WHAT TO LEARN FROM SUPPORT FUNCTIONS TO IMPROVE MARITIME SAFETY?

PREFACE

This project was funded by The Swedish Transport Administration (Trafikverket), led by Swedish Shipowners´ Association (Svensk Sjöfart) in cooperation with Chalmers University of Technology. The project continues the work performed in “The impact of digitalization on maritime safety and the work environment of the crew” (Trafikverket TRV 2021/100835) and builds on the results that stakeholders in the shipping industry found most interesting to explore further.

The 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. The project was completed in December 2024.

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SAMMANFATTNING och RESULTAT

Digitaliseringen har förändrat sjöfartsnäringen och gjort drift av fartyg säkrare och effektivare. Denna utveckling har också på många sätt bidragit till en bättre arbetsmiljö och slutanvändare verkar i stort vara överens om att den tekniska utvecklingen har varit positiv. Men denna utveckling har också sina utmaningar, t.ex. uppdaterad mjukvara som orsakar oväntade fel på grund av buggar, komplexa gränssnitt och för mycket information, för att nämna några. Tillförlitligheten och enkel tillgång till en pålitlig och kompetent support anses av operatörerna vara en av de viktigaste utmaningarna ombord. Detta eftersom sjöfartsbranschen är en 24/7-industri och support är inte alltid tillgänglig, varje utrustning ombord har dessutom sin egen support vilket snabbt adderar antalet kontakter som behöver tas när operatörerna ombord behöver hjälp med felsökning.

Syftet med detta projekt har varit att öka driftsäkerheten och effektiviteten genom att undersöka vilka åtgärder som kan tas för att minska beroendet av support samt hur ett framtida behov av support kan organiseras. Resultaten visar att de två världarna kan närma sig varandra genom att bland annat ha ett gemensamt språk, tillämpa användarcentrerad design tillsammans med slutanvändarna, en delvis standardisering av viss teknik och att prioritera support under upphandling. Fortsatt forskning behöver projekt som undersöker hur operatörerna ombord kan avlastas av en landbaserad organisation samt vad som skulle göra supportfunktionen lättillgänglig och effektivare. Det finns också ett behov att kvantifiera resultaten för att få en förståelse av hur stora problemen är.

Sökord: digitalisering, support, sjöfart, användarcentrerad design

SUMMARY and MAIN FINDINGS

Digitalisation has transformed the shipping industry making the operation and management of the fleets safer and more efficient. This development has in many ways contributed to a better work environment and the end users and operators seem to in general agree that these technical developments have been for the good. But this development has its challenges e.g. immature versions of technology causing unexpected errors due to bugs, complex interfaces and too much information to mention a few. The dependability of easy access to a reliable and skilled support is considered as important by the operators onboard. This has proved to be partly challenging since the shipping industry is a 24/7 operation and support is not always accessible; each equipment onboard has its support which quickly adds up the number of contacts to make.

The purpose of this project has been to increase operational reliability and efficiency by investigating what measures can be taken to reduce dependence on support and how a future need for support can be organised. The results show that the two worlds can be brought closer together by, among other things, having a common language, applying user-centered design together with the end users, a partial standardization of certain technologies and prioritizing support during procurement. Continued research needs projects that investigate how the operators on board can be relieved by a land-based organization and what would make the support function easily accessible and more efficient. There is also a need to quantify the results to get an understanding of the magnitude of the problems.

Key words: digitalisation, support, shipping, user centred design

INTRODUCTION

Digitalization has influenced our daily and work life on many levels (Schwab, 2016). The reasoning for introducing technologies into a work system is to make it more efficient and safer. A well-designed technology should improve individual and team situation awareness, decrease cognitive workload and reduce the risk of human error contributing to accidents and incidents. Digitalization and automation have had a disruptive effect on the way shipping is done now and certainly in the future. Despite the many positive outcomes digitalization has had on system performance, there are also reported limitations and liabilities due to the introduction of technologies which has created negative outcomes in crew performance (Bondanini et.al. 2020; Littlewood and Strigini 2000). From a human factors perspective, introducing digitalization also changes the nature of the work system, thus work as imagined (WAI) quickly becomes different from work as done (WAD) (Hollnagel, 2015).

Digitalization in the shipping industry is high on many agendas. International Maritime Organization (IMO) introduced 2006 E-navigation aiming at developing standards to improve safety, security and environmental protection utilizing disruptive technology (IMO, n.d. - a). Following the development within digitalization and an increased presence of automation onboard, IMO decided to develop the Maritime Autonomous Surface Ships (MASS) Code (IMO, n.d. – b). IMO wants to ensure that the regulatory framework for MASS keeps pace with technological developments that are rapidly evolving (IMO, n.d. – b).

As the industry has and is moving towards more digitalization and automation large amounts of operational data is collected (Bui and Nguyen, 2021). To make use of this Big Data is not without challenges but if analysed, processed and fed back to the relevant operators, it could have an impact and benefit the shipping industry (Chen et.al. 2022). These challenges within the shipping industry are complex, and to address these challenges there are different initiative ongoing. ABB has in cooperation with Wallenius developed OVERSEA Fleet Support Centre (ABB, n.d.). This digital support centre is developed to assist the vessels with the analysis of the data collected onboard and feedback recommendation to improve environmental, technical and voyage performance. Another ongoing project is the Lighthouse project FS_E_2024 Modern digital enablement for more efficient digitalization on ships (finalized end of 2024). *"The purpose of this project is to improve usability and support capabilities in the shipping industry by breaking the silo structure between operators and suppliers together with various legacy systems. To achieve that it is extremely important that quality information can be exchanged between different stakeholder and will enable targeted and accurate support built on real information* *and structured collection of additional information"* (Personal communication, Mikael Johansson, DNV).

The project "Digitaliseringens påverkan på sjösäkerhet och besättningens arbetsmiljö" ("The impact of digitalization on maritime safety and the work environment of the crew") (TRV 2021/100835) investigated how digitalization on board vessels impact safety and the work environment of the crews (Lundh et.al. 2023). This project was stimulated through discussions with the Swedish Shipowners' Association from the perspective of different representatives from the shipping industry, requesting more information and a better understanding of the challenges introduction of technologies on board have brought about. Interviews with domain and subject matter experts (SMEs) revealed gaps, pin points and identified several areas requiring improvements, 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, software problems (e.g. "bugs"), interference of programmers to update software during operation; the issue of ¨lack of support¨ was a consistently recurring theme.

IMO did as early as 2010 recognize the challenges connected to the navigational and radiocommunication equipment becoming increasingly dependent on soft- and firmware in MSC 1/Circ. 1389 (IMO, 2010). Among several things, this document emphasizes the importance of having the right software installed on board to be able to meet any changes in requirements and the importance of having arrangements for the maintenance of these systems in place. This guidance of procedures has recently been recognized in submission MSC 107/17/10 that proposed a new output for the Subcommittee on Navigation, Communications and Search and Rescue (NCSR) to develop requirements for software maintenance of shipboard navigation and communication equipment and systems. This aims to ensure that software maintenance, carried out on such equipment, is conducted in a controlled, safe and secure manner. The decision made at the 107th session (MSC 107) was to develop guidelines for software maintenance of shipboard navigation and communication equipment and systems (DNV, n.d.).

The 4th Industrial Revolution describes how the increasing speed technological changes put even more strain on organizations to maintain and develop necessary skills and knowledge (Schwab, 2017). The development within digitalization is a representative example of this and is one area where steep learning curves and rapid adaption to be able to manage the technological developments are necessary (Allee, 1996).

Purpose and research questions

As the situation onboard has become increasingly complex and less transparent, a well-functioning support with 24/7 accessibility has been highlighted as one of the major challenges within the shipping industry (Lundh et.al. 2023). Therefore, the overall purpose of this project is to increase operational reliability and efficiency by investigating what measures can be taken to reduce dependence on support and how a future need for support can be organised.

- What means and measures could reduce the dependency and need for support help?
- How can the future support function and contact between shore and ship be organised to increase efficiency?

BACKGROUND

Searching relevant sources for research related to support functions as one of the important contributors has not been found in literature, while the discussions in the ForeSea reference group as well as the first research project **"**The impact of digitalization on maritime safety and the work environment of the crew**"**" reveal a need for support to tackle various challenges related to automation and digitalisation onboard ships (Lundh et.al , 2024).

MAIB (2007) concluded in their accident report regarding the product tanker Prospero in 2007 that "Many modern vessels have become highly dependent on programmable electronic systems (PES), for example, for bridge equipment, propulsion machinery, and the automation of cargo handling systems. In many cases, the PES are integrated with each other. The risk of PES failure, and the need for such a risk to be managed has been identified, as has a need to change the way that such risks have been managed in the past (MAIB 2007). The difficulties experienced in podded propulsion systems, when different layers of software are required to work together, has been the subject of an academic paper (Islam, et.al., 2006). This paper describes the need for rigorous testing in order to eradicate intermittent faults which may occur during operation, sometimes with serious safety consequences."

Automation failure-related incidents in maritime operations are influenced by a combination of technical, human, and organizational factors (Sánchez-Beaskoetxea, Basterretxea-Iribar, Sotés, & Machado, 2021). According to a comprehensive study conducted by the UK Maritime and Coast Guard Agency (MCA) in 2007 (Demirel, 2019), over-reliance on automation by ship crews is a significant issue. Crews often trust automated systems more than manual methods, despite the latter being more reliable in certain scenarios. This overconfidence is compounded by a lack of understanding of the principles, limitations, and weaknesses inherent in automated control systems. Additionally, many systems lack ergonomic design, leading to user confusion, while improper maintenance and calibration can result in catastrophic consequences (Demirel, 2019). Human-machine interfaces, especially in screen-based systems, often fail to support effective interaction, contributing to information overload and reduced situational awareness (Demirel, 2019). Other studies highlight gaps in the training and education of seafarers. Current programs do not adequately cover the working principles of automation or prepare crews for emergency procedures during system failures. There is also a lack of internationally standardized training courses to address these deficiencies. Furthermore, the design of navigation charts, maps, and computer programs often deviates from traditional, manual systems, disrupting users' attention and operational flow (Demirel, 2019). Human performance remains a contributor to maritime incidents, near-misses and accidents, accounting for 75% to 96% of incidents since 1999. Factors such as poor organizational resource management, inadequate supervision, and ineffective policies exacerbate the risk of errors (Demirel, 2019). Environmental and technological conditions, such as non-ergonomic bridge and engine control room designs, further contribute to mistakes by impairing supervision, communication, and crew interactions (Demirel, 2019). Huffmeier, J., & Bram, S. (2018) found that the human role in ship management is significant, not only as a contributor to accidents but also in preventing them. While much research highlights human error as a cause of accidents, little attention is given to accidents avoided due to human intervention. As the shipping industry invests in autonomous vessels and increased automation, the impact of these changes on safety and efficiency remains uncertain. Automation can alter working conditions, potentially impairing human situational awareness and decision-making, which are critical for safety. Thus, assuming fewer accidents will occur simply by removing humans from the system overlooks their vital role in maritime safety.

Technostress

Automation and digitalisation without failing but with complications can lead to technostress and reduce the trust into automated or digitalised systems. (Fleron & Stana, 2024). Technostress, a term first introduced in 1983 by (Brod 1984), describes the stress individuals experience directly or indirectly when engaging with digital technologies. Since then, it has become a subject of study across multiple fields, including library sciences, information studies, and computer science. A widely used framework for examining technostress is the transactional model, rooted in traditional stress research. This model conceptualizes technostress as a dynamic process, where stress arises from the interaction between technology-related stressors and their psychological or physical effects, known as strains (Cooper, et.al. 2001; Lazarus & Folkman, 1084) This approach also considers coping mechanisms, appraisal processes, and factors that may reduce technostress (La Torre, et.al. 2019; Nisafani, et.al. 2020; Sarabadani, 2020).

Despite being coined in the 1980s, technostress has only recently gained deeper research focus, with studies exploring its antecedents, or factors that influence individual susceptibility. These include variables like age (Hauk et al., 2019), gender (Ma & Turel, 2019), cultural background (Tu, Wang, & Shu, 2005) and digital proficiency (Tarafdar et al., 2011). Commonly identified sources of technostress, or stressors, include the complexity of technology (Tarafdar et al., 2007), frequent software updates, usability challenges (Ayyagari et al., 2011), system utility and performance issues (Hertzum & Hornbæk, 2023), and terminology mismatches, which can complicate user interaction (Califf et al., 2020). This expanding body of research highlights the importance of understanding both the origins of technostress and the strategies individuals use to manage it across different technological environments.

Technostress, a type of psychological stress caused by adapting to new digital technologies, is an increasing challenge in the maritime industry. Rapid digital transformation has brought complex automated systems, advanced data analytics, and digital monitoring onboard ships. These technologies can improve efficiency but also lead to cognitive overload, anxiety, and burnout among seafarers as they adapt to these new demands (Fleron & Stana, 2024).

Several studies highlight the need for targeted strategies to mitigate technostress (Kupang, Ballangan, Carantes, & Jr., 2024; Bartra-Rivero, et al., 2024; Ragu-Nathan, Tarafdar, Nathan, & Tu, December 2008). For instance, one approach involves ongoing digital literacy and technology-specific training for crew members. This helps seafarers develop familiarity and competence with digital tools, which can reduce anxiety and enhance operational efficiency. Lifelong learning programs and skill development initiatives are also recommended to help crew members continually update their knowledge as technology evolves (WMU, 2023).

Bondanini et.al. (2020) states that "organizations need to provide tools for individuals to deal with information overload, such as technical support; it was also noted that higher levels of task-technology fit lead to lower levels of technostress. Therefore, this could present a useful avenue for organizations to evaluate task and technology context proactively in order to reduce technostress."

Another key strategy is designing more user-friendly, intuitive systems to reduce the cognitive burden on users. Complex and non-standardized interfaces can amplify technostress; thus, simplifying digital tools and standardizing platforms across fleets can make it easier for crew to manage their tasks without feeling overwhelmed (Lee and Seppelt, 2009).

Additionally, promoting a supportive work environment that includes mental health resources can be highly beneficial. For example, encouraging open communication about the challenges of digitalization and offering access to counseling can help address stress before it becomes overwhelming. Industry stakeholders have also noted the importance of integrating health and well-being considerations into digital transformation efforts (Fleron, et.al. 2024).

Challenges with automation

Based on the outcome of the Surpass project (Ziarati & Ziarati, 2010), key issues contributing to automation-related incidents in maritime operations include over-reliance on automation, overconfidence in system data without cross-checking, and limited crew understanding of system weaknesses. Poor ergonomic and interface designs make control systems confusing and error recovery difficult. Maintenance and calibration errors, inconsistent display formats, and insufficient support for situational awareness further compound risks. Modern bridge layouts often overwhelm crews with information, while poor design and a lack of standardization across systems increase human handling error. Additionally, automation design frequently fails to align with operator competencies, leaving critical system limitations hidden from users. These factors collectively pose significant safety risks.

Common unsafe acts linked to automation failures include skill-based errors, such as lapses in attention or memory, and rule-based mistakes arising from the misapplication of troubleshooting rules (Wiegmann & Shappell, 2003). Knowledge-based errors occur when operators lack applicable problem-solving routines and are forced to rely on slow, resource-intensive processing. Violations of procedures—both routine and exceptional—are also frequent, often stemming from poorly defined or impractical work practices (Lin, Yenn, & Chih-Wei Yang, 2010).

In summary, automation-related incidents are not solely due to technical failures but are influenced by a complex interplay of human, technical, and organizational factors. Addressing these issues requires improved training, better system design, and enhanced supervision to ensure safe and reliable operations in increasingly automated maritime environments (Li, Durando, & Ting, 2014).

MCA RP545, (2016). Development of guidance for the mitigation of human error in automated shipborne maritime systems (Maritime and Coastguard Agency Contract No. RP545 MSA/10/9/210), QinetiQ] derived that "Given the increasing prevalence of automated systems on board ships, it is important that the human element is considered throughout their design, implementation and operational use. Automation can be beneficial to operators of complex systems in terms of a reduction in workload or the release of resources to perform other on-board duties. However, it can also potentially be detrimental to system control through increasing the risk of inadvertent human error leading to accidents and incidents at sea."

According to Demirel (2013), the shipping industry continues to face automation failure-related accidents, necessitating measures to mitigate their potentially fatal consequences. Enhanced education on automation systems offers a short-term solution, but further actions are required. Developing new techniques, methods, and procedures is essential, and these advancements must be integrated into officer and crew training programs, including distance learning options tailored to seafarers' working conditions.

Collaboration between automation system users and producers is crucial, fostering knowledge exchange, innovation, and solutions to human-machine interface challenges (Man, et.al. 2022). Feedback from end-users can significantly inform system design improvements. These challenges are common to both merchant fleets and navies, as their systems are often similar and produced by the same companies, facilitating cooperation across sectors. Moving forward, exploring new partnerships and cooperative opportunities will be essential in addressing these shared challenges (Joiner, 2007).

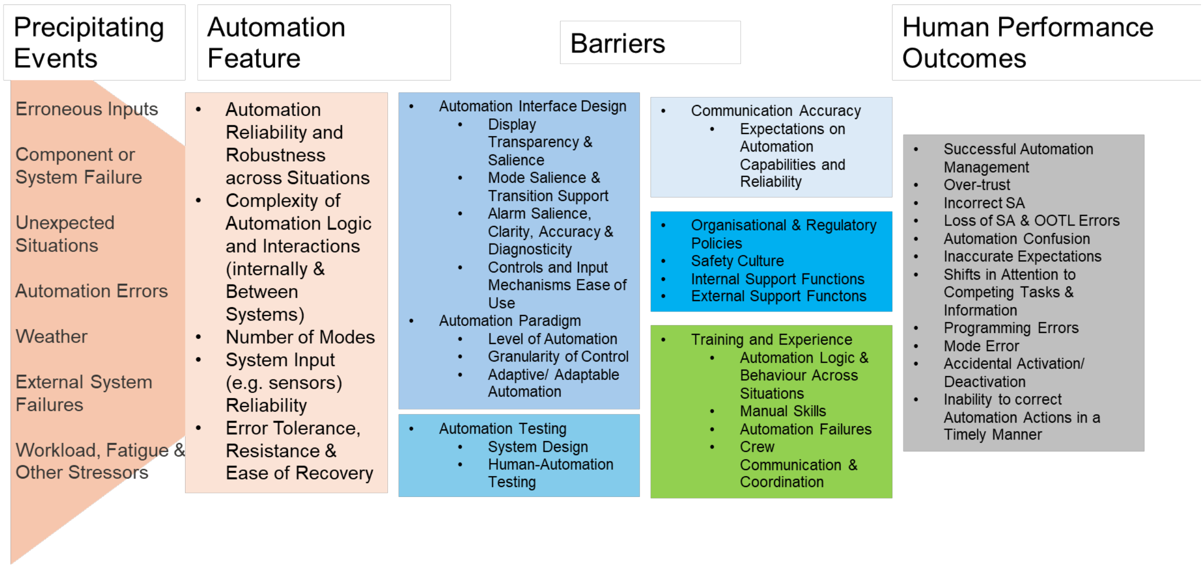

Figure 1: Anatomy of Automation Failures, Barriers for the prevention of human performance degradation, adjusted after adoption from (Endsley, 2023)

Automation related accidents

Automation systems can inadvertently lead to severe accidents and compromised safety (Wiener, 1988). These issues stem from design flaws that hinder users' ability to oversee and interact with the systems effectively. Key problems include:

- Automation confusion, where users struggle to understand system behavior,
- Reduced situational awareness (SA) from being out-of-the-loop (OOTL), slowing detection and response to unexpected events, and
- Interaction challenges, particularly in urgent situations.

(Gawron, 2019) highlights 26 automation-related aircraft accidents/incidents, with 27% involving automation confusion, 58% linked to OOTL/SA issues, and 36% due to interaction problems (some cases involve multiple factors). Contributing factors include (a) complex automation logic failing in 61% of cases, (b) mode errors in 38%, and (c) erroneous inputs in 8%, causing inappropriate system behavior.

According to (Reason, 2000), accidents are not solely caused by automation failures but occur due to a sequence of error-prevention barriers being bypassed. Viewed this way, automation-related accidents are not merely operator errors but are influenced by a combination of preceding events, automation design features, and shortcomings in providing tools, capabilities, policies, and training to help operators enhance system safety under such conditions.

Endsley (2023) suggests a model that distinguishes inputs from outputs as well as relevant intervention factors. The model as shown in Figure 1 outlines various factors that influence the relationship between automation-related events and negative outcomes. It emphasizes specific actions that system developers and organizations can take to uphold operational safety by minimizing human performance issues during failure events.

Nevertheless, the model lacks support functions as one of the barriers to prevent human-automation failures to happen and to bring the human back into the loop.

Support Functions in digital and automated systems:

Searching for information about support functions for digital and automated systems generates a vast amount of lay literature from different companies and support providers. Support functions in digital systems are essential for maintaining operational efficiency and addressing technical issues. These functions can from this perspective be categorized as follows (1), (3), (5), (6), (7):

1. Internal IT Helpdesks: Managed by in-house IT departments, these teams handle daily technical issues, including software and hardware troubleshooting, system updates, and access management. Their responsiveness varies based on workload and issue priority.
2. External Technical Support (from Vendors): Provided by software or hardware vendors, this support is often tiered, ranging from basic user assistance to expert-level troubleshooting. Response times depend on service agreements; enterprise-level Service Level Agreements (SLAs) typically ensure prompt support, while standard agreements may result in slower responses.
3. Automated Support Systems: Utilizing chatbots or AI-driven services, these systems diagnose and resolve simple issues automatically. They offer rapid responses but are limited in handling complex problems.
4. Knowledge Bases and Forums: Companies provide self-service portals with documentation, FAQs, and community forums, enabling users to find solutions independently. This scalable support method relies on user initiative for problem resolution.

Responsiveness and Problem Resolution

- Responsiveness: The speed of support depends on the support level and issue complexity. Vendor SLAs may guarantee specific response times (e.g., 1-2 hours for critical failures), while internal support times depend on staff capacity.
- Resolution Rates: Studies indicate that 70-80% of common IT issues (e.g., password resets, access problems, minor bugs) are resolved by Tier 1 support. More complex issues, such as system integration failures or hardware problems, may require escalation, leading to longer resolution times.

Investments for Improvement (14)

To enhance support and reduce issues, organizations should consider:

- Proactive Monitoring and Maintenance: Implementing systems that predict or detect issues before they occur, such as AI-based monitoring, can reduce downtime. This approach is common in critical systems like cybersecurity and cloud infrastructure.
- Employee Training: Many issues stem from user errors or unfamiliarity with systems. Regular training sessions and accessible learning resources can decrease the need for external support.
- Robust SLAs with Vendors: Ensuring that third-party vendors provide guaranteed support levels, including 24/7 availability and rapid escalation, can expedite issue resolution.

Software and Hardware Failures (2), (4), (8), (12), (13)

- Failure Rates: Software failures often result from bugs, misconfigurations, or updates introducing issues. Studies suggest that 40-50% of software failures can be anticipated through testing or simulations, though this depends on system complexity.
- Hardware Failures: Hardware failures typically arise from wear and tear, manufacturing defects, or environmental factors. Proper maintenance, such as regular cleaning and preventing overheating, can predict and prevent many hardware failures.

Hardware and Software Obsolescence

- Hardware: On average, hardware components like laptops and servers become outdated within 3-5 years, depending on usage intensity. Adopting cloud-based solutions and modular hardware designs can mitigate obsolescence.
- Software: Software generally requires updates every 12-18 months due to security patches, compatibility issues, and feature enhancements. Industries such as finance and healthcare may necessitate more frequent updates due to regulatory changes.

Key Drivers of Obsolescence

- Security Vulnerabilities: Frequent updates are essential to counteract evolving cyber threats.

- Incompatibility: As other software or hardware evolves, older systems may no longer integrate smoothly, necessitating updates or replacements.

System Responsibility (9)

- System Owner: Responsibility for overseeing the overall system typically lies with the IT department or Chief Information Officer (CIO), encompassing software updates, hardware upgrades, and integration.
- Vendor Role: Vendors often manage the uptime and performance of their systems, especially in cloud-based services. Clear contracts and SLAs with vendors help define these responsibilities.
- Shared Responsibility: Many organizations adopt a shared responsibility model, where internal teams handle daily operations, and external vendors manage system maintenance and software updates.

Avoiding System Complexity and Emphasizing User-Centered Design (10)

To prevent overly complex systems and ensure user-centered design, organizations should:

- Modular System Design: Develop systems with independent components that interact straightforwardly, reducing interdependencies that can lead to failures.
- Iterative Development with User Feedback: Regularly incorporate user feedback into system design to create tools that meet actual needs, reducing complexity and improving usability. Agile development methods prioritize user-centered changes over time.
- Standardization: Opt for standardized platforms or solutions to reduce compatibility issues. For example, using API-driven systems can facilitate integration between different components, avoiding "spaghetti architecture" where many systems are poorly connected.

Systems from Various Suppliers Without High Integration

Industries and organizations often rely on multiple vendors, leading to fragmented systems without proper integration management. Typical examples include:

- ERP (Enterprise Resource Planning) Systems: Some organizations use different systems from various vendors for finance, HR, and operations (e.g., SAP for finance, Oracle for HR) that don't easily integrate without custom middleware solutions.

- Healthcare IT Systems: Hospitals may use different vendors for patient records, lab systems, and imaging systems, which don't always communicate well, leading to inefficiencies and data silos.
- Construction Industry Software: In the construction industry, design tools (like AutoCAD), project management platforms (like Procore), and procurement systems are often from different suppliers, leading to integration challenges.

Integration Management Issues (11)

- Lack of Standardization: When various systems are not built to common standards (e.g., APIs, data formats), integrating them can require extensive customization and middleware, leading to higher complexity.
- Vendor Lock-in: Some suppliers may design systems to work only with their tools, making it difficult to integrate with third-party solutions.
- Integration Tools: Investing in middleware platforms or standardized APIs can reduce complexity and increase efficiency when

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The Role of Support Functions in the Maritime Industry

Support functions within the maritime industry play a crucial role in addressing the frequent issues that arise with digitalization and automation, particularly for the crew on board. As digital tools increasingly drive operations, support functions need to provide not only technical guidance but also facilitate effective communication and decision-making frameworks to help crews manage these technologies efficiently (Lundh, et.al. 2023).

First, a strong support system must include consistent training and knowledge sharing for crew members. Given the rapid evolution of technology, regular training helps onboard personnel stay updated on the latest software and automation tools. Training programs that focus on practical applications, like troubleshooting and routine maintenance, can reduce downtime and empower crew members to handle issues independently (UNCTAD, 2020)

Another crucial aspect is the implementation of robust, standardized digital systems across fleets. A lack of standardization across different digital tools and platforms is a common issue in maritime operations. Standardizing these systems can enhance interoperability and streamline the management of digital processes for both crew and support teams. This approach is advocated by industry bodies, which emphasize the importance of creating standardized digital ecosystems that allow seamless communication between shipboard and shore-based systems (World Bank, 2021).

Support functions should also include a responsive IT helpdesk and real-time technical support that can address issues as they arise. This is particularly valuable for automation tools used in navigation, fuel management, and cargo handling, where rapid intervention can prevent delays and operational risks. Real-time assistance could be enabled through cloud-based platforms and remote monitoring systems that allow shore-side staff to assist in diagnosing and resolving technical problems promptly (Marine Digital, 2022).

Finally, as data and cybersecurity become critical concerns, the support functions need to integrate cybersecurity protocols and data management policies. Effective cybersecurity strategies and clear protocols for data handling and issue resolution are essential to protect sensitive information and maintain the integrity of automated systems onboard. Guidance from industry bodies like the International Maritime Organization (IMO) further supports the need for standardized cybersecurity measures (UNCTAD, 2020).

Overall, a combination of ongoing training, standardization, responsive technical support, and cybersecurity measures can create a more resilient support structure to assist crew members with the challenges of digitalization and automation in maritime operations.

Frequency of Failure

There is no data available on frequencies of failures of digital systems or automated systems onboard ships that can be used as a reference. Just looking at some publicly available failure statistics, indications on frequencies that seafarers are exposed to issues, can be given.

Computer related Failures

Factors contributing to failures in advanced computer network systems can be roughly divided into three main categories:

(1) hardware failures, on processing nodes or in the network, for example, failures in the CPU, memory modules, PCI bus, and interconnection network;
(2) software errors, comprising failures in the cluster file system, compilers, libraries, operating system, MPI, and user code; and
(3) other failures, such as human (operator) errors, environmental (cooling, power), soft errors, and miscellaneous undetermined errors (Petrini, 2004)

Typical distributions are shown below in figure 2.

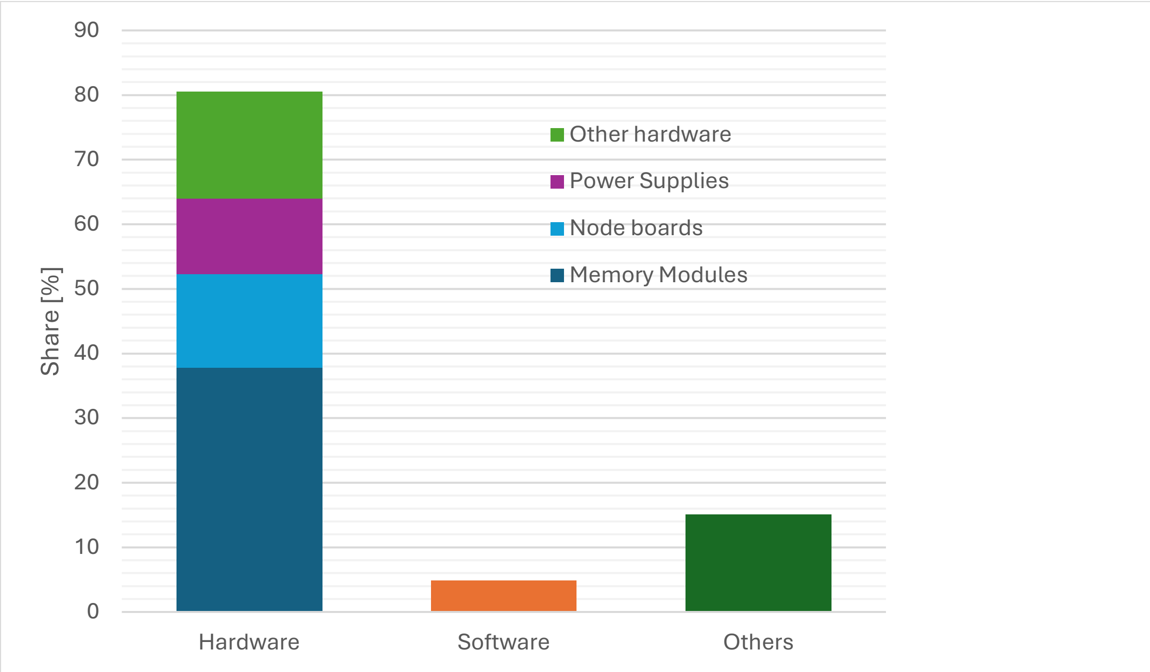

Figure2: Failure distribution for the ASCI Blue based on [ASCI Blue Mountain. Derived from https://www.researchgate.net/publication/220951720_System-Level_Fault-Tolerance_in_Large-Scale_Parallel_Machines_with_Buffered_Coscheduling .

Very few scientific data have been found providing statistics on failures related to software-hardware failure. According to Fabrizio Petrini, Kei Davis and José Carlos Sancho, MTBF for a high-quality unit is on the order of 1,000,000 hours (110 years). Regardless of nominal MTBF, typically there is a phase in component lifetime where failure rates can be higher.

Generally, the failure rate model for components follows a bathtub curve. As can be shown, there are three different phases: component burn in, normal aging, and late failure. Failures are frequent during the burn in and the late failure phases due to defects in the components, and component aging, respectively.

According to Demirel (2019), the training system for onboard automation typically focuses on teaching the elements and operations of the system, often neglecting responses to system failures. Manufacturer manuals usually address troubleshooting only in cases of total system collapse, leaving users unprepared for handling partial or sudden failures. This lack of preparation is critical as onboard automation often governs vital systems like steering gear, engine control, and autopilots. In the event of automation failure, especially in congested waters, the ship faces severe risks, but crews are often inadequately trained to respond quickly.

Demirel (2019) states further that complex automated systems, composed of multiple computer-based units and subsystems, cannot reliably self-diagnose every potential failure mode. This limitation can result in unanticipated system behavior—termed “automation surprise”—where the system acts unpredictably due to undetected malfunctions, potentially leading to accidents. To mitigate these risks, there is a need for comprehensive training programs that include responses to automation failures, enabling crews to act effectively in emergencies.

Cybersecurity

Cybersecurity is a growing concern. There are no reliable statistics on cyber attacks per machine and hour or similar, there is just general knowledge on the threats coming from cyber security issues and that these represent a growing concern. The publicly available dataset Admiral (https://www.m-cert.fr/admiral/statistics.html) is indicating the development of publicly disclosed incidents as shown in figure 3.

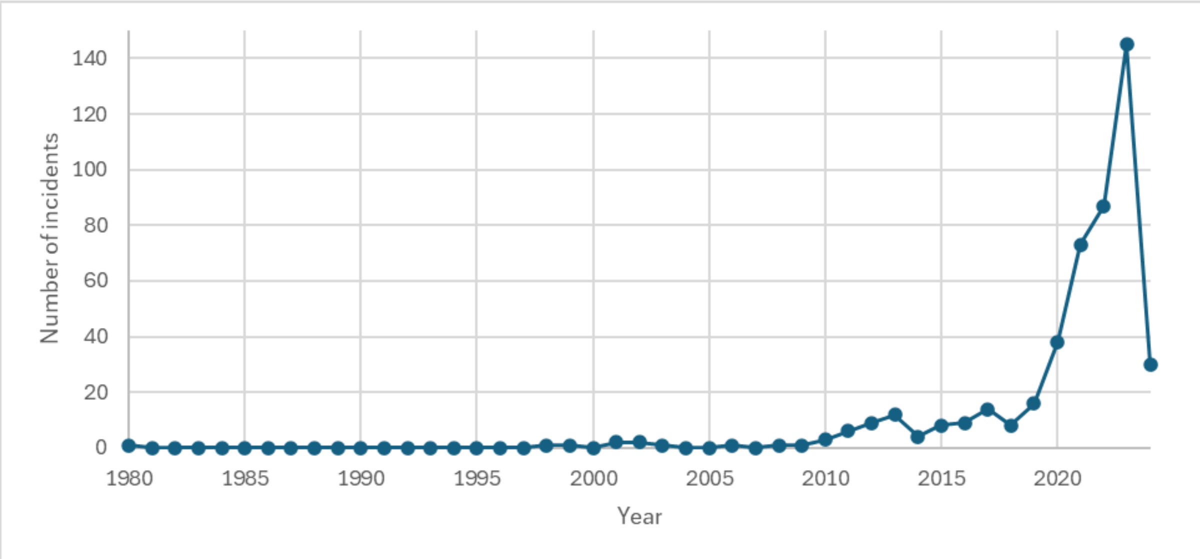

Figure 3: Publicly disclosed maritime cybersecurity incidents (https://www.m-cert.fr/admiral/statistics.html), be aware of that 2024 is not fully reported yet, trend for this year cannot be derived

Classification of support:

A Tiered approach is described in (1), (2), timings are given in (13). As trends are going toward more remote working set-ups, focus is on ensuring efficiency and resilience (3), (4). Challenges are described in (5), (9) and (10). How remote support can be handled is described in (6) and (7). In-support-services are described in (8) as well as solutions such as augmented reality (11) and integrating software based on processes (12). Based on the information cited above, descriptions are made to apply the challenges and approaches to the maritime sector.

The structure of the support can be organized in different ways. A tiered IT Support Structure, as described in lay literature and by different stakeholders in the IT-industry, are based on a classification as per below:

Tier 1 Support: This is the initial point of contact for users facing IT issues. Technicians at this level handle basic troubleshooting, such as password resets and software installations. They aim to resolve issues promptly, typically within minutes to a few hours, depending on the organization's Service Level Agreements (SLAs).

Tier 2 Support: Issues that cannot be resolved by Tier 1 are escalated to Tier 2. Technicians here possess deeper technical knowledge and handle more complex problems, including hardware repairs and advanced software issues. Resolution times at this level can range from several hours to a day, influenced by the complexity of the issue and resource availability.

Tier 3 Support: This tier deals with the most complex and specialized issues, often requiring intervention from subject matter experts or developers. Resolution times can vary significantly, from a day to several days, depending on the problem's intricacy and the need for specialized resources.

Factors Influencing Response and Resolution Times:

Service Level Agreements (SLAs): Organizations define SLAs to set expectations for response and resolution times across different support tiers. These agreements are tailored to the organization's needs and the criticality of the systems supported.

Resource Availability: The number of available technicians and their expertise levels directly impact how quickly issues are addressed and resolved.

Issue Complexity: More complex problems naturally require more time to diagnose and fix, especially if they necessitate collaboration across multiple teams or external vendors.

Applied on the maritime industry, this framework could look like the following:

Tier 1: Basic Troubleshooting by Onboard Crew: Train onboard crew members to perform basic troubleshooting and maintenance tasks, like system reboots or resetting equipment. Provide them with clear SOPs (standard operating procedures) and digital troubleshooting guides.

Tier 2: Shore-Based Engineers and Technical Experts: For more complex issues, onboard crew members can escalate to shore-based engineers and technicians who have a more profound technical knowledge and access to the digital twin or historical data.

Tier 3: Vendor and Specialist Involvement: In the case of highly specialized equipment or severe malfunctions, the shore-based team can coordinate with vendors or third-party specialists to resolve issues or arrange parts and repairs at the next port of call.

Response times vary depending on the type of support and the criticality of the issue. Support models are often categorized into internal IT teams or external vendor support, with Service Level Agreements (SLAs) dictating response and resolution times.

Internal IT Support Response Times

- Tier 1 Support (Basic Issues)
  - Response Time: 15 minutes to 1 hour.
  - Resolution Time: 1–4 hours.
  - Example Issues: Password resets, software installation, user account issues.
  - Users can get help relatively quickly for common problems like access issues or simple troubleshooting.
- Tier 2 Support (Intermediate Issues)
  - Response Time: 1–4 hours.
  - Resolution Time: 1 day to several days, depending on complexity.
  - Example Issues: Network configuration, software bugs, hardware diagnostics.
  - These are more technical problems that require specialized support and longer investigation times.
- Tier 3 Support (Critical Issues or Escalations)
  - Response Time: 4–8 hours, possibly 24 hours for non-critical cases.
  - Resolution Time: Several days to weeks, depending on the nature of the problem.
  - Example Issues: Server failures, system integration problems, malware incidents.
  - These issues usually require expert intervention from senior IT staff or collaboration with vendors.

External Vendor Support Response Times

- Vendor or Third-Party Support (SaaS, Cloud Providers, Hardware Vendors)
  - Critical Failures (e.g., system down): Response time usually within 1–2 hours per SLA agreements. Resolution can take 24–72 hours, depending on the severity and the need for specialized intervention.

- Non-Critical Failures (e.g., feature malfunctions): Response time within 24 hours, with resolution times of up to a week or more for complex issues.

- Hardware Vendors (Physical Repairs)
  - Response Time: Typically within 24 hours for diagnostics.
  - Resolution Time: 2–5 days for repairs or replacement parts.
  - Hardware support may involve shipping components or technicians coming onsite to repair critical systems.

Self-Service Options

- Automated Systems (AI Support, Knowledge Bases)
  - Response Time: Immediate, as chatbots and self-service portals can provide quick answers to common questions.
  - Resolution Time: Minutes to hours, if the issue can be resolved through self-help resources or basic troubleshooting.

Factors Influencing Response Times

- Severity and Priority of the Issue: Critical system failures or security breaches get immediate attention, while minor issues may take longer.
- Support Model: Companies with 24/7 IT support or premium vendor support (via SLAs) tend to offer faster response times than companies with limited support hours or lower service tiers.
- Geographical Location: Time zones can affect response times, especially with external vendors who may not have global 24/7 support.
- Availability of Spare Parts: For hardware failures, especially for legacy systems, the availability of replacement parts may extend the repair time.

Issues Users Typically Cannot Handle

1. Software Failures
   - Bug Fixes: When software crashes or has a bug that requires code changes or patches, users usually lack the technical expertise to troubleshoot or fix these issues. This requires vendor or internal developer intervention.

- Corrupted Software: Issues such as data corruption or broken installations after failed updates are beyond a user's scope to fix, as they may require reinstallation, data restoration, or rollback procedures.
- License Issues: Problems with software licenses (expired or invalid) need vendor support to resolve, especially in cloud-based or subscription models where activation must be coordinated with the provider.

2. Network and Connectivity Problems
    - Network Configuration: Users generally cannot troubleshoot complex network issues like firewall settings, VPN access, or router failures, which require IT support to diagnose and resolve.
    - Server or Cloud Access Failures: If the issue is with access to cloud systems or internal servers due to a network outage or misconfiguration, users won't be able to resolve this themselves. These often require IT networking teams or external cloud vendor support.
3. System Integration Failures
    - API or Middleware Failures: Users cannot usually troubleshoot when different systems (e.g., ERP, CRM, HR software) fail to communicate due to integration issues, as these often require code-level adjustments or reconfiguring middleware.
    - Incompatibility Issues: Users are unlikely to resolve situations where incompatible software or hardware versions create problems, especially in environments with multiple vendors.
4. Security Issues
    - Malware or Ransomware: Users are often not equipped to deal with significant security threats, such as malware or ransomware attacks. These need immediate IT or cybersecurity support for containment, diagnosis, and remediation.
    - Unauthorized Access or Security Breaches: If unauthorized access or suspicious activity occurs, users cannot typically handle the investigation or security patching required to resolve the problem.
5. Hardware Failures
    - Physical Hardware Damage: When hardware components (e.g., hard drives, network cards) fail or malfunction, users cannot repair or replace these themselves. IT support or vendor assistance is needed for diagnosis and repairs.

- Peripheral Device Issues: Issues with specialized hardware, such as printers, scanners, or industrial devices, typically require technical expertise to resolve, especially if they involve drivers or firmware that users can't update.

6. Data Recovery
    - Data Corruption or Loss: If critical data is lost or corrupted (due to hardware failure, software issues, or user error), users cannot typically recover this data on their own. IT support, backup restoration, or specialized data recovery tools may be needed.
7. Complex System Configuration
    - Server or Database Management: If users face issues with systems that rely on backend servers or databases, like slow response times or database crashes, they can't typically diagnose or manage these issues, which require IT administrators or database specialists.

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Learning from the shipping industry

DP systems are possibly one of the most advanced systems onboard ships, used in the offshore industry. It is highly regulated and there are guidance notes on how to handle and operate systems that are of relevance within this study.

A Dynamic Positioning (DP) system on ships is an automated system that maintains a vessel's position and heading using thrusters and propellers. It uses input from position reference sensors, gyroscopes, wind sensors, and other equipment to counteract environmental forces like wind, waves, and currents. The classification follows international standards, such as those from the International Maritime Organization (IMO, 2017) and classification societies like DNV (DNV AS, 2021), ABS (ABS, 2014), or Lloyd's Register (LR, 2024). DP systems are classified based on redundancy and reliability, as follows:

DP Class 1:

- Basic system with no redundancy.
- Failure of a single component can result in loss of position.

- Used in non-critical operations.

DP Class 2:

- Redundant system where single faults (e.g., in sensors, power units) do not result in loss of position.
- Designed for more demanding operations, ensuring higher safety.

DP Class 3:

- High redundancy with physical separation of components to avoid loss of position even in case of fire or flooding.
- Used for critical operations where failure could have severe consequences.

DP Operators are highly skilled specialists that have received specific training on the systems. Failure rates have been derived by (Clavijo, et.al. 2021). for DP systems. Reliability, Availability, and Maintainability (RAM) analysis for two generations of DP systems—DP2 and DP3—used in drilling operations. The proposed approach incorporates uncertainties in equipment failure data, offering insights into critical equipment ratings and the probability density functions (pdf) of repair times. The reliability analysis indicates that after three months of operation, the DP2 system has a total failure probability of 1.52%, compared to just 0.16% for the DP3 system. Results identify the busbar as the most critical component of the DP2 system, while the wind sensor is the priority component for the DP3 system. Over a one-year period, with a 90% confidence level, the mean reliability of the DP2 system is 70.39%, whereas the DP3 system achieves 86.77%. Asymptotic availability stabilizes at 99.98% for the DP2 system and 99.99% for the DP3 system. Maintainability analysis estimates an average system repair time of 3.6 hours. This study provides a structured framework for analysts, operators, and reliability engineers in the oil and gas industry to enhance decision-making and operational reliability.

Another paper (Clavijo et.al. 2018) provides a quantitative reliability assessment of two common configurations: a DP Class 2 semi-submersible platform and a DP Class 3 drillship. The analysis is based on current technological advancements and failure rates reported by the offshore industry. In the evaluated configurations, the control and thruster subsystems account for 1% and 7% of total DP system failures, respectively. Meanwhile, the power subsystem contributes to 10% of failures in the DP2 system and 6% in the DP3 system. The Mean Time to Failure (MTTF) analysis reveals that the drillship achieves an MTTF of 4.65 years, representing a 1.41-fold improvement over the semi-submersible platform. These findings can serve as valuable inputs for reliability-centered design and maintenance planning of DP systems.

The Marine Technology Society (2021a; 2021b) state the following to enhance safe operations:

- The client's due diligence process is usually the main driver in the critical path to return to normal operating condition. Typically, this also involves vendor support as well as the client's DP consultant.
- The potential for common mode failures increases where same vendor equipment of same type and age are installed and in operation
- Owners/ operators of DP vessels are encouraged to share lessons learned from DP incidents with the wider DP community. DP systems and equipment vendors are also encouraged to do likewise and to share information on unexpected faults, features and failures that are identified in operation.
- Ease of maintenance/repair: A well-designed system should have built-in diagnostics that enable the electrical or instrument technicians to quickly pinpoint where system failures have occurred. Most vendors now provide some type of net status page or mimic on the HMI to assist fault finding. Where possible, modules should be designed to allow them to be swapped out either without switching off the rest of the network, or by isolating just the faulty section.
- Integrator: Regardless of the contracting philosophy, the equipment specified by the design must be integrated into a system. It should be noted that when the term "Dynamic Positioning System" is used it refers to the fully integrated vessel systems. There are numerous disciplines, vendors, flag state requirements, class society requirements and design basis requirements that must be integrated into a fully functional, 'fit for purpose' system. The integration process must be closely monitored from the basis of design through to the delivery of the vessel. Design/system reviews at identified points with participation by relevant stakeholders could facilitate the integration process.
- Interface issues between various vendors should be carefully managed. Responsibility for this may lie with the shipyard or owner's team depending on the nature of the contract. Responsibility should be clearly defined, identified and made visible.

Remote support for Dynamic Positioning (DP) vessels has evolved significantly with advancements in technology, ensuring real-time assistance and enhanced operational reliability. The available types of remote support include (ref):

1. Remote Monitoring and Diagnostics

- Real-Time Data Analysis: Systems onboard send live data (positioning, power, thrusters, and sensors) to onshore support centers for monitoring and troubleshooting.

- Health Monitoring: Detection of potential issues through predictive diagnostics, helping to prevent failures before they occur.
- Alarm Analysis: Support teams assist in interpreting alarms, guiding the crew in real-time decision-making.

2. Remote Technical Support

- Expert Assistance: Onshore engineers with DP system expertise provide real-time advice and solutions for technical issues.
- Software Updates and Configuration: Remote software updates, patches, and system reconfigurations can be performed without requiring an on-site technician.
- System Calibration: Remote recalibration of DP sensors and other critical components.

3. Video and Audio Support

- Live Video Feeds: High-quality video links from the vessel allow onshore teams to visually inspect equipment and provide instructions.
- Two-Way Communication: Crew and onshore experts can collaborate through video and audio conferencing for immediate support.

4. Training and Simulation Support

- Remote Training: Live training sessions and simulation exercises conducted remotely for crew familiarization with DP systems.
- Incident Simulation: Recreating operational scenarios remotely to train the crew in handling potential failures.

5. Cybersecurity Support

- Threat Monitoring: Proactive identification and mitigation of cyber threats that could compromise DP systems.
- System Integrity Checks: Remote checks for unauthorized access or tampering with DP systems.

6. Emergency Support

- Incident Response: Onshore teams provide guidance during DP system failures, offering operational recommendations or emergency recovery procedures.

- Alternative Solutions: Suggestions for manual or semi-automatic operation modes if the DP system becomes inoperative.

These services are often provided by DP system manufacturers, third-party service providers, or in-house operational teams, leveraging satellite and high-bandwidth internet connections for seamless communication between vessel and shore.

Remote support for Dynamic Positioning (DP) vessels encompasses various services designed to enhance operational efficiency and safety. Key offerings include:

1. Remote Dynamic Positioning Trials: These trials allow for the testing and verification of a vessel's DP system without the need for an onboard surveyor. This approach is both cost-effective and efficient, enabling vessel crews to perform tests during idle periods. The results are then analyzed and verified remotely by experts. (DP Marine, 2024)
2. ASOG, CAMO & TAM Services: Activity Specific Operating Guidelines (ASOG), Critical Activity Mode (CAMO), and Task Appropriate Mode (TAM) are integral to DP operations. These services provide structured guidelines and configurations to ensure safe and efficient DP operations, tailored to specific tasks and activities. (DP Marine, 2024)
3. Remote Monitoring and Diagnostics: Advanced DP systems offer real-time data transmission to onshore support centers, facilitating continuous monitoring and diagnostics. This setup enables prompt identification and resolution of potential issues, thereby minimizing downtime and enhancing safety. (Wärtsilä, 2024)
4. Remote Technical Support and Maintenance: Manufacturers and service providers offer remote technical assistance, including software updates, system recalibrations, and troubleshooting. This support ensures that DP systems remain operational and up-to-date without necessitating physical attendance. (Kongsberg, 2024)

These remote support services leverage advancements in communication technologies, allowing for seamless interaction between vessel crews and onshore experts, thereby optimizing DP operations.

Learning from other Industries

Negative experiences with remote support, particularly in technical contexts, have been observed across several industries, including aviation, healthcare, and oil and gas. Here are some key issues and their implications for the maritime industry:

1. Lack of Immediate Technical Assistance: Remote support often struggles to provide immediate and effective assistance when technical problems arise. In

aviation, for instance, pilots may encounter delays in communication with ground support, which can lead to increased frustration and safety concerns (Bulińska-Stangrecka & Bagieńska, 2021). This delay in addressing technical issues can exacerbate stress and anxiety among personnel who rely on swift resolutions.

2. Ineffective Communication Channels: In many cases, the tools used for remote support are not tailored to the specific needs of the workers. For example, in the mining sector, workers often rely on outdated technology that hampers effective communication during critical operations, leading to misunderstandings and errors (Lebene Richmond, 2022). This inadequacy highlights the need for more robust and intuitive support systems that can adapt to the unique environments of remote operations.

For the maritime industry, learning from these experiences means recognizing the need for effective communication, timely technical support, and the importance of addressing the psychological aspects of remote work. Implementing comprehensive training for managers and support staff to recognize and mitigate the effects of technostress can also lead to improved outcomes.

Learning from other industries facing similar challenges—remote users with varying education levels using complex, automated systems—provides insights into best practices for managing technostress, knowledge sharing, and support structures. Here are key takeaways from the healthcare, energy, and aviation industries:

To apply lessons from other industries like healthcare, energy, and aviation in addressing challenges similar to those faced in the maritime industry, consider these strategies that tackle technostress, knowledge management, and remote support systems:

1. Simulation-Based Training and Knowledge Access in Healthcare

- Simulation Training: In healthcare, simulation-based training helps professionals gain practical skills and confidence in using complex technology. This hands-on approach allows staff to practice problem-solving in high-pressure scenarios without risk, which has been shown to improve patient safety. For example, Aggarwal et al. (2010) demonstrates how simulation improves emergency response competencies. Such training could be adapted for maritime crews to practice navigating system failures, reinforcing autonomy and readiness for critical situations.
- Digital Knowledge Repositories: Healthcare uses comprehensive knowledge management systems that provide easy access to SOPs, technical guides, and troubleshooting manuals. (Shahmoradi, Safadari, & Jimma, 2017) highlight how

health information systems support faster decision-making by enabling healthcare staff to access standardized protocols. Similarly, maritime operations could implement centralized repositories accessible to all crew members, helping them troubleshoot issues without depending on external assistance.

2. Structured Remote Support in the Energy Sector

- Communication Protocols for Remote Technicians: In energy, remote field workers often face challenges with system complexity and isolation. Effective protocols, including real-time remote monitoring and support, ensure that technicians receive guidance without being onsite. In the following websites (eGain, 2024), (OverIT, 2024) it is discussed how the value of mobile technology for instant troubleshooting, which could reduce the maritime industry's dependency on physical support for vessel-based systems.

3. Standardized Procedures and Team Communication in Aviation

- SOPs for Reducing Operational Stress: The aviation industry uses SOPs that are easily accessible and consistently updated to ensure crew members can handle complex technical tasks with minimal error. Kumari & Aithal, (2020) show that aviation SOPs reduce operational stress by clarifying troubleshooting procedures. The maritime industry could adopt similar SOPs, tailored to varying educational levels, to improve crew confidence when handling technical malfunctions.

By adopting these strategies, the maritime industry can foster a more supportive, knowledgeable environment for crew members, reduce technostress, and enhance safety through structured training, standardized support procedures, and accessible knowledge systems.

METHODS

The data collection was performed through Focus groups and semi structured interviews with stakeholders from the shipping industry.

Procedure

The project used an iterative process involving stakeholders representing different segments of the shipping industry. It started with a Focus Group using the aim and research questions as themes. The participants were asked to elaborate and suggest priority areas to bring further into the semi-structured interviews. In total, 14 participants were interviewed representing manufacturers, insurance companies, shipping companies and onboard operators. The preliminary results were presented for stakeholders during a second Focus Group where participants were asked to comment and suggest topics to further investigate

The Focus Groups and interviewed were recorded and transcribed verbatim. A thematic analysis was used to identify main- and subthemes (Braun and Clarke, 2006).

Demography

The participants followed a strategic selection aiming at finding participants from different segments of the shipping industry.

Focus Group 1: 20 participants. 4 women, 16 men.

The participants came from shipping companies, authorities, academia, insurance companies, classification societies as well as manufacturers and suppliers. The participants were presented to the purpose and objective of the project and were asked to define

Focus Group 2: 21 participants. 4 women, 17 men.

The participants came from shipping companies, authorities, academia, insurance companies, classification societies as well as manufacturers and suppliers.

Semi-Structured interviews: Total 14 participants, 4 females and 10 males.

Average age 46 (28/62) and average experience in current position 8 years (0.5/27). 4 participants worked onboard (2 from the deck department and 2 from the engine department), 3 from shipping companies, 5 manufacturers of onboard systems and 2 participants from insurance companies.

RESULTS

Results from Focus Group 1

The themes defined in Focus Group 1 which served as themes were;

- **(i) Support function and expectations**
- **(ii) (ii) Reduction of dependence on support**
- **(iii) (iii) Enhancing skills and knowledge.**

The analysis of the interviews resulted in eight categories and 21 sub-categories distributed over the three themes.

Theme 1: Support functions and expectations

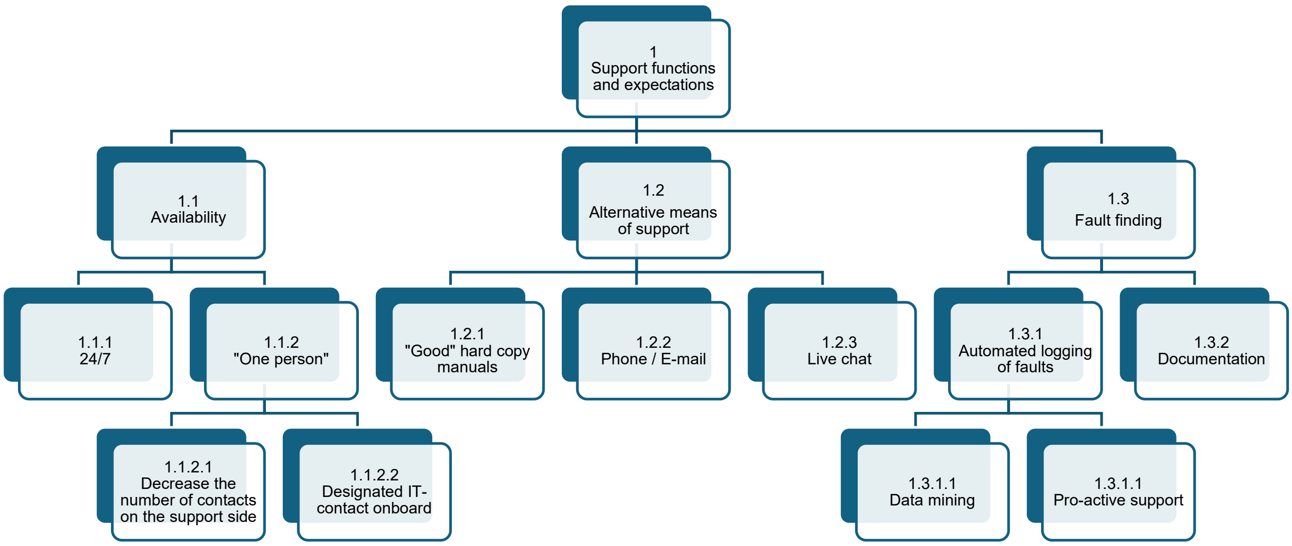

Figure 4: Support functions and expectations

Support has been identified as an important field to understand and develop. As the presence of digitalization and automation increases so does the complexity and in parallel a decrease in transparency. Figure 4 gives an overview of the categories and subcategories within this theme and below, the different categories and sub-categories in the diagram are described.

1.1 Availability

It is crucial for the operation of the ships to have an immediate access to support functions when needed. Numerous anecdotes from the participants illustrate consequences, both operational, safety related and financial, as a result from a disruption related to digitalization and/or IT.

1.1.1 24/7

The primary way to contact support is through phone or email. This is driven by the urgency of getting help as the operation onboard is 24/7. The participants stress they do not contact the support unless necessary when they have exhausted all other options. So, availability and a short response time are the most important factors when it comes to the support.

"24/7 and a direct number to prevent you from ending up in line or reaches some kind of automatic generated answer and need to hold… a lot of the times it is urgent."

.1.1.2 "One person"

It is important to have a personal contact on the support side. It builds a relationship and trust. Over time there is also a learning effect where both sides improve knowledge and skills. It has however a downside for the support providers as their staff risk being contacted around the clock which affects their work environment as they often answer although perhaps not being on duty.

"Contacting the support, it cannot be like a "black hole", an anonymous email address, you want to contact a person.

1.1.2.1 Decrease the number of contacts on the support side

The situation on board with interconnected systems makes troubleshooting difficult. This can mean that it is difficult to find which equipment is the source of the error and as each equipment has its support, the crew can be forced to a large number of support contacts in search of what is wrong.

1.1.2.2 "Designated IT-person" onboard

Today, the information from the support function ashore often follows the hierarchy onboard and use the captain/ chief engineer as point of contact. This might not be the best option. The receiver(s) of the information might not be the closely involved in the operational hands-on activities and thus need to pass on the information. There is a risk while communicating the message from the support function, that the information risk becoming diluted and/ or lost.

Depending on the size of the ship, the participants argued for the benefits of having a designated person onboard. This person could be the one contacting support and having more training and knowledge of digitalized system in general and the onboard systems in particular. Often, the electrician/ electro engineer was mentioned as a potential candidate to this "extended" position.

1.2 Alternative means of support

Depending on where the vessel is in operation the quality of the internet connection varies. However, loosing internet not only affect the possibility to get hold of the support, but it can also, in some part, affect the work onboard. From the manufacturers side suggestions were made to develop the means and tools of providing support e.g. Chatbot, live video support, Wizards, Digital Twin (exact duplication at the supplier's premises), remote connection with control, or diagnostics of the system onboard.

1.2.1 Phone/ e-mail

There were mixed results from the operators´ side whether email/chat or phone is what the operators onboard prefers however, most of the participants preferred this.

1.2.2 Live chat

The alternative function that was appreciated most was live chat, as it was a quick response and that the chat history could be saved and easily accessible.

“And then you can sit and chat via Teams there. It's actually excellent and fast contact and then it's a problem again, then you still have that history. Then you just write, now it's the same problem again... ... If I call support then, then it becomes like a lottery wheel who answers.”

1.2.3 “Good” hard copy manuals

Well written hard copy manual as a “safety net” if the internet is not available was also mentioned as a good “back-up”.

1.2.4 Other alternative support functions

Part of the respondents mentioned alternative means to get support, an inbuilt “help” function (compared to Office Word) was mentioned.

1.3 Fault finding

Sharing information is important and should be done in wider circles reaching more end users. But the success builds partly on how and what information is collected and how it is analysed and fed back to the operational side.

The manufacturers have a lot of data but not always easily accessible as it can be in different formats, ownership of the data can also be an issue, and the quality of the data varied as a standardized way of collecting it is lacking. Similar challenges can be found in the data collected onboard, information stored in different formats, information not always recorded/ logged and/ or incomplete. The actual root cause is sometimes unknown (comment from supplier). A standardized way to collect information and report problems is lacking. Suggestions were made to upgrade crucial systems or sensors added so that better analysis/diagnostics and remote support could be given.

The operators expressed an interest to learn more about how the support operators tackle different problems, what information is needed and what fault-finding strategies are used. How is the support collecting information and is it used to improve the equipment?

There is, from the support functions point of view, a tendency to work around problems onboard to “fix” problems rather than reporting these “hassles” to the support. This makes the work for the support more complicated as they lack information of what has been done and also that documentation can be lacking.

1.3.1 Automated logging of faults

The manufacturers of different systems suggested the possibility of automatically log disruptions and fault occurring in the different systems onboard. This would, however, generate substantial amounts of data which must be processed in order to make sense. This should not be done by the crew; it needs to be managed from a shore based function.

1.3.1.1 Data mining

To be able to fully utilize information the data needs to be categorized in a standardized way. According to manufacturers, it is the customers who own the data connected to their specific systems. They therefore need to agree for the manufacturer to use it and allow them to use the data in their analysis and if they are allowed to share the results and spread information.

According to manufacturers, the reason/ root-cause to why some fault occurs is often left out. There could e.g. be lack of maintenance or wrong handling of the system which affect the function. IT-service would benefit from this knowledge as the possible root cause or events that happened at the time of the problem could contribute fault tracing and possible action(s) to avoid it from happening again. Technical problems could be the result of work arounds and creative ideas, to find a way around the problem if the crew cannot get in touch with the support. The fault could be due to user interaction if the interface is not intuitive and user friendly.

1.3.1.2 Pro-active support

Another suggestion from the results is the possibility of the support to take on a more pro-active role, feeding back information to the vessels. It could be operational issues but also how to contact the support. Examples were given when information about changes in the organization had not reached the crews which used outdated contact information.

"...support can provide more tangible recommendations for improvement measures..."

1.3.2 Documentation

Changes made needs to be documented, both on a systems level and how different issues/ problems are resolved. The support functions gave as example when the crews do "work arounds" to solve problems when they can't get hold of the support. More often than not, this is not documented and causes problems for the support as it can be difficult to understand what changes that has been made. Also, the root cause is sometimes lacking together with a description of what measures the support has done.

Theme 2: Reduction of dependence on support

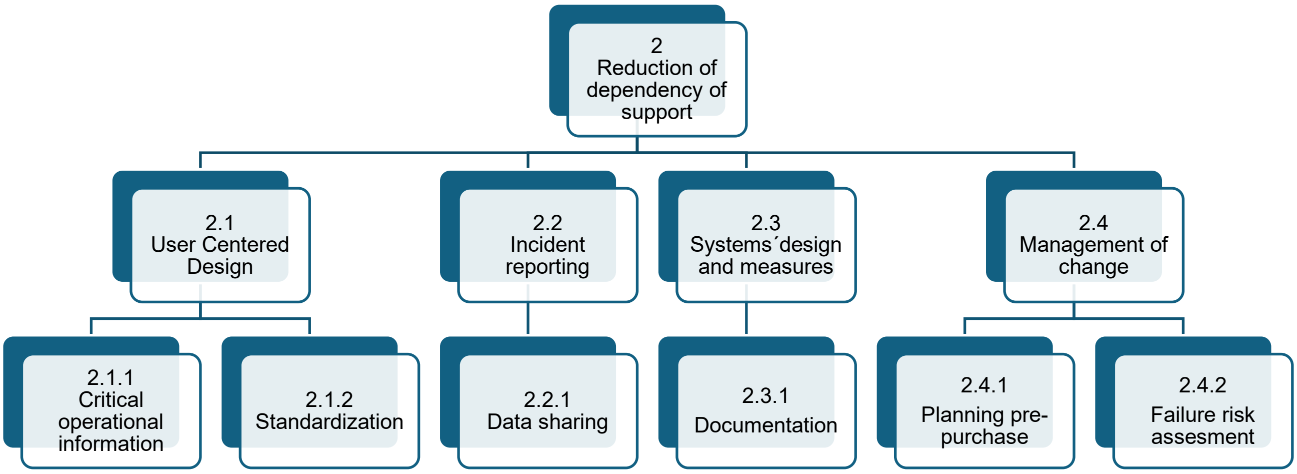

Figure 5 Reduction of dependence on support

Although the results did not clearly give strategies on how to learn from the support, the participants discussed different means to improve the situation, means to bring the operational side closer to the support function and thus decrease the dependability of support, see figure 5 and detailed description of categories and sub categories below. As the digitalization onboard increases the situation become more complex. One consequence of this is that the number of different stand-alone systems increases and thus the number of different support functions to contact which further complicates the situation.

"It means you don't have one support to turn to, you might have 10 different supports to contact."

2.1 User Centred Design (UCD)

Too much information on the interfaces was mentioned as problematic. This together with a less intuitive interface implies tasks takes longer to perform, more difficult to learn and takes attention away from other tasks.

"If we're talking about interfaces, that means you're talking about very user-centred design, it also means that you simply don't understand the interface.

2.1.1 Critical operational information

Most systems contain a lot more information than most operators need to perform their tasks. This risk cluttering the interfaces and makes it time-consuming and difficult finding the relevant information the operator needs. The operators are not opposing to additional information, the system could contain more/extra information, but it should only be displayed on request from the operator.

"So that there is of course a lot of functionality in the systems that is never used and then you have to start by removing it."

2.1.2 Standardization

The results indicate that a marine standard could improve the situation. Today, the design and lay-out set-up is not standardised but up to the manufacturer to decide upon. Comparison was made to the aviation industry but there was an agreement that it is not realistic to expect a "cockpit"-like situation onboard a vessel. But part of the frequently used equipment onboard could be subjected to standardized lay outs.

"It would be absolutely wonderful if you could standardize at least these main functions that basically everyone uses... ... but if you had succeeded in being able to impose some requirement on the industry that it would be like that, it would have been great."

"Yes, it had been a dream, of course, if you recognized the interfaces... ...it would have been great if there was a marine standard that was more like that... After all, you are constantly inventing the wheel."

2.2 Incident reporting

There is not much reporting of IT related issues into e.g. ForeSea. The participants did not regard this as "incidents" but merely as of the work and the every-day hassle. However, if an incident led to a larger consequence it was reported.

2.2.1 Data sharing

It is common that information about different systems is shared within its organization using different channels but it could be challenging making sure the information reaches end-users. Anecdotes were shared exemplifying that e.g. Online-meetings are good but not everyone can attend, and information is lost, or e-mails being filed and due to the turnaround of crew lost and/ or forgotten.

General information sharing was discussed and regarded as important and preferable. However it presupposes that data collection is done in a structured way, an agreement on how to categorize problems needs to be in place and a common platform which is readily accessible for those interested. (See also 3.1.1)

“Simply provide a sustainable support. It's easy for things to get lost over time. People come and go, perhaps both on board and in relevant organizations, and then information needs to be stored.”

2.3 Systems’ design

Furthermore, the result also pointed out that it is common onboard that the different systems are connected into complex systems designs which not always are easy and transparent to understand. Numerous examples were also given that how systems are connected is not always documented which further complicates the situation.

“And then to the question what support to call because everyone says “nothing wrong with our system. And, in reality, the fault can be somewhere else.”

2.3.1 Documentation

The manufacturers especially mentioned a need for documenting any changes and/ or alterations to the systems made by operators and support personnel. This also includes how new systems are installed and connected to existing technology.

“…if you bring this out to the ships, which is a completely different world, and there it doesn't work quite as optimally as it did on land, and then there will be a lot of special solutions, and you may have an extra antenna to amplify to get things to work…”

2.4 Management of change

The results indicate that a more thorough planning of the purchase and introduction of new technology is a way forward. An early plan prior to any purchase of technology is by the participants seen as important. This pre-planning is to give the end-users an understanding of what the new system/technology is supposed to do, the purpose of the investment in time and money and the context.

2.4.1 Planning pre-purchase

To early and thoroughly plan any purchase of new technology was pointed out as important. It aimed to give an understanding of what the system is expected to do, its context, help foresee problems and what support is available and how/ when. This could mean to specify and demand from the shipyard/ shipowners the level of required support from the vendors, which could be stated and agreed upon in the contract with the shipyard.

Both operators and manufacturers saw an increased need to early in the process discuss and document the expectations surrounding support and maintenance of the different system and possible training needs for the operators together with a follow up plan with scheduled meetings.

The operators also want to understand how the implementation of new technology would benefit them, to understand the purpose. There is a wish for a “Birds-Eye” perspective of the existing systems and the purpose and goal of adding another system. Participant gave examples of when these measures has been in place and the positive outcome of it, when the operators feel that it is easy to use and makes work more efficient.

Robustness of the system was considered as important, meaning when systems are launched that they are mature. The operators raised concerns when systems are implemented onboard that is not develop to operational/functional level. They do not have time to deal with bugs in the systems and fault-finding which also risks creating a negative attitude which inhibits the implementation and cause frustration among the operators. Some participants also mentioned, that in this context, the support is not fully developed and cannot always advice.

The more and better the conditions and expectations are formulated the easier it is to do a follow up. A follow-up meeting could be scheduled to review the past year’s issues and support (incl. service, aftersales, tech and user support, etc.) and work on improvements.

2.4.2 Failure-Risk assessment (act proactively)

The shipowners together with the vendor could both benefit from performing a failure-risk assessment to identify high risks or risks that could have a severe impact and agrees on preventive risk mitigation actions like adding redundancy, training, spares, etc.

Theme 3: Enhancing skills and knowledge.

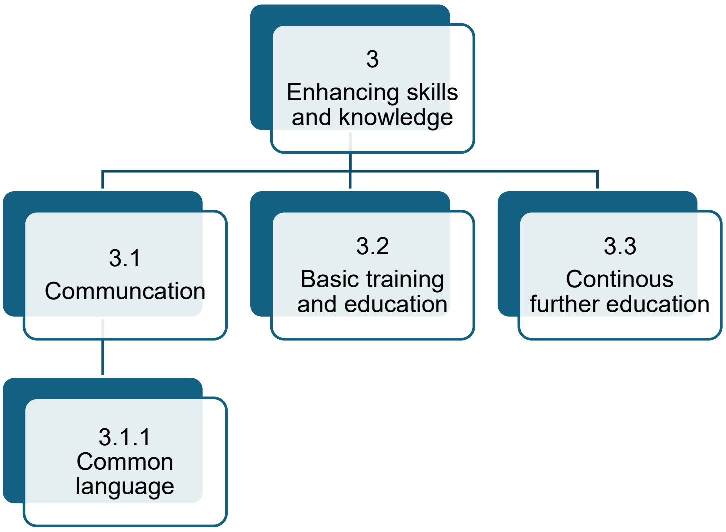

Figure 6 Enhancing skills and knowledge

There was a consensus that training is important but a utopia that both the end users and support fully could gain each other's knowledge and create a complete overlap. Today's system and technology are too complex to think one person could possess complete knowledge in both fields. The view was however, that the future technological developments will need more and possibly a different kind of education and training. Figure 6 shows the categories and sub-categories connected to enhancing skills and knowledge.

"You don't need to know exactly why a lightbulb broke, just that it is fixed. Same with digital systems"

3.1 Communication

An efficient communication between the operators and the support function requires some overlapping knowledge. The operators must be able to correctly describe the problem, and the support must be familiar with the environment onboard where their equipment is situated. This is necessary to establish a common understanding of problems, possible solutions and what information to be collected and distributed to facilitate fault finding.

3.1.1 Common language

This is about using a language that both parties understand, and it is twofold. The operators onboard need to understand the terminology used by the support operators and vice versa.

Both onboard and at the support function represent different levels of knowledge. Both sides were thought to benefit from receiving training/education about their respective fields to be able to communicate in an efficient way, to have a common language.

"So, it's important to find out as many facts as possible before sending out a technician."

3.2 Basic training and education

To raise the level of knowledge among the operators onboard, could make work more efficient. To facilitate the support function, there is a need of a general understanding of IT-systems, how they are designed, what components that are included and the purpose of those components. This knowledge and correctly naming the components could better describes the problem and could give a better understanding of the recommended measures the support offers.

A "Bird´s eye" perspective was also noted as important. To complement the detailed knowledge with an overview of the system and its functions. It is also essential that the system overview includes how the system is configurated and connected to other systems on board. Also, how the system is intended to work, its contribution to the operation of the vessel.

"So that you become less and less dependent on the supporters, can solve things yourself. That you move this, this threshold, to call support one step further away..."

The basic understanding could be provided by the maritime academies, continuing education and/or a more specified training courses provided by the manufacturers, or the shipping companies themselves.

The support personnel on the other hand needs to understand the environment onboard, what type of equipment generally found there and its purpose together with a system understanding. Also, basic knowledge about the lay-out of a vessel and the challenges it creates, e.g. reach of signals. What safety requirements are in place that cannot be violated and how to relate to the prevailing rules and regulations was also pointed out.

3.3 Continuous further education and spreading/sharing knowledge onboard

As new technology is introduced, training courses are offered. However, it is not enough to send a few people to a course, there must be a strategy on how to share and make this knowledge available to other crew members. Crew members move on to other vessels or might not be onboard and available when their gained knowledge is needed.

"...yes, so you can probably train them in a better way, which It was mentioned before, with digital courses and maybe more frequent. My experience is that you train very rarely and so you let it go. We may train upon delivery of a new vessel..."

The contents of these courses were also discussed. Most software systems are complex with more function than needed for the daily use/operation onboard. The training does not necessarily need include all functions, only the ones necessary ("Need to know" base). The operators also asked for more fault-finding skills, not only how to manage a functioning system.

"How... what do we do if it doesn't work, how do you troubleshoot, what do we do, what kind of support do we have and things like that? It's never mentioned?"

Result from Focus Group 2

The results from Focus group 2 identified 3 areas of importance to continue with.

(i) **Quantification**
The problems described in "Digitaliseringens påverkan på sjösäkerhet och besättningens arbetsmiljö" (TRV 2021/100835) and in this project, are relevant for the industry with a high level of recognition among the participants and stakeholders within the shipping industry. To continue working on these issues

(ii) **Management of change/purchases**
How do you make an efficient purchase of new technology? What demands can you have on the system and the support and what can you expect from the manufacturer? What data can be collected, who does the analysis and is data shared and if so, between whom?

(iii) **Availability to expertise**
As the technology becomes more complex, available expertise from the shore side is becoming increasingly important. The crew cannot be experts on everything, need time to do their core tasks onboard and need to be unburdened. Efforts must be made to decrease the need for support and when support is necessary it should be easily accessible.

DISCUSSION

The result from this study shows there is an agreement that digitalisation has contributed positively to the safe and efficient operation of the vessels albeit requiring new knowledge and changes in task performance (Lundh and Rydstedt, 2016). It was evident that the participants agreed that both ”worlds” of on board operation and support functions are complicated and require a deep specialist knowledge and competence is necessary. A well-functioning support will always be necessary, but one of the key-themes defied by Focus group 1 in this study raised the question if the dependability of the support could be decreased.

What means and measures could reduce the dependency and need for support help?

To be able to sufficiently describe and communicate both problems and solutions, a common language is necessary and a basic knowledge of system structure and the environment onboard and the specific challenges this particular environment holds. It was regarded as a utopia that the operators and the support staff fully could gain each other’s knowledge, but both sides could benefit from additional training to obtain relevant knowledge to facilitate the communication between the operators and the support function. Support personnel could benefit from a general understanding of the environment onboard, the lay-out of a vessel and common operations onboard. Also understand the technology onboard and their purpose and how their specific technology relates/connects to other equipment onboard. The operators on the other hand need a general understanding of an IT-system, its components and their purpose to be able to provide sufficient information and a clearer description of the problem they need help with and to understand the instructions given on how to solve the issue(s).

Previous research gives evidence of interfaces being too complicated and containing too much information causes confusion, wrongdoings and distractions (Lundh et.al. 2023). This was confirmed in this study and User Centred Design was regarded as an important area that possibly could reduce the need for support. The participants also mentioned that parts of critical technology could also benefit from being standardized. Previous results address this albeit with a split opinion as it is thought that it could restrict innovation (Lundh et.al. 2023).

Historically, the participants argued that during a procurement process, the expectations on the support has been a bit “forgotten” and now need to be high up on the agenda. As the complexity of technology increases on board a fast and reliable access to support will be increasingly important in the future.

How can the future support function and contact between shore and ship be organised to increase efficiency?

As the situation onboard drifts towards more digitalization and automated systems the crews need to be unburdened by a shore-based organisation. There is a strong need for a 24/7 availability and simple means of contact. A majority of the participant also said they preferred a more traditional means of contact, phone or email, but most importantly to talk to one person. Over time, trust has developed, knowledge and experience about the specifics and history of the vessel has been gained. This is however practically an unsolvable problem. The support staff is not available around the clock, get assigned different tasks and all companies have a turnaround on staff.

As the systems are often interconnected the original source that sparks the problem might not be clear and the crew spend too much time trying to identify and get help from the "right" support. Could this search for the right system owner be supported from a shore-based function? This calls for a new organizational thought on how to do this and who is doing what. Ongoing initiatives and projects looking into operational data could be an interesting starting point. OVERSEA Fleet Support Centre (ABB, n.d.) aims at assisting vessels by analysing data collected onboard and feedback recommendations on e.g. voyage performance. Could a similar structure, a call centre connected to certain vessels, be used as a connection hub to communicate with the different manufacturers, help processing information concerning data connected to the support onboard and facilitate knowledge building?

As of today, large amounts of data can be and are recorded. Given the future developments we are facing going to higher levels of automation in the operation of the vessels, it is reasonable to suggest that there will be even more data available. The results pointed at automatic logging of faults as a way forward to better understand the fault of the system. However, the collected data needs to be analysed and "Data Mining" was put forward as a way to extract usable information and feed that back to vessels and end users to increase the knowledge and build on existing experiences. However, this cannot be handled by the crew, they need to be unburdened and to be on the receiving end of processed data.

The operators themselves, who experience problems and challenges with the digital equipment and support, have opportunities to file incident report within the company and also to independent incident reporting systems e.g. ForeSea. There is however believed to be hidden statistics here as the results indicate that operators abstain from filing reports simply because they see the hassle surrounding digitalization and support as "part of the job". Nor does searches within ForeSea reflect the magnitude of the different problems described by operators (Lundh et.al. 2023). Furthermore, the reports found are very diverse, often lacking root causes thus making the data difficult to analyse.

CONCLUSION AND FURTHER RESEARCH

Digitalisation has positively influenced the safe and efficient operation of vessels. It has however created an increasingly complex environment for the operators to manage which has its disadvantages and challenges. A major challenge is the dependency of an easy 24/7 accessibility of reliable support. Onboard operation and support functions are complicated and require a deep specialist knowledge and competence. To facilitate the knowledge exchange and reduce the need for support certain remedies could be made;

- Common language to facilitate communication
- User Center Design to adapt to the operators' requirements
- Partial standardisation of certain operational critical technology
- Develop routines for procurement processes to include expectations and demands of support
- Data mining of automated logged faults and incident reporting
- Share information related to fault finding and incidents

As the complexity increases with higher levels of automation the operators onboard need to be supported from the shore side. Future research need to;

- Quantify the magnitude of these problems to understand to be able to prioritise actions
- Understand Management of Change, in particular what demands on support that need to be present during procurement processes
- Discuss how the operators onboard can be unburdened from the shore side and the role and organisation of future support services

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