groups

Two focus groups were performed. There were two researches moderating the group discussion, one leading the discussion and taking notes, the other managing the recording and also taking notes. This firs one focus group discussed research question 1; “What problems do occure?” The participants were then asked to agree on five of the most common problems. Once the group had agreed, they were asked to rank them from one to five where one was the most serious one. In the second focus group the results from the interviews were reported. The participants were then asked to select the three most important areas to research further and rank them.

ForeSea search

The results from the interviews and focus groups were later used to perform a search in ForeSea to investigate if there is a correlation between what the participant describes as problems and what is reported into ForeSea as incidents. The used search words/phrases were alarm, bug, interface, alarm in IT, distractions, support in IT, in IT search, much information, complexity, interfaces, complex, hazzle, internet, internet connection, updates, bugs, computer, software.

Participant Demographics

Interviews;

In total 10 participants were interviewed. After having completed these interviews, the researchers experienced saturation in the data (Corbin and Strauss, 2008). The answers were starting to repeat themselves and no depth was added.

The average age was 46 years (max 62/min 24) and the average time in their current position was 7 years (max 24/min 1). 8 participants were male and 2 female. Out the 10 participants, 3 were captains, 2 chief engineers,1 technical manager with a previous background as captain, 1 Safety manager also with a with a previous background as captain, 2nd mates and 1 People and technology manager/IT.

Focus Group 1;

In the first focus group 12 participants were present where off all were men with an average age of 54 years (max60/min40). Seven represented shipowners, one represenatative from the Transport Agency, one form a research institute, one from the academy, one IT supplier and one representative from the Shipowners Association.

Focus Group 2;

In the first focus group 11 participants were present where off 10 were men and 1 woman with an average age of 47 years (max60/min40). Six represented shipowners, one represenatative from the Maritime Administration, one form a research institute, one from the academy, one IT supplier and one representative from the Shipowners Association.

Analysis

The analysis was performed as a Thematic Analysis according to Braun and Clarke (2006). The steps used in the analysis was as follows (a) familiarization of the data (b) initial coding of text relevant to the different research questions (c) grouping codes and searching for themes(d) reviewing themes (e) naming themes and (f) writing the report. The transcribed interview material was imported into NVivo software (https://www.alfasoft.com/en/products/statistics-and-analysis/nvivo.html) to facilitate the coding and the identification of themes.

Ethics

Prior to the interviews, the participants were informed about the purpose of the study and the ethical rules applied in the project. They were also asked to give their permission to have the interviews recorded for analysis purpose. The personal data was handled in accordance with EU General Data Protection Regulation (GDPR).

RESULTS

The results from the interviews and focus groups are reported separately. Table 1 gives an overview of the main and sub themes found in the analysis of the interviews

Interviews

Table 1: Overview of the main-themes and sub-themes

Questions	Main Themes	Sub-themes
What problems occur?	1 ”Hassles”	1.1 Bugs
		1.2 Updates
		1.3 Internet Connection
	2 Complexity	2.1 Many systems
		2.2 Interface
		2.3 Too much information
	3 Distraktions	3.1 Alarms
		3.2 Interface
	4 Support	4.1 Larger/smaller companies
		4.2 “Personal” contacts
How do you prevent and solve the problems occurring?	5 Adjusting	
	6 Colleagues	
	7 Creativity	7.1 “Work around” the problems
How frequent are these problems?	8 Maturity of the programs/systems	
What targeted measures need to be developed?	9 Support	
	10 Standardization	10.1 Advantages
		10.2 Disadvantages
	11 User centered design	11.1 Structure
	12 Interconnected systems/programs	

General

Taken together, digitalization is considered a good thing by the participants. When working as expected it saves time, makes work more efficient and makes data and information available and accessible in a way analogous system cannot. However, given the results of this study, there are room for improvements to fully reach the goal of using digitalization as a mean to make shipping more efficient and safer.

> *“*
> *… just that information is available all the time, that you can get things that you had to wait for weeks for before…”*

> *“*
> *… it saves time… … the information is also available now in a way that was not possible earlier…”*

What problems occur?

1 ”Hassles”

Although the interview material contained long descriptions of errors, “hassle”, insecurity and partly added workload, the respondents were positive about digitalization and saw several advantages such as contact with shipping companies and other on shore organizations, access to information and in some cases easier and more efficient handling of some systems. It was also clear that digitalization had changed work performance and the expectations of the crew. One major concern was about the safety-critical systems failing affecting the trust in the systems.

> *“*
> *… it takes a lot of time this, this administrative burden has increased incredible for the senior officers in particular…”*

1.1 Bugs

Bugs in the programs are by the participants mentioned as a problem. The program will freeze you need to re-start the computer. Apart from creating more work it also contributes to an uncertainty which affects the trust in the systems. What also contributes to the uncertainty is that there is no real expiation to what went wrong and thus how to avoid it. However, the participants saw a difference in more mature systems as opposed to newer systems which they felt were released to the market too early.

> *“*
> *… yes, the program will freeze, you will loose the data you have entered and have to start all over again…”*

1.2 Updates

Several participants gave evidence of updates causing different problems. A functional program can after an update causes new and unexpected problems. The updates are not always planned or scheduled and as the manufacturer can remotely control the update could lock a system in use jeopardizing safety as the system was in use during a critical operation. Updates can also generate a new and different interface causing additional work for the operator. Updates has also left the system unfunctional.

“… when it works… … then it should be updated and every time we update then there will be new problems…”

“… they had done an update of something and changed a computer… … now everything works he said and just left. When we left, we didn’t have a single chart, it was all white screens… … it was completely disastrous…”

1.3 Internet Connection

Although there was an agreement that access to internet has improved it is still a problem. The connection is unstable, and signal is sometimes lost. One participant also described that it was weather dependent as heavy rain would disrupt the internet. Large and complex programs could also be a problem as a weak internet slowed down the response time. This was especially present when the on-board staff connected against the shore-based organization. Some participants gave evidence of situations where a lost signal stopped a safety critical system during operations.

The availability of internet connection also affects the planning of the work onboard. Tasks need to be postponed as the crew members are aware of when the internet is weak.

“… it is a very worrying consequence when the system itself is not really stable and working as it should…”

“… because if it is a thunderstorm or heavy rain in XX, where the land station for the satellites is, the internet or the cash registers in the shops don’t work… … we actually have to wait until it is over…”

2. Complexity

There was an agreement among the participants that User Centered Design is not fully implemented in the design process of interfaces. This resulted in extra, time-consuming work and a situation where you need to spend time learning and re-learning.

2.1 Many systems

The participants argued that there are too many standalone systems that they need to enter the same or similar information into. This adds to the workload, time spent doing administrative work and increased the risk of mistakes being made.

“… we use a lot of different systems and I think that is a problem…”

“…the negative can be that you must use several systems for the “same thing”, for example posting an invoice means double work. Then you need to post it in one system and then go into another to say that you have posted…”

2.2 Interface

The participants were united in the opinion that often the interfaces are complicated with long structures to navigate in. It requires concentration and a learning curve to manage the program efficiently. Every manufacturer has also their unique solution and design strategy which, even though the necessary functions are there you need time to get used to a new system. It was especially obvious when the participants talked about systems they more seldom use and forgot, al lot of time was spent on relearning.

“… simply a larger menu first as you graze down… now there are lots of menus that you can certainly graze your way through, but it shouldn’t have to be so much from the beginning…”

2.3 Too much information

In general, the participants thought the systems displayed too much information. Several participants said that having access to a lot of information was a good thing, but it should be structured in a way that you easier find what you are looking for and not having all the information displayed at once.

“… after all, this is something of a fad, it’s about getting as many functions as possible…”

3 Distractions

The participants mentioned examples when the design and the workplace and interfaces forced them to take attention away from their task. This was especially distressing in safety critical maneuvers.

3.1 Alarms

There are too many alarms according to the participants. These alarms are described as annoying and hard to locate at the signals sounds the same and you cannot distinct between them. Systems which are not stable or dependent on e.g. GPS signals display error messages. These can under certain circumstances block the interface and you need to see and you need to manually acknowledge them. The alarms are also spread out over the bridge/ECR.

“… you can walk if you like and listen for any sound like something beeping somewhere… … crawling under desks and all over the place. You will never find it!...”

3.2 Interface

With too much information available, participants mentioned you need to concentrate on finding the “right” information. How to navigate in the system and finding the information is not always intuitive and simple.

“
… I also think a big problem today is that those who develop the programs and interfaces are experts in software development, many of them are engineers… … but they rarely take the end user´s perspective into account…”

4 Support

Having access to support is described by the participants as crucial. The experiences that the participants are mixed, both positive and negative.

“
… I think it works well to get in touch with the IT department ashore and get it fixed…”

4.1 Larger/smaller companies

There is a discrepancy between smaller and larger shipping companies as well as smaller and larger manufacturers. Larger shipping companies tend to have a lot of knowledge in house having access to their own IT-department while smaller companies need to rely on support from the manufacturers. Especially the smaller shipping companies experienced a difference in response from larger manufacturers, they lacked confirmation on reported errands and felt down prioritized. The support function is not always available 24/7 which tends to be a problem as the ship is in operation around the clock.

“
… it is rarely you get the support you need exactly when the problem occurs…”

“… and it’s really bad response, that is what it is… from the big companies. And it is very tragic because it can affect us a lot…”

4.2 “Personal” contacts

Most participants describe the value of having someone to call, a person at the manufacturer, someone at the office or a colleague. This is a “fast track” to solving problems.

“
… after all, she has acquired, so to speak, personal contacts at that company, so that we have a shortcut to enter…”

How do you prevent and solve the problems occurring?

5 Adjusting

The availability of internet connection also affects the planning of the work onboard. Tasks need to be postponed as the crew members are aware of when the internet is weak.

> "… *we learn, for example invoicing and accounting, I don't do that at sea…"*

6 Colleagues

Systems that are used more seldom can be difficult to learn and remember how to use. Colleagues on board and on shore are valuable recourses to use.

7 Creativity

There is a slight resignation and acceptance that problems will occur. The crews find strategies to manage situations and creative ways to sometimes work around problems to find solutions and to move forward.

> "… *I mean… our crews are a bit like MacGyver, they fix anything with cones and wire if necessary…"*

How frequent are these problems?

The participants agreed that the frequency of problems occurring has become less but still are too many. It was mentioned a span from weekly occurrences of problems to a monthly occurrence.

> "… *yes problems and problems… yes there are far too many…"*

8 Maturity of the programs/systems

Systems that have been on the market for longer time appears to be more stable than newer systems. The participants give evidence of less mature systems that are introduced too early onboard which creates an uncertainty and lesser trust in the technology. Especially when it comes to safety critical systems.

“
… development of fire alarm system… …, such important systems you don’t want a prototype to test onboard to see if it works or not…”

What targeted measures need to be developed?

9 Support

The crew members high light the importance of having access to support 24/7. It is often emphasized that operating a vessel is an around the clock business and that sometimes rather minor events can have a major impact and from a regulatory perspective make the vessel not sea worthy and delay it leaving port.

“
… the check-in system was updated so they could not take out the passenger list for departure and they simply had to wait… …this happened at 5 and they had to wait until 9 when the staff of the manufacturer started working…”

10 Standardization

The participants´ opinion was divided when it came to standardization, they saw both advantages and disadvantages with this.

10.1 Advantages

The main reason for those in favor of standardization was that they felt the development of technology and its design is driven by the tech companies. This created a situation with a plethora of different interfaces and solutions demanding a learning curve for the user. Also, that familiar interfaces could change significantly after an update which again required time to get familiar with. The participants especially mentioned safety-critical systems as something that could benefit from being standardized.

“
… I absolutely think so… … for example fire alarm system interface…”

10.2 Disadvantages

The disadvantages mentioned that this could possibly restrict and limit innovation and development and thus miss out on possible improvements.

“
… it could have the opposite effect, you can limit the development of the digital tools…”

11 User Centered design

The was a general agreement that the systems are often very complex and tend to have and display too much information. There is no objection to have access to a lot of information but to display too much makes the interface cluttered, information is hard to find and it also affects the readability negative. To add more information should be optional.

"… users need to decide for themselves what and how much information they want to see…"

"… the maintenance system, I've worked with it for 15 years but it took years before you started to get good at it because it is not very user-friendly…"

11.1 Structure

The structure of the interface needs to be simple and intuitive. A complicated structure is confusing and time-consuming to work with and takes too long time to learn where to find the information you need.

"…yes simply a larger menu first that you graze down. Now there are a lot of menus that you can certainly graze your way through, but it shouldn't have to be so much choices from the beginning…"

12 Interconnected systems/programs

The participants gave many examples of different systems which require the same data, data that must be entered manually into each system. It adds to the workload, is time consuming and increase the risk of wrong data being entered. There are also situations where multiple systems need to be used for one task.

"… we have a lot of different systems and that is what I think is a problem…"

"… the negative can be that you have to use several programs for the same thing, e.g. for posting an invoice means double work. You need to post it in one program and then go into another to say that you have posted the invoice…"

Focus group 1

Table 2: Results from Focus group 1 "What are the five most serious problems that occur?"

Problems: (Ranked from 1 to 5 wheras No 1 is the most serious)	Description:	Consequencies:
1. **Support**	This was regardes as the most serious problem. The participant saw a "concentration of power" where smaller companies (who used to have a good support service) is bought up by a larger company which tend to make support less available. It is difficult to get feed-back, long waiting time for reply and the answers are not always helpful. In the cases the support is functioning, you usually has a specific person and phone number to call this person.	This is not only a risk to safety when the systmes onboard fail but is also a risk to finacial consequencies as the ship can be classified as not being sea worthy and stopped from leaving port. Often are the faults minor but requires help from the support.
2. **Complexity**	Many systems are too complex and it seems like there is an ambition to add as many functions as possible into one system. ECDIS is mentioned as a typical example of this. There are also too many alarms, "everything" has an alarm and is generating fault messages. The interfaces are not thought through.	There is a risk to misinterpret information and a risk of information overload. Also a risk to focus on "wrong things", eg. on acknowledge alarms and/or fault messages and thus taking the attention away from the operation of the vessel.
3. **Small problems – large consequencies**	Relatively ”small” fualts eg. bugs in the system can lead to major consequencies. It often difficult to understand what the cause was and why it went wrong. Service engineers is changing "something" and cannot really explain why and what went wrong or broke down. You need to ”hope” it will work again.	It is easy to loose trust in the technology, you dare not to trust it. Especially when an explanation and understanding what went wrong and why is lacking.
4. **Standardizing**	Every manufacturer has their own design and their own solutions. This means the crew members frequently need to learn and re-learn. Certain equipment would benefit from some kind of standard solutions which means that if you have learned one eg. ECDIS you should know them all.	This means that all too often the crews are facing a learning situation which cannot be solved by generic training courses as all manufacturers are allowed to create their own solutions.

5. Immature technology	Unfinished, not compleately thought through somlutions are fitted on board. Looks good ashore but is not tested for the maritime environment.	This is frustrating for the crews as they feel like they are being used as “testbeds”. This risk also leading to possibly dangerous situations.

Focus group 2

Table 3: Results from Focus group 2 “What are the three most important problems to further research?”

Problem:	Anteckningar:
1 Support	The participants agreed that a functioning support is the most important area to solve. The ships are in operation around the clock and all over the world in different time zones. It is not possible to stop operations and wait for a support function on the other side of the world to open and start working. Online support can also be problematic as the ships do not always have a sufficiently stable internet connection. A concern was also raised about data breaches when the ship is online. A special case is also when new systems and/or major system updates have been implemented on board, that there are routines that ensure functioning systems before the supplier can leave the ship.
2 User friendliness	Not all systems are user-friendly from the perspective of end users. They are difficult to navigate, not intuitive, complex and often contain too much information on one single interface.
3 ”Right” information	If the interfaces are to be developed, we need to understand what information needs to be prioritized, is necessary and what is "good to have". It is important to understand what is "Critical Information in Tactical Navigation". If not a standardization of interfaces can be agreed, then a common design strategy that includes safety critical systems should be developed to minimize the risk of mistakes, "information overload", risk of being distracted and lessen the demand of learning and re-learning.

ForeSea and incident reporting

While searching for incident reports, many incident reports describe incident where no root cause was found and thus the cause of the fault was unknown or presumed to be a "bug" In the system. Support was on occasions contacted and/or the computer had to be restarted and/or the software updated.

> *"…Exact reason unknown. It seemes like the ECDIS was "confused" about which computer was master/slave and therefore the system was very slow and the sensor input/output was sometimes faulty."*
>
> *"…The reason why the ME2 tripped remains a mystery.".*

Bugs in the system causes a plethora of problems, e.g. frozen screens, malfunctioning radar, GPS showing wrong date andtime, VDR out of order, loading compuster slow, communication failure between different types of equipment on the bridge, Auto pilot affected and the ECDIS. Apart form contacting the support, the system(s) need to be restarted and sometimes the system(s) reboot themselves automatically.

> *"…Communications failure in between of the gyrocompasses and the rest of the bridge equipment due to errors in the software."*

The surrounding hard ware, especially cables coming loose due to vibration is a contributing factor to the systems lacking the correct signal and thus not operate as expected; *"The loose wiring contact were tightened and the Auto pilot restarted".*

The consequences describes are anythng from "none" to the vessel being delayed or a situation that risk developing into something serious e.g. gronding.

> *"…The departure was suspended. Planned voyage had to be rescheduled with 2 days"*

The "hazels" described in the results also has another consequence, the trust in the systems that should improve maritime safety is affected.

> *"…The trust in the systems is gone."*
>
> *"…Immediate cause: Power management not trustworthy."*

DISCUSSION

Overall, the participants saw digitalization as positive progress which align will with other research results (ADSinsight, 2022; Ichimurs et.al. 2022). There was also an agreement that the systems on board had developed, but according to the results, there are still too many challenges and regularly occurring faults in the systems that the crew needs to manage so clearly there is room for improvements.

The introduction of computers and a plethora of digital tools to operate the vessel has changed how work is done and added an increased administrative burden (Rydstedt and Lundh, 2016; Österman and Hult, 2016). The overall aim for these changes, to make work safer efficient, is thus partly failing given the results from this study, where testimonies of an increased workload and errors in the digital systems potentially can lead to dangerous situations are given. This was e.g. expressed as a presence of "Hassles" thus referring to bugs in the systems and sudden updates causing unexpected effects and/or forced restarts and a feeling that prototypes are being launched on board for the crew to test. In the ForeSea incident reports it is also found a lack of thrust in the systems which aligns with previous research stating that attempts of digitalization to increase safety might turn out to be counterproductive (Lûtzhöft, 2004).

User friendliness was by the participants mentioned as one of three important areas to further research as interfaces are seen as difficult to navigate in, too much information is given, and systems are complex. The need for a holistic approach from an interdisciplinary team using a Human Centered Approach is well documented and given the exponential increase in technical tool a necessity to succeed in the overarching goal of digitalization (Lützhöft 2004, Grech and Lützhöft 2016, Conceição 2017, Mallam et al. 2017, Costa 2018, Gernez 2019, Aylward 2022; ADSinsight, 2022). Still these types of problems remain which signals for a different approach to the design and testing/benchmarking of new technologies to ensure the technical and human readiness maturity of the equipment before introduced onboard. So rather than research the need for an early involvement of the end users ask; "Who own the question?", who and how can a User Centered design approach be made mandatory and assuring mature and well-functioning digital tools? It is also important to stress the need for a "Work as Done" (WAD) approach to position the operator in the center (Aylward, 2022; Hollnagel, 2017). This is especially important and challenging given the rapid technological developments that the shipping industry is subjected to. Technology devices cannot be evaluated as stand-alone units but must be seen in a socio-technical systems perspective as added technology affect how work is done and decisions made and can generate unforeseen outcome and affect the operators' performance and then not only in a positive way (Lützhöft, 2007; Aylward, 2022).

There is a slight resignation among the participants thus anticipating that digital tools and equipment will fail in one way or the other. Colleagues are important here to cope but the crews are also creative and work around the problem and by doing so adjusting how work is done.

What was classified as the largest problem on board in this study was by the participants said to be the lack and/unavailability of support. The consequences are that what sometimes is a rather “minor” fault have large consequences and on occasion hindered the ship from leaving port. This needs to be addressed in future research and instead of asking why the support fails it function rather ask how can the need of having 24/7 access to support functions be minimized.

CONCLUSIONS AND FUTURE WORK

- The gap in the evaluation of incidents requiring support by investigating how those responsible for the it-support work to correct faults in digitalized systems on board needs to be closed to make the support function transparent.
- Due to the rapid development and integration of technologies on board, create a greater emphasis on continuing education and proficiency testing, akin to what is undertaken in other safety- critical domains.
- The normalisation of a contextualised human centered design framework, supported by all stakeholders (I.e. ship owners, regulators, and technology developers) that address end-user needs and address knowledge gaps.
- Standardisation and regulations that promote goal-based, research-informed and fit for purpose approaches to implement new technologies within the shipping system.

REFERENCES

ADSinsight (2022) “Investigating the Increased use of digitalization On Board and Possible Benefits/Improvements to Shipboard Safety and Welfare” Final Report

Aiello, G., Giallanza, A. and Mascarella, G. (2020) “Towards Shipping 4.0 A preliminary gap analysis”. Procedial Manufacturing 42: 24-29

Aylward, K. (2020) “Automated Functions: Their Potential for Impact Upon Maritime Sociotechnical Systems”. Licentiate Thesis Chalmers University of Technology

Aylward, K. (2022) Towards an understanding of the consequences of technology-driven decision support for maritime navigation, Chalmers University of Technology, Doctoral Thesis

Aylward, K.; Weber, R., Lundh, M., Dahlman, J., MacKinnon, S.N. (2022) Navigators’ views of a collision avoidance decision support system for maritime navigation, Journal of Navigation, Vol. 75 Issue 3 p. 1-14

Bainbridge, L. (1983) “Ironies of automation” Automatica 19(6): 775-779

Baum-Talmor, P. and Kitada, M (2022) “Industry 4.0 in shipping: Implications to seafarers’ skills and training”, Transportation Research Interdiciplinaaty Perspectives, Vol 3

Bloor, M., Thomas, M., & Lane, T. (2000). “Health Risks in the Global Shipping Industry: An Overview”. *Health, Risk & Society, 2*(3)

Bureau Veritas (2019) “Guidelines for Autonomous Shipping" https://erules.veristar.com/dy/data/bv/pdf/641-NI_2019-10.pdf

Conceição, V., Carmo, B., Dahlman, J. and Navarro, A. “Visualization in Maritime Navigation: A Critical Review”. Presented at the 8th International Conference on Applied Human Factors and Ergonomics, 17-21 July, Los Angeles, USA, 2017

Costa, N. (2018) “Human-centred design for maritime technology and organizational change” Doctoral Thesis, Chalmers University of Technology

EfficienSea http://www.efficiensea.org/ (Visited 2022-12-02)

EfficienSea II https://efficiensea2.org/ (Visited 2022-12-02)

European Commission (n.d.) https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en (visited 221213)

Gernez, E. (2019) “Human-centered, collaborative, field-driven ship design: Implementing field studies for the design of ships in operation” Doctoral Thesis Oslo School of Architecture and Design

Grech, M. and Lützhöft, M. (2016) "Challenges and opportunities in user centric shipping: developing a human cetred design approach for navigation systems". Proceedings of the 28th Australian Conference on Computer-Human Interaction, ACM

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

Hollnagel, E. (2017) "Why is work-as-imagined different from work-as-done?" Resillient Helath Care, Volume 2, CRC Press: 279-294

HUMANE https://www.hvl.no/en/project/591640/ (visited 221208)

Höivold, I. (1984). "Norwegian Research and Development in the Field of Ship Automation. *Modelling, Identification and Control, 5*(3), 171-178.

Ichimura, Y. Dalaklis, D. Kitada, M. and Christodoulou, A. (2022) Shipping in the era of digitalization: Mapping the future strategic plans of major maritime commercial actors, DataDigital Business, ISSN: 2666-9544, Vol: 2, Issue: 1

IMO (2006) MSC 82/15/2 ROLE OF THE HUMAN ELEMENT Research into interaction with automated systems

IMO (2021) MSC.1/Circ.1638 Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)

IMO (n.d.) MSC. 85/26/Add.1 Strategy for the development and implementation of E-navigation

ISO (2019) "Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems" International Organization for Standardization ISO 9241-210:2019

Kongsberg (2021). Autonomous Ship Project, Key Facts about Yara Birkeland. https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-aboutyara-birkeland/.

Lloyd's (2017) "LR Code for Unmanned Marine Systems" https://www.lr.org/en/unmanned-code/

Lundh, M., Rydstedt, L., (2016) "A static organization in a dynamic context – A qualitative study of changes in working conditions for Swedish engine officers". Applied Ergonomics Vol 55, 1-7

Lundh, M., Lützhöft, M., Rydstedt, L. and Dahlman, J., (2011) "Working Conditions in the merchant ships", Applied Ergonomics Vol 42(2011) 384-390 Engine Department - A qualitative study among engine room personnel on board Swedish

Lurås, S. (2016) "Layered scenario mapping: a multidimensional mapping technique for collaboratve design" CoDesign 12(3): 133-150

Lützhöft, M (2004) “The technology is great when it works”: Maritime Technology and Human Integration on the Ship’s Bridge, University of Linköping University, Dissertation

MAIB (2021) “Applications and usability of ECDIS safety study” Marine Accident Investigation Branch https://www.gov.uk/government/publications/application-and-usability-of-ecdis-safety-study

MarineLink https://www.marinelink.com/news/shanghai-debuts-chinas431886 (Visited 2022-12-08)

Mallam, S. C., Lundh, M. and MacKinnon, S. N. (2017) “Integrating Participatory Practices in Ship Design and Construction” Ergonomics in Design Vol. 25 (2) p. 4-11

Meland, P; Bernsmed, K; Wille, E Rødseth, Ørnulf Jan; Nesheim, Dag Atle “(2021) A Retrospective Analysis of Maritime Cyber Security Incidents” *TransNav : International Journal on Marine Navigation and Safety of Sea Transportation* Vol. 15 Issue 3, pp. 519–530, 2021

MUNIN http://www.unmanned-ship.org/munin/ (Visited 2022-12-02)

Ozoga, B. and Montewka, J. (2018) “Towards a decision support system for maritime navigation on heavily trafficked basins” Ocean Engineering 159:88-97

Patraiko, D. (2007) “The development of e-navigatin” International Journal of Navigation and Safety of Sea Transportation Vol 1 Issue3

Pietrzykowski, Z. and Wolejsza, P. (2016) “Decision Support in System in Marine Navigation”, Cham Springer International Publishing

SARUMS https://www.eda.europa.eu/docs/documents/SARUMS-Flyer-2012.pdf?sfvrsn=0 (Visited 2022-12-02)

Schwab, K. (2016) The Fourth Industrial Revolution, World Economic Form ISBN 978-5247-5886-8

Sea Traffic Management (STM) Mona Lisa https://www.seatrafficmanagement.info/ (Visited 2011-12-02)

STM ”Mona Lisa 2” http://stmvalidation.eu/projects/monalisa-2/ (Visited 2022-12-02)

The Maritime Executive https://maritime-executive.com/editorials/fifty-years-since-the-first-computer-at-sea (visited 221013)

Tarafdar M, Tu Q, Ragu-Nathan B, et al. (2007) The impact of technostress on role stress and productivity. J Managem Inform Syst; 24:301–328.

Svilicic, B., Kamahara, J., Celic, J. *et al.* Assessing ship cyber risks: a framework and case study of ECDIS security. *WMU J Marit Affairs* 18, 509–520 (2019). https://doi.org/10.1007/s13437-019-00183-x

World Maritime University (2019) "Transport 2040: Automation, Technology, Employment - The Future of Work" (2019). Reports. 58. https://commons.wmu.se/lib_reports/58

Wärtsilä https://www.wartsila.com/voyage/insights/article/the-evolving-intelligence-behind-smart-navigation (visited 221208)

Österman, C. & Hult, C. (2016) Administrative burdens and over-exertion in Swedish short sea shipping, Maritime Policy & Management, 43:5, 569-579, DOI: 10.1080/03088839.2016.1154994

APPENDIX A

Result of searches in the incident report system ForeSea using search terms “software”, “power management system/ PMS” and those categorized with involving computers

As the idea with this project was based on the work with the Foresea Experience knowledge sharing database and its working group within the Swedish Shipowers’ Association, the database has been utilised to describe typical events that have been shared. Foresea is the common experience sharing database of the Swedish Shipowner Association. Incidents are anonymously reported by ship owners and shared amongst the other ship owners.

In order to exemplify further typical incidents onboard related to digitalisation from the database, different searches in the database have been performed and the results analysed. These can be seen as complementary to the main report, supporting the findings and give insights into details of typical occurrences onboard related to digitalisation.

Method used:

Typical search words that are synonyms of digitalisation, have been identified based on the discussions in the Foresea focus group. Search terms were “*Computer*”, “*Software*”, “*Power Management System/ PMS*” and those categorized with involving computers to exemplify certain typical digitalisation failures onboard impacting marine safety. These searches have been summarised to identify common patterns and the outcome is described below:

Computer

The analysis of data provided in Foresea shows that many incidents related to computers have a wide range of characters.

The incident log contains reports of various technical issues and malfunctions that occurred onboard a vessel during its operations. Some of the incidents mentioned are related to cargo and ballast transfer, including equipment failures such as the cargo control computer not being set to harbor mode, and malfunctioning cargo pumps. IT equipment and cyber security issues are also reported, including missing USB locks, an inability to connect the new loadmaster computer to the old UPS due to different power supply connections, and a malfunctioning BWTS remote screen. Machinery and hardware failure incidents reported include the printer falling off during rough weather, S-band radars not working as they should, and all multifunction displays except ECDIS malfunctioning.

Additionally, incidents involving supplier errors and control issues are reported, such as Supplier X's power management for auxiliary engines not working as programmed and an unauthorized remote login during docking assistance. The incident log also reports failures in the AIS automation system and the Auto mooring system, as well as a delayed check-in and the absence of passenger lists and cargo manifests. The incidents were reported by various departments, including Deck and Engine, and reported by an officer or rating rank. Most of the reported incidents are categorized as occurrences related to cargo and ballast transfer, equipment failure, machinery and hardware failure, or IT equipment and cyber security. The categorisation of the incidents as done in Foresea, is exemplified by causal diagrams, based on Ishikawa diagrams, shown in the figure below.

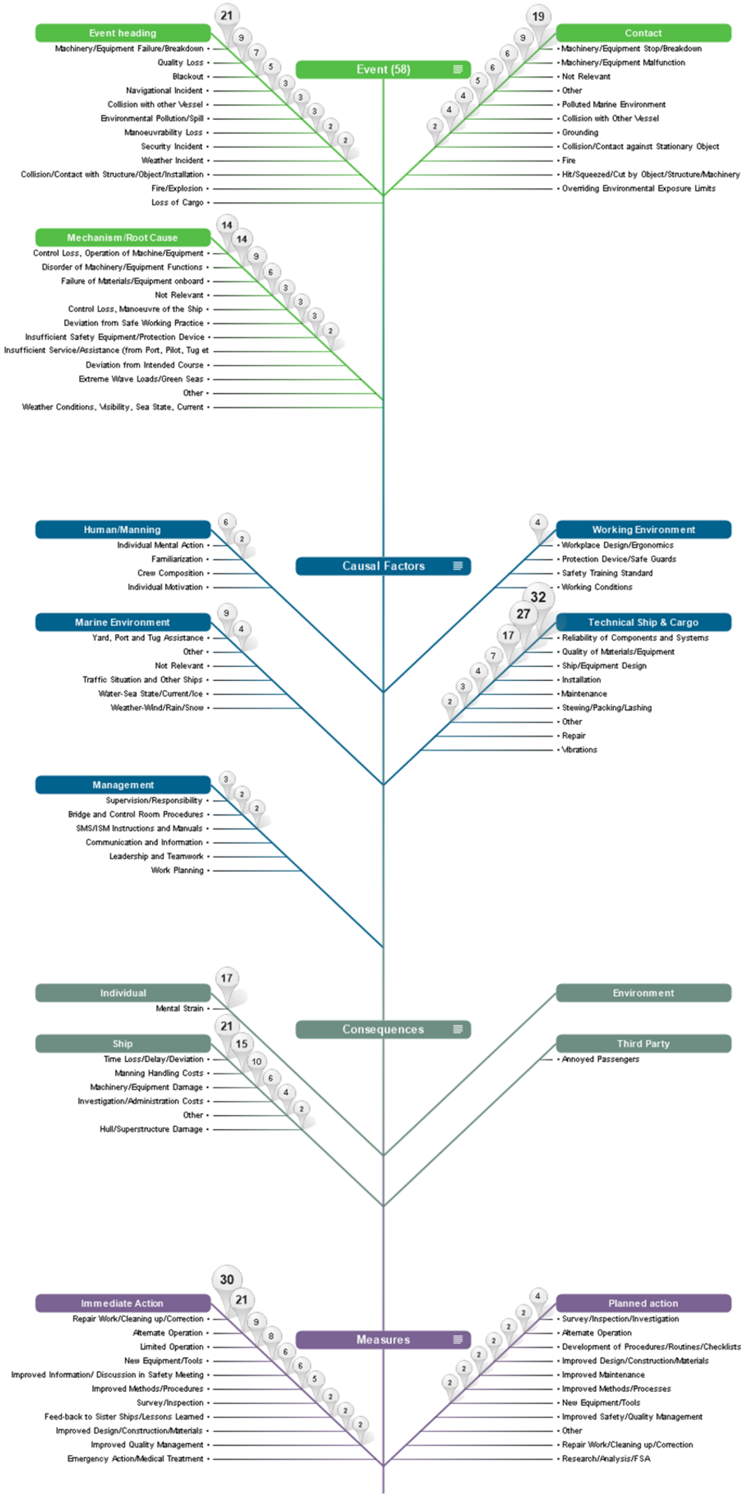

Figure A1: Ishikawa diagram for incidents from the Foresea database involving "Computer"

The immediate and root causes of each incident are mentioned. Forgetting to change settings and no item on the checklist, equipment performance and maintenance, non-compliance with policies, procedures, guidelines, practices, etc. are identified as contributing factors for various incidents. The incidents mentioned in the text are related to automatic doors, loading computer, power supply couplings, cyber-security, automooring system, booking/check-in system, navigation system, and various technical equipment. In some incidents, the root cause is unknown and is still under investigation. Some incidents were caused due to planned server moving or unknown bugs in the latest software update. Equipment performance and maintenance-related incidents were caused due to various reasons like the malfunctioning of IAS/Engine control system, power management not trustworthy, unidentifiable IT problems, etc. In some incidents, the root cause was related to equipment device wear or due to the sensors' improper connection. The incidents mentioned in the text show that proper equipment maintenance and compliance with the guidelines and policies are necessary to avoid technical faults and malfunctions on ships.

There were various incidents reported with potential consequences, but most had no actual consequences or losses. Some incidents had potential consequences such as minor environmental effects, loss of revenue, and direct costs. Some incidents involved equipment malfunction, non-compliance with regulations, and danger to navigation. A few incidents resulted in a delay in departure or arrival, but there were no major consequences reported.

Various corrective and preventive actions were taken in the different situations. These actions were taken in response to issues such as incorrect settings, computer errors, equipment malfunctions, and other similar problems. Most of these actions were preventive in nature, as they involved updating checklists, modifying procedures, or ordering new equipment to prevent similar problems from occurring in the future. In some cases, the corrective action involved contacting technical support, making modifications to equipment or systems, or manually controlling equipment until it could be repaired.

Power Management System Failures

A short analysis of the power management system related incidents has been performed in order to indicate failures not related to navigational incidents:

The first incident describes a problem with the power management system (PMS) on auxiliary engines (AE). AE3 automatically started and disconnected the Gen Breaker for AE2 due to high reactive power, leading to a near-blackout situation during maneuvering. Fortunately, AE3 remained connected to the switchboard and running during the situation, while non-essential load groups disconnected automatically. The second incident refers to a computer system failure related to the PMS mimicry in the box for DG4, where it normally says Auto or Semi-auto. This failure occurred during the departure from port, and the computer system could not start DG4. The third incident relates to a similar computer failure with DG3, where the PMS mimicry in the box for DG3 showed a configuration failure during a test after service. The fourth incident describes a PMS failure with the power management for auxiliary engines, specifically the "Stop Block" function, which did not operate as intended, causing the automatic disconnection of the second auxiliary engine when the load per engine was less than 35%. The fifth incident refers to problems with PMS

DG1, where a computer configuration file was corrupted. The cause of the problem is unknown. The sixth incident is related to DG3, which received a configuration failure and could not be checked or controlled by the supplier. The seventh incident is a bridge equipment failure where a ghost alarm from the PMS caused a control failure alert on the BB side. The eight incident describes a safety hazard, where no routines for testing the emergency stop for aft mooring winches were in place in the PMS.

The ninth incident is related to the bridge design, where the UPS power button was easily pushed with the knee while sitting in front of the PMS-computer, causing the UPS to switch off and shutting down the computer. The tenth incident occurred during grounding outside the port in connection with arrival. AE2 was switched off automatically and stopped without warning, while AE1 started automatically and the generator switch was connected. Ship engineers were troubleshooting the PMS system when AE1 disconnected and stopped, leading to a blackout situation.

Overall, these incidents highlight various types of failures, including PMS failures, computer system failures, bridge equipment failures, and other equipment failures. Some incidents were related to safety hazards, and some were related to design flaws or issues with routine maintenance.

The incident causes can be summarised as follows: AUX GEN.2 was out of service due to the Automatic Voltage Regulator (AVR) delivering the wrong voltage to the Main Switchboard because of a broken AVR. The power management system (PMS) was not trustworthy due to a configuration failure in the PMS mimicry where DC config of the system was not working. The fault was located in a supplier module that controls the power management functions and DPU's for auxiliary engines. After restarting the module, all power management functions returned to normal.

DG1, DG3 and AE3 experienced configuration failures due to some error in the configuration files. The cause of the error is still unknown, but it may be due to interference on the CAN bus. The new UPS for PMS system was installed in a way that allowed it to be easily switched off by accident. This was due to other factors. A malfunction of the bilge alarm was caused by an electrical issue. Human mistakes caused several incidents, including the removal of the lub oil temp sensor while the engine was running, and a manual synchronisation that resulted in a blackout. The crew did not follow the MOB launching instructions in the FMS system and the life-saving manual posted in the day room and bridge, which could have resulted in a serious injury to all crew members on the rescue boat.

The emergency generator did not start because it was not put in standby mode, which could have been caused by inadequate procedures or knowledge. The software was not updated by the maker, which caused a malfunction in the hydraulic steering system. The malfunction in the hydraulic block could have been caused by wear and tear or by service works by the maker during the scheduled maintenance. Overall, the incident causes were a combination of factors, including equipment performance and maintenance, human error, inadequate procedures, non-compliance with policies and guidelines, and poor recognition of hazards due to complexity of the PMS system.

The incident involved various issues ranging from broken AVR, engine not stopping automatically or manually, blackout during docking, failure of electricity supply, delayed vessel, grounding, and BT2 being unusable. However, most of the incidents did not result in any consequence or loss. A few potential consequences were identified, including serious injury, single fatality, and direct cost of up to 50,000 USD. The incidents mostly affected the engine and deck departments, but there were no injuries to people. The vessel managed to avoid pollution or damage during grounding, but it resulted in a 4-day off-hire with a cost of 80,000 USD. The vessel was delayed in some instances, but the consequences were kept to a minimum, with the tank cleaning operation delayed by about 30 minutes. The incident required a service engineer to come onboard and carry out fault-finding and rectifying of malfunction.

The incidents provide several instances where corrective and preventive measures were taken in response to PMS maintenance and safety issues on the ships. In one instance, the supplier was contacted for remote troubleshooting, and the system was restarted after a DC config was made, which resolved the problem. In another case, a SW-system was isolated and replaced, and manual valves were exercised to prevent recurrence. In another instance, an emergency stop was tested, and the control of the emergency stop was added to job cards. Lastly, the emergency generator was put in standby mode, and instructions were posted in the EMG room that the EMG should always be in standby mode. The crew was informed about the importance of the EMG being in standby mode, and this issue was discussed at the next SMS meeting.

In addition, various job cards were added to detect and address issues, and modifications were made to prevent recurrence. The text also details measures taken to address engine and diesel alternator problems, including scheduling routine maintenance, testing software updates, and creating job cards for drills.

Software:

As software is one of the cornerstones of digitalisation, searches in the database were performed in order to exemplify typical incidents related to software. One incident report describes a vessel that was not seaworthy due to three S-band radars not functioning correctly. Another report documents a software failure in which the software froze on two parallel computers while the vessel was sailing, causing concern as the redundancy should have prevented this. In another incident, a software bug caused the GPS to show the wrong date, time and year, and this error fed incorrect information to all equipment connected to the GPS. A malfunction occurred in a vessel's camera surveillance system, while the fire alarm's 'Fire' button failed to activate an alarm during a fire drill. The loss of control occurred when a supplier updated software during operation, causing the ship's speed to increase rapidly, and the vessel was not affected significantly by either bank or suction power. Another incident report describes a failure of the maneuvering mode after updating software, causing the ship to vibrate more than before, and the lever positions were significantly higher than those previously used. Finally, during the initial stage of loading, there was no indication that cargo was loaded onboard, and the vessel was waiting for the terminal to increase to the agreed start-up rate. After a while, the terminal asked if they could increase to full rate, but as they had not received any quantities on-board, the officer on watch was confused and informed the terminal. When the terminal replied that they had pumped about 450m3 to the ship, the officer manually ullaged using UTI and confirmed the cargo quantity on-board. An attempt to restart the TGEs was unsuccessful, and the entire SCU stopped working, with the display freezing. After the system restarts, the correct ullage/volume was displayed, and loading continued as a safety measure. Manual sounding was done every 60 minutes during the loading, and cargo quantity exchange was done between ship and shore. The incident reports suggest that technical failures and software bugs can occur at any time, resulting in various malfunctions and potential safety hazards onboard ships.

Looking at causes, In one incident, an update to the software in Platinum caused an unknown bug, which was later removed. The heaters to scanners were not working due to thermostatic failure, but it was not established as a root cause. In another incident, some bug or problem with the software caused the system to freeze on two separate terminals, and the root cause is unknown. The software supplier is investigating the case.

In another case, the SCC software got locked and froze without any alarms or other signs, and equipment performance and maintenance were contributing factors. The GPS week number rollover for GPS equipment was also a cause of lockup in GPS counters. The on-board surveillance cameras turned themselves off because the disk storage containing recordings locked itself or failed, and some technical error on a disk storage system or software failure was the root cause.

In another incident, the fire groups could not be called out with the fire dectection system due to the software, and software failure could occur if computer servers are not restarted regularly. In another case, the service engineer from the supplier connected his laptop to the control system in the appliance room, and he got access to functions in the system that took over the control of the maneuver. The root cause was the service technician not following the orders/instructions he received from the captain.

In the next incident, the software in PMS did not work as it should, so that the crew could not use operator mode in reality because of software problems. The try of manual synchronizing and recurring blackout was a human mistake. The technique, equipment failure from an external maker, was the cause of communications failure between the gyrocompasses and the rest of the bridge equipment due to errors in the software. The poor standard of software programs, lack of response from supplier, inadequate resources for operations, and not updating software from the maker were other causes of incidents.

Probable bugs in the loading computer software (Loadmaster LMC - 5652) and the software for the Radar Tracking feature were the cause of incidents. In another case, an error in the computer that was supposed to remedy the disconnection order from ECR caused a problem. The ADG 3000 and MK 37 VT Gyrocompass equipment had roll-over times associated with software, and when the roll-over time passed for Gyro, no output signal was received by other equipment such as auto-pilot, repeaters, GPS, and ECDIS electronic charts.

Finally, upgrading and installation of new software in the DGPS system due to jumping waypoints were the probable immediate cause at the time of the incident.

The first incident resulted in the suspension of the departure, which was rescheduled two days later due to frozen software. There were no actual consequences, but there was a slight potential effect on the environment.

Other incidents included camera monitoring of the bow visor and hull openings being out of function, failed equipment, speeding in the fairway, and a blackout while the ship was alongside. These incidents did not cause any actual consequences or losses, but they had the potential to create slight or serious effects on the environment or the ship's maneuverability.

Other potential consequences of software issues included oil flushing out over engines and out in the engine room, damage to the land winch, unsafe navigation, collision, and grounding. There was also an issue with the S-VDR not working, which could impact the ship's ability to provide evidence in case of an accident. The text also noted that the loading computer software had a bug, resulting in delays and frustration for the crew. The X-band radar was also identified as a potential source of serious consequences if it failed, combined with poor visibility, heavily trafficked waters, and proximity to land and groundings. Overall, while many incidents had the potential for serious consequences, most did not result in any actual losses or harm. However, the text highlights the importance of ensuring that all ship equipment is functioning correctly and that potential risks are identified and managed appropriately. This examples includes several examples of corrective and preventive actions taken to address issues with ship equipment, including software and machinery. These actions were taken to ensure the safety and smooth operation of the ship. In one example, the loading system received incorrect input data, leading to errors in the displayed ullage/volume. The issue was resolved by restarting the relevant computer systems and implementing a safety measure of manual sounding every 60 minutes during loading. If the issue were to recur, the system software and database would be reinstalled by a service technician.

Another example involved a problem with software affecting the lever, propeller revolution, and speed. The old software boxes were reinstalled after tests showed that the functions were back to normal. Maker service engineers were contacted to fix the issue and install a new software update, which was tested and approved by the Chief Engineer.

In another instance, a risk assessment was conducted and communicated to crew members to prevent a human error from occurring during work with oil sensors. Additionally, job drills were implemented to train engineers in using machinery in different modes.

Other examples include measures such as not using constant speed until system faults were resolved, contracting a new chart distributor, installing new computers and upgrading software, and conducting a detailed review of bridge equipment communication.

In some cases, service engineers were not immediately available to address issues. In one case, a S-VDR (ship voyage data recorder) issue was resolved by the service engineer attending the vessel in the first available port. In another case, the software was updated by the crew after communicating with the maker.