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Designing Human-Machine Interfaces for Maritime Engine Control Rooms

A User-Centered Co-Design Approach to Reduce Cognitive Load and Enhance Usability

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Abstract

This thesis explores how user-centered human-machine interfaces (HMIs) can support maritime engine control room (ECR) operators in managing cognitive load and improving usability. Current ECR HMIs are often fragmented, non-standardized, and cognitively demanding, posing safety and operational risks. In collaboration with the German Aerospace Center (DLR), this project addresses the challenge of designing modular, ergonomic, and context-sensitive HMIs that reflect user needs and operational realities.

The research follows a user-centered design approach and includes two main phases: expert interviews and a co-design workshop. Five maritime professionals with extensive seagoing and instructional experience were interviewed to identify usability challenges and interface needs. Their insights informed a scenario-based co-design workshop in ECR simulator with six engineering participants, who collaboratively developed interface concepts and low-fidelity prototypes for a blackout scenario.

Thematic analysis of the qualitative data revealed six key themes: embodied knowledge, automation challenges, visual clarity, information overload, lack of standardization, and communication barriers in multinational teams. Based on these findings, the thesis proposes seven design principles for ECR HMIs, emphasizing multisensory awareness, visual clarity, transparent automation, operational resilience, standardization, contextual prioritization, and communication support. In addition, the study presents UI mockups and multimodal design solutions derived from the workshop and interviews.

This work contributes to the limited HCI research in ECR contexts and provides practical design guidance for future maritime HMIs. It highlights the value of co-design and user-in-the-loop methods in developing safety-critical systems and underlines the need for maritime-specific interface standards to enhance operational efficiency and crew well-being.

Keywords

Maritime Human-Machine Interface, Engine Control Room, User-Centered Design, Co-Design, Cognitive Load, Maritime Safety

Sammanfattning

Denna avhandling undersöker hur användarcentrerade gränssnitt mellan människa och maskin (HMI) kan stödja operatörer i maskinkontrollrum (ECR) inom sjöfarten i att hantera kognitiv belastning och förbättra användbarheten. Nuvarande HMI-system i ECR är ofta fragmenterade, icke-standardiserade och kognitivt krävande, vilket innebär risker för både säkerhet och drift. I samarbete med det tyska rymdcentret (DLR) tar detta projekt sig an utmaningen att utforma modulära, ergonomiska och kontextkänsliga HMI-lösningar som speglar användarnas behov och den operativa verkligheten.

Studien följer en användarcentrerad designmetod och består av två huvudfaser: expertintervjuer och en samskapandeworkshop. Fem maritima yrkespersoner med omfattande erfarenhet från sjöfart och utbildning intervjuades för att identifiera användbarhetsutmaningar och gränssnittsbehov. Deras insikter låg till grund för en scenariobaserad co-design-workshop i en ECR-simulator med sex ingenjörsstudenter som gemensamt utvecklade gränssnittskoncept och lågupplösta prototyper för ett blackout-scenario.

Tematisk analys av det kvalitativa materialet identifierade sex centrala teman: förkroppsligad kunskap, utmaningar med automation, visuell tydlighet, informationsöverflöd, brist på standardisering samt kommunikationshinder i multinationella team. Baserat på dessa resultat föreslår avhandlingen sju designprinciper för ECR-HMI: multisensorisk medvetenhet, visuell tydlighet, transparent automation, operativ resiliens, standardisering, kontextuell prioritering och kommunikationsstöd. Studien presenterar även UI-skisser och multimodala designlösningar baserade på workshopen och intervjuerna.

Arbetet bidrar till den begränsade HCI-forskningen i ECR-sammanhang och ger praktisk vägledning för framtida maritima HMI-system. Det lyfter fram värdet av co-design och användarcentrerade metoder i utvecklingen av säkerhetskritiska system, samt understryker behovet av maritima gränssnittsstandarder för att förbättra operativ effektivitet och välbefinnande för besättningen.

Nyckelord

Maritimt gränssnitt mellan människa och maskin, maskinrum, användarcentrerad design, samdesign, kognitiv belastning, sjösäkerhet

Zusammenfassung

Diese Masterarbeit untersucht, wie nutzerzentrierte Mensch-Maschine- Schnittstellen (HMI) Schiffsingenieure im Maschinenkontrollraum (ECR) bei der Bewältigung kognitiver Belastung und der Verbesserung der Benutzerfreundlichkeit unterstützen können. Aktuelle HMI-Systeme in ECRs sind oft fragmentiert, nicht standardisiert und kognitiv belastend, was Sicherheits- und Betriebsrisiken mit sich bringt. In Zusammenarbeit mit dem Deutschen Zentrum für Luft- und Raumfahrt (DLR) adressiert dieses Projekt die Herausforderung, modulare, ergonomische und kontextsensitive HMIs zu gestalten, die den Nutzerbedürfnissen und den operativen Realitäten entsprechen.

Die Forschung folgt einem nutzerzentrierten Designansatz und umfasst zwei Hauptphasen: Experteninterviews und einen Co-Design-Workshop. Fünf maritime Fachkräfte wurden interviewt, um Usability-Probleme und Interface-Bedürfnisse zu identifizieren. Ihre Erkenntnisse flossen in einen szenariobasierten Co-Design-Workshop im ECR-Simulator ein, in dem sechs Ingenieurstudierende gemeinsam Interface-Konzepte und Low-Fidelity-Prototypen für ein Blackout-Szenario entwickelten.

Die thematische Analyse der qualitativen Daten ergab sechs zentrale Themen: verkörpertes Wissen, Herausforderungen der Automatisierung, visuelle Klarheit, Informationsüberflutung, fehlende Standardisierung und Kommunikationsbarrieren in multinationalen Teams. Auf dieser Basis schlägt die Arbeit sieben Designprinzipien für ECR-HMIs vor, mit Fokus auf multisensorisches Bewusstsein, visuelle Klarheit, transparente Automatisierung, Standardisierung, kontextuelle Priorisierung, design für operative Ausfallsicherheit und Kommunikationsunterstützung. Darüber hinaus werden UI-Mockups und multimodale Designlösungen vorgestellt, die aus den Interviews und der Co-Design-Workshop hervorgegangen sind.

Diese Arbeit leistet einen Beitrag zur bislang begrenzten HCI-Forschung im ECR-Kontext und bietet Gestaltungsempfehlungen für zukünftige maritime HMIs. Sie unterstreicht den Wert von Co-Design-Methoden und Nutzerbeteiligung in sicherheitskritischen Systemen sowie die Notwendigkeit maritimer Interface-Standards zur Förderung von Effizienz und Wohlbefinden der Crew.

Schlüsselwörter

Maritime Mensch-Maschine-Schnittstelle, Maschinenkontrollraum, nutzerzentriertes Design, Co-Design, kognitive Belastung, maritime Sicherheit

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Hamburg, Germany, August 2025
Malin Brilon

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List of acronyms and abbreviations

AR	Augmented Reality
DG	Diesel Generator
DLR	German Aerospace Center
ECR	Engine Control Room
HCD	Human-Centered Design
HCI	Human-Computer Interaction
HMI	Human-Machine Interface
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISA	International Society of Automation
ISO	International Organization for Standardization
KTH	KTH Royal Institute of Technology
ME	Main Engine
RTA	Reflexive Thematic Analysis
UAS	University of Applied Sciences
UCD	User-Centered Design
UI	User Interface
UX	User Experience

Chapter 1

Introduction

Maritime engine control rooms (ECRs) are the operational hubs where marine engineers oversee propulsion and auxiliary systems under demanding environmental and temporal conditions. Human-machine interfaces (HMIs) in these settings play a central role in ensuring safe and efficient operation. However, many current ECR interfaces are not standardized, present fragmented information, and struggle to support operators effectively during time-critical situations [1, 2, 3]. These shortcomings increase cognitive workload and elevate the risk of human error [4, 5]. This thesis investigates how user-centered design can be applied to improve ECR HMIs, with particular attention to reducing cognitive load and enhancing usability. The research is situated at the intersection of human-computer interaction (HCI), maritime technology, and co-design, and is conducted in cooperation with the German Aerospace Center (DLR), specifically the DLR Institute of Maritime Energy Systems.

1.1 Context

The maritime industry is undergoing significant digital transformation, introducing more interconnected and software-driven systems on board [6]. This accelerates the pace of system updates and requires interfaces that can integrate new technologies without extensive redesign. Modular HMI architectures, already proven in sectors such as nuclear energy and industrial automation, offer a way to manage this complexity by reusing standardized building blocks, reducing integration effort, and enabling scalable adaptation to evolving operational demands [7, 8].

In maritime ECRs, modular design refers to organizing interfaces into discrete, function-specific units that can be configured or adapted to specific operational contexts [7]. When combined with human-centered design (HCD) approaches, such systems have the potential to address usability gaps, promote standardization, and enhance operator performance [9, 10].

1.2 Focus

This research focuses on understanding operator needs and usability challenges in current ECR HMIs, and on exploring design concepts that could address these challenges through user-centered principles. While the study does not develop or test high-fidelity modular prototypes, it examines whether the principles of modularity align with user requirements and operational realities. The scope is limited to maritime ECR contexts and to qualitative methods: expert interviews with marine engineers and a co-design workshop conducted in a simulator environment.

1.3 Relevance

From an industry perspective, improving HMI usability in ECRs can help reduce operational inefficiencies, lower cognitive demands, and increase safety in high-pressure environments. From an academic standpoint, the study contributes empirical insights into applying HCD and modular principles to a maritime context, an area that remains underexplored compared to other safety-critical domains. The findings aim to benefit interface designers, maritime technology developers, and ergonomics researchers, offering strategies for more consistent, adaptable, and user-friendly ECR interfaces. Broader implications include supporting sustainable operations, enhancing communication in multicultural crews, and enabling responsible adoption of automation.

1.4 Research Questions and Objectives

The central research question is:

> *How can modular, standardized, and user-centered HMIs be designed for maritime engine control rooms to optimize usability, reduce cognitive load, and improve operational performance?*

To address this question, the project pursues the following objectives:

1. Identify key usability issues and operator needs in current ECR HMIs.
2. Explore conceptual interface solutions informed by user experience and ergonomic design principles.
3. Develop annotated interface concepts grounded in qualitative findings.

1.5 Methodology Overview

The research follows a user-centered methodology combining:

- Semi-structured expert interviews with experienced marine engineers, analyzed using reflexive thematic analysis [11].
- A scenario-based co-design workshop where end users collaboratively generated and evaluated low-fidelity interface prototypes.

Insights from the interviews informed the co-design activities, ensuring that proposed concepts are grounded in operational practice.

1.6 Delimitations

The study focuses solely on ECR environments in maritime vessels. Evaluation is limited to qualitative data from interviews and workshop activities; no functional, deployable prototypes are developed or tested.

1.7 Structure of the thesis

Chapter 2 provides detailed background information and discusses related research in HMI design for maritime systems. Chapter 3 presents the applied methodology, including interview and co-design procedures. Chapter 4 contains the results and analysis of the interviews and the co-design workshop. In Chapter 5, the design concepts which are based on the prototypes developed during the co-design workshop are presented, linking the resulting prototypes to empirical findings from the interviews and relevant ergonomic guidelines. Chapter 6 reflects on the findings in light of the research goals and academic literature. Finally, Chapter 7 concludes the thesis and proposes directions for future work.

Chapter 2

Background

This chapter provides the necessary background for understanding the context and objectives of this thesis. It also presents and discusses related research relevant to the development of modular, standardized, and user-centered HMIs in maritime ECRs. The aim is to position the present study within the field, identify established knowledge, and clarify where this thesis contributes new insights.

2.1 Introduction to the Problem Domain

The maritime industry plays a crucial role in global trade and logistics [12]. Seafarers are central to ensuring safe navigation and ship maintenance, particularly in technically demanding environments such as ECRs [13]. These workplaces are characterized by high system complexity and the need for continuous multitasking, making them both high-stress and high-stakes [1].

Human error remains a major cause of maritime accidents [14, 4, 15], with cognitive overload being a prominent factor [4]. When operators are faced with excessive information and unclear interfaces, their ability to make timely and accurate decisions is compromised [4]. This underscores the need for intuitive, well-designed HMIs that streamline decision-making and reduce cognitive demands. Closely linked to cognitive overload are crew fatigue and stress, which further impair attention, reaction time, and judgment [5, 4, 16].

Prolonged stress can also affect long-term health and cognitive function. Chronic exposure to stress hormones like cortisol may damage the hippocampus, impair memory, and accelerate brain aging, potentially increasing the risk of neurodegenerative conditions [17, 18]. While acute stress can temporarily enhance alertness, sustained stress reduces mental performance and adaptability, especially in older operators. These physiological impacts emphasize the importance of designing systems that help mitigate both mental workload and stress during maritime operations [5, 16].

Importantly, human errors are not solely the result of individual failings, but often reflect broader systemic issues such as poor communication, inadequate training, and limited resources [19]. Effective HMI design should therefore address not only the interface itself, but also the broader sociotechnical context in which operators work. Simplifying complexity, improving clarity, and preventing miscommunication through design can help reduce the likelihood of errors and enhance operational efficiency. Human decision-making in high-pressure contexts like ECRs is deeply influenced by the interplay between user, system, and environment [19]. This makes context-sensitive design essential. Interfaces should support multitasking by minimizing distractions and presenting information in a prioritized and structured way. Features like guided alerts, visual hierarchies, and intuitive controls could improve operator focus and decision accuracy [19].

Adopting HCD principles and conducting usability evaluations are key strategies for reducing human error and enhancing safety in maritime environments [2]. Challenges such as cognitive overload, ambiguous interfaces, and ineffective support systems can be addressed through ergonomic design practices [20]. By aligning interface design with human cognitive processes and decision-making patterns, systems become more intuitive, reduce mental workload, and enhance user performance.

As maritime systems become increasingly digitalized, standardization and consistency in interface design are critical to avoid confusion and ensure smooth interaction [6]. Studies show that excessive workload slows task performance and impairs accuracy [21]. Thus, reducing operator workload through well-structured and user-friendly interfaces remains a fundamental goal for improving safety and efficiency in ECRs [1, 22, 21, 23].

2.2 Human-Centered and Co-Design Approaches

Human-centered design (HCD) focuses on aligning system development with users' tasks, contexts, and capabilities [24]. Co-design, a key strategy within HCD, emphasizes direct user involvement through workshops and iterative prototyping, allowing users to contribute insights and evaluate emerging concepts [24].

The CyClaDes (Crew-Centred Design and Operations) project strengthened the role of HCD in collaborative maritime design processes. A case study by Costa et al. (2017) describes an HCD approach for the redesign of a ship's bridge wing. The process involved crew interviews and iterative feedback loops [10]. Comparable approaches are well-established in high-risk industries such as nuclear energy. For example, in nuclear control room modernization projects, user feedback is integrated into iterative prototyping and simulation-based evaluation cycles [25, 26].

One prominent example is the U.S. Department of Energy's Light Water Reactor Sustainability program for control room modernization. Boring et al. (2017) describe a successful approach that "combines advanced human factors methods with unique laboratory facilities" to co-design new digital interfaces with operators. They developed realistic, functional prototype mock-ups of new control room technologies and interfaced them with a full-scope simulator, the Human Systems Simulation Laboratory at Idaho National Laboratory, to enable hands-on operator-in-the-loop workshops. In these workshops, licensed plant operators interact with the prototype HMIs through simulated scenarios, while designers and human factors engineers observe and gather feedback. Crucially, the process is iterative: multiple rounds of design refinement and evaluation are conducted. Using this "iterative process of design workshops and operator-in-the-loop studies", the team was able to optimize the control room design for enhanced human performance before actual deployment. Early operator feedback helped identify usability issues and "error traps" in the new interfaces, which could then be corrected prior to implementation [25].

Other power generation and industrial domains have reported similar co-design efforts. For example, in the oil and gas industry, control room upgrade projects often follow human-centered design guidelines akin to ISO 11064. An experienced Human Factors Engineering practitioner notes that regardless of industry, an "operator-first" approach is key. The goal is to "design from the human out", ensuring the control system interface supports operators' tasks and decision-making [26]. In practice, this involves workshops, simulations, or at least structured consultations with end-users during design. Even legacy systems such as analog panels are being modernized through user-informed designs. For example, utilities have engaged plant operators in reviewing static mockups and 3D models of proposed new control rooms to gather usability input before construction [25].

Other related industries show great examples, but the key difference to maritime ECR is that those domains, such as nuclear power and oil and gas, typically have more formalized human factors engineering integration, established regulatory frameworks, and dedicated simulation facilities for iterative testing [25, 26]. In contrast, the maritime sector often lacks standardized HMI development processes [10], has limited access to full-scope simulation environments, and tends to involve end users less systematically in design stages [10, 2], making structured co-design and user-in-the-loop testing more difficult to implement effectively.

These examples show that iterative and co-design design approaches not only enhance the usability of HMIs, but also ensure that the resulting systems are better aligned with the needs and mental models of the people who will actually use them, meaning the aligned with the internal representations users form about how systems work, based on experience and expectations [10, 25, 26].

2.3 Modular HMI Design Principles

Modularity has gained attention in interface design as a strategy to manage system complexity, enhance maintainability, and support flexible adaptation. In the context of maritime ECRs, modularity remains largely theoretical, with limited empirical validation or implementation in practice. This section introduces modular design not as an established solution, but as a conceptual lens to frame opportunities for future ECR interface development.

Modular HMI systems consist of discrete components, software modules, hardware controls, and interface elements, each responsible for a specific function. These components can be updated or reorganized independently, allowing systems to scale and adapt to changing technical configurations. Modular principles are often categorized into functional (e.g., propulsion monitoring), technical (e.g., touchscreen versus tactile interfaces), and physical (e.g., detachable consoles) dimensions [7].

In high-risk domains such as nuclear energy and industrial automation, modular HMIs are used to enhance consistency, reduce development redundancy, and simplify maintenance. For instance, Westinghouse's control room modernization uses predefined HMI "building blocks" to streamline display design and layout across projects [27, 8]. Industrial standards such as Module Type Packages enable plug-and-play functionality by allowing new process modules to automatically populate standardized HMI interfaces [28]. Although maritime systems do not yet support Module Type Packages, like automation, suppliers have begun offering configurable interfaces with modular software extensions [29].

Compared to these sectors, maritime ECRs pose unique challenges. Interfaces in ECRs must accommodate diverse subsystems like machinery, auxiliary systems, power distribution which are often supplied by different vendors. The lack of interface standardization across these systems can lead to visual inconsistencies, poorly grouped information, and increased error potential [3]. Studies show that poor grouping of information and controls undermines system overview and increases cognitive workload for operators [3]. Modular design principles, such as grouping displays by system function or using standardized alarm widgets, could mitigate these issues by aligning interfaces more closely with user mental models and task flows [30].

Moreover, maritime interfaces must meet stricter environmental requirements than their land-based counterparts. Harsh conditions, distributed redundancy, and limited workspace demand compact, intuitive, and resilient interface solutions [31, 3, 32]. These constraints reinforce the relevance of modular HMI strategies, which can facilitate standardization, improve spatial organization, and support easier reconfiguration.

While modular HMIs were not directly investigated in this study's interviews or co-design workshop, they are referenced in related literature and industrial white papers as an emerging design opportunity. For example, the EAO Marine HMI framework proposes modular, functionally grouped interface layouts to improve clarity and reduce training effort across vessels [30]. Similarly, the Rolls-Royce Unified Bridge concept demonstrates how modular control arrangements can enhance ergonomics and reduce cognitive load in ship bridges [33], principles that are equally applicable to ECRs.

In summary, modular HMI design offers potential advantages for maritime ECRs by promoting scalability, reducing operator workload, and enabling future system upgrades without major redesigns. These principles are supported by established applications in other sectors and preliminary industrial efforts in the maritime domain. However, empirical studies validating their impact in ECR-specific use cases remain scarce, highlighting the need for further user-involved design research.

2.4 Maritime-Specific Challenges

The maritime environment presents significant challenges for HMI design. ECRs are confined spaces subject to loud noise, constant vibration, heat, and humidity. These conditions, combined with long shifts and extended sea duty, can increase fatigue and stress, degrading operator alertness and raising the risk of errors [1]. HMIs for such settings must remain effective under adverse conditions. Screens should be visible in changing light, controls usable despite movement-induced tremors, and alarms perceptible over machinery noise [1]. Ergonomic design should minimize unnecessary movement and supplement audio alarms with visual or tactile cues.

A modular and integrated HMI can address this fragmentation. By presenting a coherent dashboard with consistent colors, icons, and interaction patterns, such systems enhance usability and reduce training time [1]. Man, Lundh, and MacKinnon (2018) propose moving from piecemeal "patching" to a service-oriented architecture, where ECR systems function as modular services communicating via a shared platform, akin to apps in a smartphone ecosystem [1]. The EU's EfficienSea2 project illustrated how this model could standardize integration and simplify operations [34].

Yet, implementation faces hurdles. Interoperability requires shared protocols and cooperation between manufacturers, still rare in maritime contexts [1]. Ships are often custom projects, and procurement choices prioritize cost or preference over interface consistency [35]. Binding standards for uniform HMIs are lacking, and regulations lag behind technical capabilities [36]. However, trends like increased automation and the development of autonomous ships are prompting a shift. Maritime authorities and classification societies are beginning to incorporate human factors into guidelines, creating opportunities for modular HMI concepts [37, 38].

In summary, ECR interfaces must overcome harsh environmental conditions and fragmented systems that contribute to operator fatigue and error risk [1, 39]. Modular design offers a path forward by enabling coherent, ergonomic, and adaptable HMIs [1]. Service-oriented architectures could unify disparate systems, but realization depends on technical standards, vendor cooperation, and institutional support [34, 36, 35, 37, 38].

2.5 Simulation-Based Evaluation

Evaluating human–machine interfaces in safety-critical maritime environments requires methods that balance ecological validity, repeatability, and safety. While approaches such as field studies and heuristic evaluations are available, simulation-based testing offers a controlled yet realistic setting to observe user interaction under diverse operational conditions. In the following, the principles and relevance of simulation-based evaluation for maritime engine control rooms are discussed in more detail.

Simulation has become a critical tool for evaluating HMIs in maritime contexts. In controlled simulator environments, researchers can systematically vary scenarios and observe operator performance and behavior without real-world risks. These simulators offer repeatable conditions, objective performance measurement, and safe testing of interface designs under high workload or failure scenarios [40].

For example, full-mission engine room simulators have been used to study crew workload and interface usability under different operational conditions [40]. Wu, Miwa, and Uchida (2017) conducted an engine room simulator study where participants performed both standardized tasks and realistic marine engine operations; this allowed the authors to measure how interface design and task complexity impacted mental workload using objective metrics [22]. Likewise, on the navigation bridge side, Hareide and Ostnes (2017) employed a ship bridge simulator with eye-tracking to identify suboptimal design elements in the bridge layout and graphical user interface [41]. Their maritime usability study revealed how certain display placements and formats led to inefficient visual scanning patterns, demonstrating the power of simulation-based testing to uncover design flaws [41].

These examples show that simulation-based studies can mimic the demanding and complex conditions of ship operations, while providing detailed measurements of workload and usability that would be difficult to achieve on board real ships. Simulation studies in this domain often combine objective performance data (e.g., task completion times, error rates) with subjective feedback (e.g., user satisfaction, perceived workload) to assess usability. By iterating interface prototypes in a simulator, designers can obtain early insights into what HMI configurations allow operators to maintain situational awareness and manage their workload effectively [40, 22].

2.6 User Acceptance and Ergonomics

User acceptance of HMI systems in engine control rooms is closely tied to usability and ergonomic design [20, 6]. Interfaces that align with operators' mental models and are intuitive to use reduce training time and resistance [4, 2]. Usable systems, those that clearly support goal achievement and minimize frustration, are more likely to gain acceptance [4, 30, 42].

By contrast, unintuitive systems often lead to workarounds or reluctance, undermining the technology's intended benefits. Applying human-centered design principles, gathering end-user input and iteratively testing interfaces, is essential to meet users' expectations [43, 2].

Ergonomics in ECRs involves both physical and cognitive aspects [36, 1]. Physically, screens and controls should be placed based on use frequency and importance, minimizing awkward postures. Cognitively, information and alarms must match human processing limits to avoid overload. Poor design can lead to missed cues or errors, especially in high-stress situations [36].

The IMO's guidelines (MSC/Circ.834) emphasize ergonomic ECR layout to improve safety and efficiency. They address lighting, noise control, familiar interfaces, and risk reduction through thoughtful spatial arrangement [44]. Yet, research finds many ECRs still fall short [36, 1]. Modern ships often feature a patchwork of digital and analog systems added over time. Mallam and Lundh (2013) described this as a lack of cohesive ergonomic strategy [36]. Operators may work in cramped, noisy, or hot conditions, facing scattered displays and fragmented interfaces from different eras and vendors [1]. This environment taxes both physical comfort and cognitive capacity, especially under time pressure. Interfaces that fragment information or obscure situational awareness reduce usability and acceptance. Unlike ship bridges, ECRs lack comprehensive international standards for HMI layout and interaction design [36, 1]. International Maritime Organization (IMO) regulations often focus on technical performance (e.g., control redundancy, fire safety), with limited attention to human-technology interaction or workload [1]. As a result, designers lack clear targets for effective human-system integration, leading to inconsistent implementations [36].

Ergonomic and user-friendly design is often overlooked in favor of functional or regulatory priorities [36, 1]. This highlights the need for stronger human-factors-based standards and design guidance for ECR HMIs. Broader awareness and industry demand, supported by research-backed recommendations, are essential to improve the user experience and acceptance of maritime control systems.

2.6.1 Ergonomic Guidelines and Standards for Control Room Design

The ISO 11064-5:2008 guidelines for Ergonomic design of control centers Part 5: Displays and controls offer human-centered principles for the design of displays and controls, focusing on minimizing cognitive load and supporting safe and efficient operation, objectives that are relevant in maritime ECRs, especially under stress or time pressure [45]. It outlines ergonomic criteria regarding display and control layout, labelling, signal prioritization, modality selection (visual, auditory, tactile), and reach and visibility. When applying these principles to maritime ECRs, ISO 11064-5 supports multi-modal information presentation, e.g., combining visual and auditory alarms depending on urgency. This aligns with ECR needs for auditory signals for critical alarms when visual attention is diverted, and visual displays for continuous process monitoring and trend detection. This principle directly supports reducing overload and prioritizing responses in high-stress maritime settings. The guideline also includes recommendations for control arrangement, grouping related controls/displays together, keeping frequently used controls within optimal reach and view (based on anthropometric data), and minimizing hand-eye movement. This supports ergonomic task flow in ECRs, particularly for frequently performed procedures such as fuel transfer, propulsion monitoring, or emergency stops. The guideline for alarm prioritization and coding discusses alarm differentiation by color, sound, and placement, avoidance of alarm flooding, and use of hierarchical coding. These are essential principles in ECRs, where irrelevant or excessive alarms, often noted under MSC.302(87), can obscure critical cues. ISO 11064-5 can thus provide a basis for more effective alarm management [45].

ISO 9241 offers complementary standards for interaction design and interface presentation:

- **ISO 9241-110** outlines principles for dialogue design such as suitability for the task, error tolerance, and learnability [46]. It supports intuitive system behavior and adaptability for diverse user skill levels, though it was primarily developed for graphical UIs rather than multi-modal environments like ECRs.

- **ISO 9241-112** addresses information presentation, encouraging salience and cognitive clarity. This is valuable for alarm filtering and context-sensitive displays [47].

- **ISO 9241-125** extends ISO 112 with visual grouping and scaling recommendations [48], although it lacks consideration of motion or ambient vibration.

- **ISO 9241-161** concerns visual interface elements such as icons and layout standards [49], helpful for international crews, but originally designed for office environments.

- **ISO 9241-220** promotes organizational HCD integration [50], and **ISO 9241-920** explores tactile and haptic interactions [51], both increasingly relevant in maritime contexts.

Despite their value, these standards require adaptation to the maritime domain and should be considered alongside field-specific requirements like MSC.302(87) and IEC 62288.

2.7 Research Gaps and Motivation

Despite growing interest in improving HMIs in maritime operations, several critical research gaps persist in the context of ECRs. First, the majority of usability and simulation-based studies focus on bridge operations, while ECRs remain significantly underexplored in empirical interface research [2, 3]. Although 3D simulators exist for ECR training, they primarily emphasize operational realism over HMI usability evaluation [52, 53]. As such, there is limited evidence on how new modular interface concepts affect cognitive load, situational awareness, and user performance in this specific environment.

Second, while human-centered and co-design practices are widely adopted in other safety-critical industries, such as nuclear power [25, 26], their application in maritime settings remains limited. The few existing examples, such as the CyClaDes project, highlight both the benefits and the challenges of implementing co-design methods in maritime companies [10, 54]. However, the limited adoption to date indicates that further structural and methodological adaptation is necessary to integrate co-design effectively into maritime system development. Economic pressures, a lack of standardized ergonomic guidelines, and weak regulatory support continue to hinder broader adoption of co-design [54, 36].

Third, although modular HMI design has proven effective in other domains for improving consistency, maintainability, and cognitive efficiency [27, 55, 56], its implementation in maritime ECRs is still in early stages. Fragmented system landscapes, diverse supplier technologies, and inconsistent visual logic increase cognitive workload and error potential for operators [1, 39, 3]. Modular approaches offer a promising solution but require further validation in maritime use cases, particularly through user-in-the-loop evaluations.

Moreover, ECRs pose unique challenges, including harsh environmental conditions and system heterogeneity, that are not yet fully addressed by current design standards or ergonomic practices [1, 36]. These gaps contribute to suboptimal operator experiences, fragmented situational awareness, and increased risk of human error [4, 5, 19].

Fifth, while ISO 11064-5 and ISO 9241 provide useful ergonomic and interaction design principles, they fall short in several key areas relevant to maritime ECRs. First, they are primarily based on land-based control environments and do not address ship-specific conditions such as constant motion, ambient machinery noise, or lighting constraints. Second, they often assume single-user, stationary workstations, whereas ECRs involve shared use, mobility, and simultaneous multi-system interaction. Third, while ISO 11064-5 emphasizes spatial layout and physical ergonomics, and ISO 9241-110 focuses on interactive logic and feedback, there is no integrated guidance for hybrid interfaces combining analog and digital elements. Finally, many standards (e.g., ISO 9241-125, -161) do not reflect current technologies like touch-based HMI, mobile displays, or AI diagnostics. As a result, there is a gap in standards that fully accommodate maritime ECR realities, reinforcing the need for domain-specific, user-centered adaptations and validation through empirical research [45, 46, 47, 49, 48, 57, 50, 51].

Motivated by these gaps, this thesis aims to generate actionable insights for user-centered interface design tailored to the specific needs of maritime ECRs, a domain currently underrepresented in usability research. Unlike prior studies that primarily focus on ship bridges or industrial control environments, this work explores the operational challenges and user requirements within ECRs. By applying simulation-based co-design methods, the project bridges the divide between theoretical principles and applied solutions, embedding end-user perspectives into early design stages. While modularity was identified as a promising future strategy, it is addressed only through related literature and is not directly explored in the co-design workshops or interviews. Ultimately, this thesis aims to contribute to safer, more efficient maritime operations by supporting operators in managing cognitive load and enhancing situational awareness [2, 22, 21].

Table 2.1 summarizes key approaches discussed in the background, highlighting their benefits and limitations, which inform the design space for this thesis.

Table 2.1: Summary of HMI Design and Evaluation Approaches in the Maritime Context

Approach	**Core Idea**	**Benefits**	**Drawbacks / Limitations**
Human-Centered Design (HCD)	Iterative design with user involvement throughout the process	Improves usability, reduces errors, aligns design with user needs [24, 2, 10]	Requires time, resources, and user access; lacks widespread application in maritime due to cultural and institutional barriers
Co-Design Workshops	Collaborative design sessions with end users (e.g., engineers)	Builds user ownership, captures tacit knowledge, enhances acceptance [10]	Requires skilled facilitation and participant availability; limited scalability
Modular HMI Design	Interfaces built from reusable, function-specific modules	Supports standardization, scalability, cognitive offloading, maintainability [7, 3, 29]	Implementation is challenging in fragmented maritime systems; lack of shared standards
Simulator-Based Evaluation	Testing HMIs in high-fidelity, risk-free environments	Enables early usability testing, workload assessment, repeatability [40, 22, 41]	Most simulation studies focus on bridge systems; underutilized for ECRs [2]
Ergonomic Standards (e.g., MSC/-Circ.834, ISO 11064-5, ISO 9241 series)	Ergonomic and usability guidelines for layout, display, and interaction design	Provide foundational principles for reducing workload, enhancing legibility and alarm logic [45, 46, 47, 49, 48, 50, 51]	Require adaptation for maritime use; enforcement is inconsistent [36, 1]

Chapter 3

Methods

3.1 Scientific Methodology and Justification

This study adopts a User-Centered Design (UCD) approach to evaluate how a modular, user-friendly, and standardized HMI for maritim ECRs can be developed, and what key aspects must be considered in the development process. The methodology consists of two key phases: (1) qualitative groundwork through expert interviews and (2) a simulation-based co-design workshop.

UCD is grounded in the principle of designing interactive systems that align with users' real-world tasks, needs, and operational contexts [24]. In safety-critical domains such as maritime ECRs, understanding human behavior, cognitive demands, and environmental constraints is crucial to ensure system usability, operator performance, and operational safety.

UCD promotes the active involvement of users throughout the development cycle, enabling iterative design decisions informed by their lived experiences. This is particularly relevant in maritime contexts, where poor interface usability has been associated with increased cognitive load, error potential, and task inefficiency [4, 2]. UCD principles have proven successful in other high-risk industries such as nuclear energy, where standards like ISO 11064 and NUREG-0711 mandate participatory methods and operator-in-the-loop validation [25, 26]. Within the maritime field, the CyClaDes project illustrated the value of user engagement in redesigning ship systems, while also revealing institutional barriers such as limited awareness of human-centered design practices [10].

Building on these insights, the first phase of this study employed semi-structured expert interviews to establish a foundational understanding of real-world practices. This method was chosen to gather experience-based knowledge from maritime professionals regarding usability challenges, operational routines, and system interactions in ECR environments. In line with HCD best practices, early user engagement through interviews and contextual inquiry helped define the design problem space and prioritize relevant requirements [24].

The second phase implemented a simulation-based co-design workshop, enabling end users to actively participate in shaping and evaluating HMI concepts. Co-design facilitates mutual learning between users and designers while empowering operators to contribute their domain-specific knowledge [24, 58].

The simulation environment provided a controlled, repeatable, and risk-free setting for this co-design process. It allowed participants to engage with realistic interface scenarios and provide feedback under representative conditions without compromising safety. This methodological choice builds on prior research demonstrating the benefits of simulation for HMI evaluation, particularly in domains where real-world testing is infeasible due to operational or safety constraints [22, 40, 41].

3.2 Research Goals

The primary goal is to gain a deeper understanding of user needs and how HMIs can optimize operator performance, streamline workflows, and reduce cognitive load. Secondary, I want to identify gaps in current ECR interfaces, validate modular design principles in a real-world context, and provide empirical support for ergonomic and standardized HMI development.

3.3 Construction and Evaluation Process

3.3.1 Interviews

Semi-structured interview with open-ended questions were designed following established user research guidelines as outlined by Baxter, Courage, and Caine (2015) [9].

The primary objectives of these interviews were to gain contextual understanding of work in the ECR, explore the perceived usability of existing HMIs, identify opportunities for modular and standardized interface design, assess cognitive load in interface interaction, discover critical scenarios where interface design matters most and collect suggestions and unspoken needs.

The interviews followed a pre-established interview guide (see Appendix A.1 and Appendix A.2) and encompassed a series of topics. These included a typical example of your day-to-day work in the engine control room, information flows & data interaction in the ECR, their workload and areas for improvement.

The scope of the interviews was to:

- Understand the tasks, responsibilities, and operational scenarios faced by engine room personnel.
- Learn how operators interact with current HMIs, including displays, alarms, tools, and workflows.
- Identify usability issues and design shortcomings that contribute to cognitive overload or inefficiencies, particularly in high-stakes scenarios such as system startup, troubleshooting, and failure response.
- Investigate how current interfaces support or hinder intuitive interaction and situational awareness.
- Analyze the types and causes of information overload (e.g., excessive text, poor grouping, unclear prioritization) and how these impact mental workload.
- Understand the stakes and consequences of operator errors or delays caused by confusing or cluttered interfaces.
- Elicit user-driven suggestions for improvements and gather descriptions of what "ideal" HMIs might look like from the operators' perspective.
- Capture latent needs or issues they may not articulate unless prompted or during open-ended questions.

Interviews were conducted in German with five male professionals who were recruited via convenience sampling through academic and professional networks, specifically from the DLR and the Flensburg University of Applied Sciences (UAS). An overview of the interviewees' current roles and relevant experience is provided in Table 3.1.

Table 3.1: Overview of Interview Participants and Their Backgrounds

ID	Current Role	Key Experience	Education & Certification	Areas of Expertise
1	Lab Engineer, Flensburg UAS	Seagoing engineer; lab-based engine testing facility	Marine Engineering; Chief Engineer license	Engine testing, system design, training
2	Researcher, DLR	Cruise ship engineering; Staff Chief Engineer	Officer licenses; apprenticeship as ship mechanic	Cruise ship operations, applied research
3	Lecturer, Flensburg UAS	Chief Engineer and Captain; coastal cargo vessels	Ship Operation Engineering & Nautical Science	Engine room operations, officer training
4	Lecturer, Flensburg UAS	Chief Engineer; Managing Director; project and inspection roles	Engineering apprenticeship and certifications	Technical management, inspection, engine operations
5	Lecturer, Flensburg UAS	Second Engineer; ship inspection	Marine Engineering	Traditional and digital engine control systems

These individuals represent a blend of field-level expertise and higher-level systemic understanding, including international ship operations, technical inspections, interface usage, and crew coordination. All participants reviewed the participant information sheet (see Appendix A.3) and signed a consent form (see Appendix A.4) prior to participation. The interviews were conducted in German, either in-person or via Microsoft Teams, depending on participant availability. Sessions lasted between 30 to 80 minutes, depending on the extent of discussion.

All interviews were audio-recorded, transcribed, and thematically analyzed following the principles of reflexive thematic analysis (RTA) [11]. To protect participant confidentiality, full transcripts have not been included in the appendix. The transcripts are securely stored and accessible only to the research team. The interviews were approved by the ethics committee of the University of Twente by the committee of Computer & Information Sciences (Application nr. 250670, date: 14-04-2025). An overview of interview methodology can be seen in Table 3.2.

Table 3.2: *Overview of Interview Methodology*

Topic	Choice
Participants	5 participants through convenience sample
User profile	Professionals with extensive hands-on experience in maritime engine control rooms, including chief engineers, technical inspectors, captains, and maritime educators
Format	Semi-structured interview
Medium	In person, Microsoft Teams (Online)
Duration	30 – 80 minutes
Recording	Audio recording

3.3.1.1 Interview Analysis Procedure

RTA is a method for identifying, analyzing, and interpreting patterns of meaning “themes” across qualitative data. It is especially well-suited to exploring lived experiences, perceptions, and practices in-depth [11]. Braun et al. (2023) outline six flexible, recursive phases for conducting RTA:

The first step is familiarization with the data. You immerse yourself in the data to gain a deep understanding. I read the interview transcript closely, section by section, with attention to both what was said (explicit content) and how it was said (tone, focus, emphasis). This phase is especially important to get a feel for the interviewee’s context, voice, and meaning-making.

The second step is generating initial codes to identify interesting features or “meaningful fragments” across the dataset. Each segment of the interview was systematically coded, distinguishing between: Semantic codes (explicit content) and Latent codes (underlying ideas or assumptions). The coding was data-driven and flexible, one segment could have multiple codes.

The third step is generating initial themes to collate codes into broader patterns of shared meaning, preliminary themes. Codes were grouped into clusters that captured broader narratives or issues expressed by the participant.

The fourth step is reviewing and developing themes to refine themes to ensure they are coherent, distinctive, and well-supported by data. Themes were revisited and sharpened: some were merged, renamed, or clarified to better reflect the underlying meaning. Relationships between themes were considered.

The fifth step is defining and naming themes to give each theme a concise, informative name and write a rich description of its scope and focus. Provisional theme titles were developed, each summarizing the essence of the pattern. Narratives were constructed around these themes for the analytical report.

The sixth step is writing the report to present a coherent story of your analysis with data extracts and interpretative commentary. Each theme was introduced with a brief explanation, illustrated with verbatim quotes, and followed by an interpretive discussion showing how it relates to the research question and broader context.

3.3.2 Co-Design Workshop

The co-design workshop served as a direct continuation of the expert interviews and acted as a translation phase within the research process. The findings and recurring themes identified in the interviews, such as a lack of standardization, insufficient visual clarity, lack of transparency in automation and the risk of information overload in emergency situations, were translated into concrete interface ideas together with the intended users.

The aim of the workshop was to develop results that improve the ECR HMI design and are tailored to the needs of the users. The session aimed to gain deeper insights into user requirements and explore how HMI systems can be optimized, simplified and designed to reduce cognitive load during use.

Following the principles of co-design defined by Burkett (2012), the workshop participants were involved in scenario-based activities based on realistic ECR sequences through an ECR simulator [58].

Methods for the workshop were selected from the Design Method Toolkit developed by the Amsterdam University of Applied Sciences [59], the book *Getting started with design thinking: including 20 creative techniques* by Eveline van Zeeland [60] and from the book *Interaction Design: Beyond Human-Computer Interaction* by Rogers, Sharp, and Preece [24]. The co-design workshop was structured into three phases. The first phase served as an introduction to initiate brainstorming among participants. The second phase focused on ideation, and the third phase involved hands-on design, where participants worked in pairs to create low-fidelity prototypes and reflect on their results.

The workshop took place on June 11th at Flensburg University of Applied Sciences in a large room next to the simulator and was equipped with a large screen (see Figure 3.1). The workshop was approved by the ethics committee of the University of Twente by the committee of Computer & Information Sciences (Application nr. 251358, date: 19-05-2025). A total of 6 participants were students recruited from Flensburg University of Applied Sciences though convenient sampling. Participants received 15€ after participation and during the workshop snacks and drinks were provided as a compensation for their participation.

Figure 3.1: Workshop room

All individuals were required to complete a short survey collecting demographic and background information (see appendix B.4), to screen participant profiles. This included age, completed training in the maritime sector (if applicable), current role or status, previous experience working at sea (and duration in months), experience in ECR operations (in months or years), and prior participation in usability testing or design workshops.

The results of the screening questionnaire showed that 6 male students participated. The average age was 26 years, with a range from 23 to 34 years. 5 participants have completed training as a ship mechanic and 1 participant has completed training as an assistant for technical ship operation. All participants are students at Flensburg University and have trained in the simulator before, 4 participants are marine engineering students and 2 participants are nautical science students. All 6 participants have already worked at sea. The total time at sea reported ranges from 17 months to 4 years, with an average time at sea with 26.5 months (~2.2 years). 5 out of 6 participants reported work experience in an ECR. Experience duration ranges from 2 months to 2 years, with an average ECR experience 8.6 months. None of the participants have previously participated in usability testing or design workshops. An overview of the results of the workshop questionnaire can be found in Table B.6 in the appendix.

To ensure that the workshop was conducted with relevant end users, all participants were required to be engineers or technicians with experience in ECR operations. Their backgrounds ensured that the insights gathered were grounded in real-world operational knowledge.

The workshop lasted 4 hours. I acted as the moderator, while Mirco Schomburg, a colleague from DLR, observed participant behavior and took structured notes on key ideas and interactions. Dipl.-Ing. Holger Schönhoff, a research assistant at the Department of Mechanical Engineering, Process Engineering and Maritime Technologies at the Flensburg University of Applied Sciences, was the facilitator of the simulator session with the participants.

The workshop was both audio- and video-recorded. Audio was captured using the moderator's phone, while video was recorded with the moderator's iPad. All recordings were transcribed and subsequently deleted within 48 hours of the transcription's completion to ensure data protection. An overview of which phases of the workshop were recorded is provided in Table 3.3. All participants received a participant information sheet (see Appendix B.1) and signed a consent form prior to taking part (see Appendix B.2).

3.3.2.1 Workshop Sceanrio

A blackout scenario for the simulation was selected because such events represent high-stakes, high-load situations in ECRs, where time-critical decisions and rapid situational assessment are essential. During a blackout, multiple alarms are typically triggered simultaneously, requiring the crew to prioritize responses, interpret cascading failures, and coordinate actions under pressure. This creates a realistic setting with elevated cognitive demands, which is ideal for evaluating how well HMIs support user performance during emergencies.

By immersing participants in a high-pressure situation, the scenario helped to surface usability challenges, information gaps, and interface features that either hinder or help operators in managing workload. The aim was not to test operational performance, but to explore what information, interactions, and visualizations are most critical when mental load peaks. This made it possible to identify design needs for intuitive, low-friction interfaces that support users in regaining control quickly and safely.

We mimicked the blackout scenario in the ECR simulator at the University of Flensburg, using the model L11 of a tanker vessel. The simulated voyage went from Rotterdam to Gibraltar with the ship fully loaded and running at full head out, with a speed setting of 50. The scenario involved bad weather conditions and an electrical blackout, created by intentionally blocking a specific filter in the system to induce failure. The engine room and generator behavior were configured as follows: Diesel Generators 1 and 2 were initially connected, while Generator 3 was disconnected and on standby. The load-sharing system was set to automatic, Generator 3 would auto-start and connect if the load increased, and the last generator in the priority order (3 → 2 → 1) would disconnect if the load dropped. A manual override was available, allowing operators to connect or disconnect generators, and electricians were on standby to intervene if necessary. Participants experienced emergency procedures in response to system failures under realistic stress conditions. The following roles were assigned to the participant's chief engineer, two as Euler, second engineer, third engineer. The facilitator supervised and controlled the scenario, which lasted for 40 minutes.

3.3.2.2 Workshop Phases

Phase 1: Introduction

This phase introduced the participants to the research project and emphasized the importance of improving HMIs in ECRs. It also aimed to build rapport among the participants and immerse them in the scenario. The first phase lasted approximately 80 minutes.

Introduction and Context Setting

- **Objective:** Welcome participants, introduce the research project, the team and explain why improving HMIs in ECRs matters. Emphasize that this is a radical, user-led design session, participants are co-designers, not testers. Clearly communicate the workshop goals and have participants sign the ethics forms.
- **Method:** Presentation covering:
  - Human factors and HMI challenges in ECRs
  - Impact of poor design during emergencies
  - Goal: Co-create improved workflows for a blackout scenario

Icebreaker Activity

- **Objective:** Create a comfortable environment and build rapport among participants. Encourage playful, radical answers to open minds.
- **Method:** Light, non-workshop-related activity to ease participants into the session.

> "Hi! My name is ___ and if I could redesign one button in the ECR, it would be the ___ button, and it would do ___."

Empathizing through Simulator Session

- **Objective:** Immerse participants deeply into the context.
- **Method:** Participants experienced the scenario in a simulator.

Discussion / Focus Group Session

- **Objective:** Create an open discussion with participants.
- **Method:** Discuss briefly: "How did you experience the situation?". Each participant writes down thoughts or frustrations on sticky notes. After writing, they can sort the notes together on a board into categories or themes (e.g., information overload, alarm issues, response timing).

Phase 2: Idea Generation

In the second phase, participants generated a wide range of creative ideas for the ideal HMI workflow during a blackout scenario. This phase emphasized divergent thinking, peer feedback, and initial prioritization. This phase lasted approximately 30 minutes.

Brainstorming

- **Objective:** Enable participants to individually explore and generate creative ideas for an ideal HMI workflow in the blackout scenario, focusing on personal insights and diverse design possibilities.
- **Method:** Using the Crazy 8 method to create rough sketches or notes for ideas. Crazy 8 is a brainstorming method in which each team member visualizes eight possible solutions to a problem or question in eight minutes and eight fields on a sheet of paper [60].
- **Prompt Questions:**
  - What would a perfect workflow look like?

– What information or controls would you want instantly?
– What actions should be available immediately?

Discussion and Voting

- **Objective:** Have participants explain their ideas by going around the table. Facilitate discussions to review and refine initial ideas for creating a prototype in the next phase.
- **Method:** Each participant presents their crazy 8 sketches. Then, all sketches are circulated, and participants vote by placing 3–4 dots on features or elements they find most valuable. Together, the group reviews the top-voted ideas and agrees on a Top 5 list of features.

Phase 3: Prototyping Final Solutions

In the final phase of the workshop, participants created low-fidelity prototypes in small groups based on the ideas developed during the ideation phase. This phase lasted approximately 70 minutes.

Group Formation: Participants worked in pairs or groups of three.

Prototyping

- **Objective:** Develop visual and haptic prototypes of ideal HMI concepts.
- **Method:** Provide materials like paper, pre-cut UI elements (see Appendix B.5), cupboard etc. for groups to craft representations of their chosen concept. Each group has 30 minutes to prototype.

Scenario Walkthrough

- **Objective:** Evaluate the functionality of the new HMI ideas in a realistic situation.
- **Method:** Each group presents their prototype by "acting out" their prototype. Asking questions like: "Where do you look first?" "What actions are fast?"

Prototyping Review

- **Objective:** Facilitate discussions with the entire group about final prototype ideas. Sharpen and improve initial designs.

- **Method:** Each group presents their prototypes to the larger group. Facilitators initiates group discussion, "What works?" and "What could be improved?". Peers can get feedback for the group.

Wrap-Up and Closing Interview

- **Objective:** Capture final insights and reflections.
- **Method:** Semi-structured group interview asking:
  - What were key moments?
  - Which features could improve safety or efficiency?
  - What surprised you?

Participants were thanked and informed that the results may feed into future development and testing. The PowerPoint slides used during the workshop can be found in Appendix B.3.

3.3.2.3 Workshop Timeline

An overview of the co-design workshop timeline, including phases, methods, and materials used, can be seen in Table 3.3, the workshop was planned for four hours.

Table 3.3: *Overview of the Co-Design Workshop Timeline, including phases, methods, and materials used*

Time	Phase	Method	Description	Materials	Recording
~10 min	1: Introduction & context setting	Presentation & signing ethics forms	Introduce the project, explain workshop structure, highlight the importance of HMI improvement. Ask participants to sign consent forms.	PowerPoint slides, ethics forms	Not Audio Recorded
~10 min	1: Icebreaker activity	Participant round & prompt	Each participant shares a fun intro using a template: "Hi! My name is ___ and if I could redesign one button in the ECR, it would be the ___ button, and it would do ___."	Name tags	Audio Recorded
~40 min	1: Simulator session	Scenario experience	Participants go through the blackout scenario in the simulator.	ECR simulator setup	Not Audio Recorded
~20 min	1: Focus Group Discussion	Post-it sorting	Participants write down reactions on sticky notes, then sort them together on the board by theme.	Post-it notes, pens, board or wall space	Audio Recorded

Time	Phase	Method	Description	Materials	Recording
~20 min	Break	–	–	–	–
~10 min	2: Crazy 8 Brainstorming	Sketching	Participants sketch 8 fast HMI ideas in 8 minutes. They are encouraged to think broadly and creatively.	Crazy 8 templates, pens	Not Audio Recorded
~20 min	2: Discussion & Dot Voting	Sharing & voting	Participants present their ideas, then vote on features or elements they find most important using stickers or markings.	Sketches, sticker dots, voting board	Audio Recorded
~20 min	Break	–	–	–	–
~30 min	3: Group Prototyping	Paper prototyping in small groups	Groups of 2–3 participants sketch improved HMI interfaces using materials provided.	Paper templates, sticky notes, markers, physical props	Not Audio Recorded
~15 min	3: Scenario Walkthrough	Enacted walkthrough	Each group presents their prototype by "acting out" their prototype. Ask questions like: "Where do you look first?" "What actions are fast?"	–	Audio Recorded
~20 min	3: Prototyping Review	Open discussion	Peers give feedback. Discuss strengths, improvements, and insights.	Group prototypes	Audio Recorded
~10 min	3: Wrap-up & Closing Interview	Semi-structured group interview	Reflect on workshop experience: "What worked well?" "What should be improved?" "What surprised you?"	Optional feedback forms	Audio Recorded

3.3.2.4 Workshop Analysis Procedure

The transcripts of the workshop, the observer notes, and all materials produced by participants during the workshop were analyzed using the following process:

- **Stage 1:** Identifying codes, that are, descriptive keywords for each participant's opinion expressed during the workshop; and
- **Stage 2:** The identified codes were grouped into categories according to each phase of the workshop; and
- **Stage 3:** Based on these categories and the research question, the assessment criteria were created and the codes were grouped into them; and
- **Stage 4:** an emerging theme was selected for the codes under each assessment criterion.

This method is a customized and adapted version of the approach developed by Choe et al., used in their workshop on co-designing user interfaces for conflict management on OpenStreetMap [61].

For example, during stage 1 of analyzing the workshops transcripts, the keywords/phrases such as "*Too many alarms at once*", "*Hard to silence alarms*", and "*Confusing or misleading alerts*", "*Overlooked important alarms*", "*Noisy and stressful environment*", "*No differentiation between alarms*", "*No smart sorting of alarms*" were identified.

These identified codes were then in stage 2 sorted under themes, this was done for each workshop phase: "*Too many alarms at once*" and "*Hard to silence alarms*" were sorted under the theme Alarm Handling and Communication.

During stage 3 of the analysis, the codes were categorized into relevant assessment criterion. These assessment criteria were based on the research question and the themes: "*Too many alarms at once*" and "*Hard to silence alarms*" were categorized into Alarm Handling & Information Management. This step was made to refocus the results on the research question.

During stage 4 of the analysis, for each assessment criterion, all participant codes were reviewed looking for patterns. Then a concise theme was created that summarizes this feedback clearly, and this was repeated for each criterion. As an example the codes under "*Cognitive Load*", such as: "*Too much alarm info leads to overload",* "*Overwhelming alarm lists*", "*Hard to know where to focus*", "*System should suggest causes and next steps*", "*Wishing for AI assistant provides explanations*" and "*Different combinations of alarms change context*" can be summarized in "*Users overwhelmed by unsorted, unclear alarms and seek clearer guidance and system support*". This captures both the problem (overload, stress, confusion) and the wish (guided support, explanations, context).

Chapter 4

Results and Analysis

4.1 Interview Results and Analysis

The comprehensive analysis of the interviews using Braun and Clarke's Reflexive Thematic Analysis (RTA). From this analysis, the following themes have been formed.

- **Experiential knowledge**
- **Visual clarity**
- **Automation**
- **Communication**
- **Information overload**
- **Lack of standardization**

Going more into detail about each theme, the theme **"Experiential knowledge"** describes the experiential knowledge and physical perception as the foundation of system control. Despite modern interfaces and increasing automation, physical experiential knowledge remains indispensable. Interviewee 1 said "*The problem with remote shipping is that you can't see when it is dripping somewhere.*" explaining that without people on board, small warning signs like leaks or unusual conditions might go unnoticed, making it harder to spot problems early. He further said "*But in the end, someone has to be there to wield the wrench and get things done*" explaining that you will always need people on the ship who can fix machines directly. Interviewee

1 and 2 were also skeptical about remote ship operation, where the crew is not physically present, "*Would you sail across the Pacific with 10,000 people without a crew?*" (Interviewee 2). All interviewees emphasize that hearing, touch, vibration and direct observation are crucial for fault detection and system diagnosis, "*You have to perceive the machine with all your senses.*" (Interviewee 1).

Digital interfaces provide only abstract representations of machine conditions, lacking the sensory richness of on-site interaction. Interviewee 2 illustrated this by saying, "*Pump runs out of round [...] you feel it at first, because it vibrates*", meaning that subtle mechanical issues are often detected through bodily perception. Interviewee 1 added that in digital systems, multiple alarms can obscure the true source of a problem: "*Most of the time, you ignore 20,000 alarms and look for the first error.*" Here, experience and intuition are essential for identifying faults. This reliance on physical sensing becomes especially important in stressful situations, which is why experienced engineers still trust their instincts over digital readouts. Interviewee 4 expressed concern that less experienced crew member, who are more accustomed to remote digital tools, may lack this embodied understanding. These insights suggest that the core limitation of remote interfaces is their reduced informational depth, they should aim to support, rather than replace, physical interaction and sensory awareness.

Continuing with the next theme **"Visual clarity"** which explains the visual clarity and functional simplicity as the key to actionable HMIs. All interviewees emphasize the importance of visually clear, functionally reduced interfaces for fast and safe action in the machine control room. Interviewee 3 said, "*But I believe that a display that you can see out of the corner of your eye is good*" explaining that clear symbols and figures who showcase exactly what is going on without needing him to interpret it would support him. Especially in stressful situations, such as alarms or malfunctions, simple navigation, central visualization and intuitive feedback are crucial, "*How many clicks do I need? How many screens do I have to click back and forth?*" (Interviewee 5). Graphic elements such as color gradients, gradient curves or bar charts support situational understanding. Complex menu logic, cryptic codes and split screens, on the other hand, lead to operating errors and cognitive load. Interviewee 4 mentioned the principle "*KISS, Keep it simple and stupid as possible, that always applies to our seafarers.*" underlining the desire for clear, understandable systems.

The next theme, **"Automation"**, explains that even though automation is generally seen as helpful, for example, to sort alarms or support maintenance, all interviewees also had concerns. They said that digital systems do not always understand the situation well, and sometimes they are unreliable or make mistakes. Touchscreens and AI, in particular, made some feel unsure, especially during critical moments. Interviewee 3 described a situation in which dirty fingerprints on a touchscreen, left from working in the engine room, accidentally triggered an alarm. It took some time to identify the cause, as the team initially believed it was a technical fault, only to later realize the issue was due to the unclean touchscreen. Most participants said that they only trust digital systems if there are clear backup options, like paper printouts, manual controls, or other ways to take over if something goes wrong. As interviewee 4 said, "*If you run out of ribbon, and you have blackout [...] you can read [...] what was your last alarms.*". They emphasized that real trust is built through experience, not just technology. Another point raised was that automation does not really reduce workload. Things like the ship's age, how many crew members are on board, and how complex the systems are still having a much bigger impact on how much work there is. Some participants also mentioned that automation can make people too relaxed or too dependent on systems, which can be dangerous if something fails. They warned against "system blindness," where people stop thinking critically because they rely too much on the screen. Interviewee 4 mentioned an accident where a boat hit the reef because the navigator, due to an incorrect zoom level, had not seen a reef that was in the way. So, while automation has benefits, it also needs to be designed in a way that supports manual control and clear feedback, so in consequence it should give users confidence in their action.

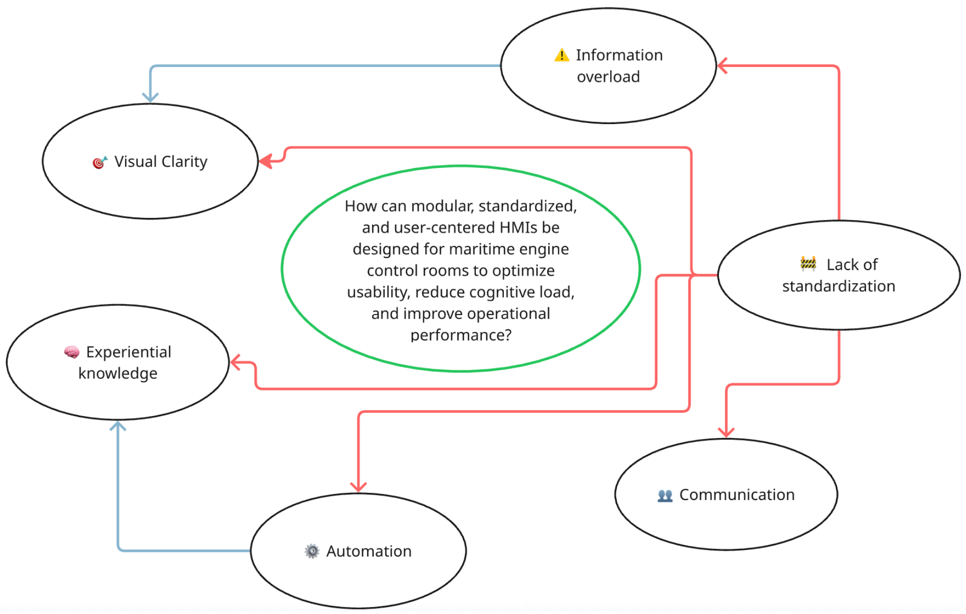
The theme **"Communication"** also comprises social dynamics in the control room. Clear and effective communication is very important for safe and smooth operations in the engine control rooms. The interviewee 4 highlighted how cultural hierarchies and communication styles can lead to misunderstandings, even when technical systems such as alarm signals clearly indicate a problem. He described a case in which a subordinate employee responded affirmatively with "Yes Sir, Yes Sir" even though he clearly did not understand the instructions. This behavior reflects a culturally rooted tendency towards deference and respect for authority, which in some hierarchies can discourage questions or the expression of uncertainty. Such submissive affirmations often serve to show respect or avoid confrontation, but can compromise safety when they mask misunderstandings or uncertainties. In high-risk environments, like the ECR, this poses risks as operators may act without fully understanding the situation or instructions. Interviewee 4 pointed out that this dynamic was particularly noticeable in crews with strong hierarchical norms, where it is considered more appropriate to say "yes" than to admit confusion. Another issue is that the control room is sometimes not only a workspace but also used for social conversations or meetings. This can cause noise and distractions, especially in stressful situations. "*You can prevent that by making a small conference room.*", interviewee 2 said. Furthermore, when someone from the engine control room calls someone in the engine room via phone, communicating can be difficult during to the background noises which makes giving instructions or receiving information difficult interviewee 2 explained. To improve focus and safety, participants suggested having more structured communication, better sound conditions, and a separate room for meetings and discussions.

The theme **"Information overload"** is about information overload and cognitive relief through targeted interface design. Interviewees explained that the engine control room systems show a lot of information at once, alarms, data, and complex menus. "*So sometimes less information is more.*" said interviewee 4 and "*The presentation of information must be intuitive, not invasive.*" said interviewee 2. Information should be shown based on what the operator needs at that moment. Like when a lot of errors and their consequential error come in, "*The computer should sort out what is a consequence and what is a cause.*" Interviewee 1 said. No clear feedback also increases the workload, "*For example, that I perform a switching operation via a touchscreen and don't get sufficiently clear feedback [...].*" (Interviewee 3). Examples mentioned for improving the work in the ECR include modular screen layouts, displays that highlight only the most important data and a calm enviroment. The goal is to reduce stress and help people act quickly and confidently. As Interviewee 1 said, a good interface is clear with graphically supported states (sensors, lines, color).

The theme **"Lack of standardization"** describes a risk for orientation and confidence in action. The interviews show that the variety of operating concepts, both software and hardware, is a central problem for safe and efficient work in the control room. "*Alfa Laval's separator works very differently than Westfalia's.*" as Interviewee 1 said, and "*The interface was different for each ship.*" Interviewee 2 said. Operating logics differ not only between manufacturers, but also between individual ships of the same shipping company. Interviewee 1 explained a situation where error messages had codes that you had to look up if you were new to the ship, "*Error message t 95 03 - you have to look in the manual to find out what this means.*". This heterogeneity leads to uncertainty, high training costs and potential operating errors. Especially in critical situations, the necessary orientation is often lacking. The interviewees therefore emphasize the need for modular and standardized HMIs to shorten acclimatization times and increase safety.

The theme map (seen in Figure 4.1) visually organizes the six final themes from analysis in direct relation to the research question, which is stated in the middle of the map in a green circle. It not only shows how each theme addresses different dimensions of my research question, but also highlights key interconnections between themes.

Figure 4.1: Overview of themes identified from the interview analysis



The blue arrows illustrate how one theme influences another, while the red arrows illustrate how these affected themes originate from the root problem of "Lack of Standardization".

"Automation" influences "Experiential knowledge" because "Automation" influences how much reliance is placed on embodied expertise. Excessive automation can erode hands-on skills and perception-based control. Furthermore, "Information overload" influences "Visual clarity". High information density necessitates clarity and simplification. Thus, to mitigate overload, good visualization and structure are essential

The theme "Lack of standardization" acts as a core barrier that impacts every other theme. Visualized by the red arrows. It is a cross-cutting structural issue that amplifies or complicates problems in all other areas of

HMI interaction.

“Lack of standardization” is a foundational issue that undermines usability, trust, clarity, efficiency, and teamwork visualized by the red arrow’s. Each theme reflects a downstream consequence of this root problem. It is a cross-cutting structural issue that amplifies or complicates problems in all other areas of HMI interaction.

“Lack of standardization” influences “Experiential knowledge” because inconsistent systems force engineers to constantly rely on experience and sensory knowledge because interfaces can not be trusted or interpreted uniformly. Without standard indicators or logic, “Every ship is unique” as interviewee 1 said, the experience becomes the fallback system.

“Lack of standardization” influences “Visual Clarity” because without shared design standards, visual and structural clarity suffers. Each system uses different display logics, colors, layouts, which prevents intuitive use and increases errors. As interviewee 5 staged “*How many clicks do I need?*”, the unclarity of how long it takes to reach the user’s goal is a direct symptom of inconsistent user interfaces.

Different systems present information differently, with no consistent hierarchy or relevance filter, which is why “Lack of standardization” influences “Information Overload”. This adds mental effort, especially in critical situations. The lack of standard filtering and visual conventions could lead to higher cognitive load.

“Automation” gets influenced by the “Lack of standardization” because inconsistent automation implementations across systems make it hard for users to trust or control them. Without standards, automation logic is not transparent and varies by ship or manufacturer.

Lack of standardization affects “Communication”, moreover the shared understanding within multinational crews. When everyone is interpreting interfaces differently due to lack of uniform design, coordination and communication suffer. As Interviewee 4 said, “*Then he didn’t understand you, and he didn’t understand the alarm either.*”, it is not just language, but interface logic that is part of the problem.

4.1.1 HMI design principles

The following HMI design principles can be derived from the interviews.

1. **Preserve Multisensory Awareness and Embodied Interaction**
   Derived from: Experiential Knowledge

Experienced engineers rely on sensory cues like vibrations, smells and sounds to detect subtle faults that screens alone may not convey.

- Avoid over-reliance on digital displays, maintain access to real-world cues.
- Design interfaces that complement and not replace human senses.
- Incorporate sensory feedback (e.g., vibration, audible alerts) that reflect real-world conditions.
- Enable physical inspection and manual overrides where appropriate.
- Support redundancy by allowing both digital and analog means of monitoring.

2. **Ensure Visual Clarity to Reduce Cognitive Load**
   Derived from: Visual Clarity & Information Overload
   In time-sensitive situations, operators need to understand the system state quickly and accurately to avoid mistakes.

   - Apply the KISS principle (Keep It Simple and Stupid as possible).
   - Use "at-a-glance" dashboards for rapid overview, without overwhelming detail.
   - Highlight only relevant, context-sensitive information.
   - Reduce unnecessary steps, clicks, or deep navigation layers.
   - Ensure visual grouping reflects operational logic.

3. **Design for Trust and Transparent Automation**
   Derived from: Automation
   Automation can save time, but people still want to be in control.

   - Let automation assist, not replace human control.
   - Provide clear feedback on actions taken.
   - Always offer manual fallback options.
   - Avoid unpredictable automation.
   - Keep the user in the loop.

4. **Standardize Interfaces Across Systems**
   Derived from: Lack of Standardization
   Every ship and system is different. That makes it hard for crews to learn fast and work safely.

- Use the same buttons, colors, and layout across systems.
- Design in modules, so screens can be reused.
- Avoid hidden meanings or random codes.
- Ensure that standards are openly accessible and not locked behind paywalls, so designers, operators, and smaller stakeholders can implement them without financial or bureaucratic barriers.

5. **Support Clear Communication in Multinational Teams**
   Derived from: Communication
   Clear communication is essential in international teams, but cultural norms and social habits can interfere with information exchange and safety.

   - Reduce communication barriers by keeping interface language simple and standardized.
   - Address hierarchical dynamics by encouraging clarification requests in training and system prompts.
   - Integrate communication tools into HMIs (e.g., push-to-talk, noise filtering) to improve clarity in noisy environments.
   - Separate operational zones from social areas to reduce distraction and noise.
   - Include visual or written confirmations for critical instructions to prevent misunderstandings.

6. **Design for Contextual Prioritization and Alarm Management**
   Derived from: Information Overload & Automation
   Too many screens, numbers, or alarms make it hard to think and act, especially in an emergency.

   - Implement smart alarm grouping (show root cause first, filter consequences).
   - Use visual hierarchy to show what is urgent vs. informative.
   - Present situation-based views (e.g., startup mode vs. emergency mode).
   - Allow operators to customize display filters or predefine "quick views".

7. **Design for Operational Resilience, Not Just Efficiency**
   Cross-theme integration
   Things go wrong at sea, power cuts, errors, confusion. The system should still help, even then.

   - Design for emergencies, not just routine use.
   - Keep some analog tools like paper checklists or manual controls.
   - Make systems resilient, not just fancy.

4.2 Workshop

4.2.1 Workshop Results

4.2.1.1 Workshop Results Phase 1

In phase 1 of the workshop, participants were introduced to the research project. The phase aimed to build rapport among the participants and immerse them in the scenario. After the Introduction to the topic, a light, non-workshop-related activity was used to ease participants into the session. To do this, everyone was asked to introduce themselves and tell which button in the ECR they would redesign and what would it do. Answers that participants gave included: A problem-solving button, a button that activates AI-based help, which sorts and shows a list of alarms in the order they should be solved, a button that plays different sounds based on the system, so you can hear which alarm is active, a magic problem-finding button that checks every engine parameter and, when asked about a problem, tells you exactly what to do.

After the Icebreaker activity, participants experienced the blackout scenario in the simulator. Following the simulator scenario, participants were asked how they experienced the situation, with a focus on the interaction with the HMI. Thoughts were written down on sticky notes. These sticky notes were then sorted by the participants into categories, which you can see in Table 4.1. DG stands for diesel generator and ME for main engine.

Table 4.1: Card sorting results

Solutions/ Organization	What worked	Problems
Button you can press to show the actual flow	Systems give a good overview, but graphics could be better	High noise level due to many alarms that have not been silenced
1st priority should be at the top of the alarm panels	Easy to switch valves and progress of opening + closing	Important information are not always obvious (start air DGs & ME → priority of alarms)
Seeing real-time changes of parameters		Hard to acknowledge some alarms → complicated to find them
Different ways to acknowledge alarms to recognize more important alarms		Not visible for some functions if they executed or not (e.g., filter % blocked)
		Alarm ”Start Air Pressure Low for DG2” was not easy to see
		No alarm structure regarding the priority of the alarms
		A lot of information (alarms) on the panel
		Status of filter not visible
		Confusing overview of systems

4.2.1.2 Workshop Results Phase 2

In the second phase, participants generated a wide range of creative ideas for the ideal HMI workflow during a blackout scenario. This phase emphasized divergent thinking, peer feedback, and initial prioritization.

For brainstorming, participants expressed their ideas doing the crazy 8 method, each participant sketched or wrote eight different ideas within eight minutes. After 8 minutes, the participants presented their crazy 8 sketches. The sketches were then circulated, and participants voted on their favorite elements using 3 voting dots.

See Appendix B.7 for results of crazy 8 method per participant, including the dots from the dot voting.

Reviewing the results form the crazy 8 method ideas for intelligent support systems and search tools included a “search engine” for searching within the manuals (P3), which received three dots in the dot voting. Another idea was an assistant capable of intelligently answering all questions and helping to solve problems by giving suggestions on what to do (P6, P3, P1), this idea received one dot. Additionally, an intelligent pre-alarm system that indicates when a problem may occur in the future was suggested (P6), receiving two dots. Lastly, an automated system that displays intervals for cleaning time slots of the fillers, separator, etc., was proposed (P6), but it did not receive any dots.

Ideas that can be summarized under visual system mapping and fault localization include a digital system plan that provides the exact location of an issue (P6, P5), which received one dot in the dot voting. Another idea was a function that displays the actual situation in real time, showing the flow and indicating which filter, pump, etc., is active, on an overview panel (P5, P4), this idea received three dots. An additional suggestion was an overview of all filters and pumps, showing their blockage status (P5). Furthermore, an overview of WOLKE (Bowle) was proposed, displaying status information for each engine. Elements of WOLKE are water cooling (Wasser), lub oil (Öl), start air (Luft), fuel oil (Kraftstoff) and electricity (Elektrizität). This idea got 2 dots.

Ideas that fall into the category of alarm system enhancements include showing alarms sorted by priority (P1, P5, P4, P2, P3), which received two dots in the dot voting, and providing an alarm listing option by time or priority (P5). Another suggestion was to implement different buttons for acknowledging alarms of varying importance, so that critical alarms, such as a main engine (ME) shutdown, can be clearly recognized (P1). It was also proposed that the system should recognize shared system dependencies; for instance, if multiple systems rely on the same supply pump, the system should detect and display if this pump is not functioning (P1). To give a better overview of a system where an alarm occurs, one idea suggested showing detailed information such as: diesel generator (DG) 2, start air low, bottle pressure, compressor startup, pressure, and engine status (P2), which received two dots. Additional ideas included having different alarm sounds for the ME, DG, and supply systems like freshwater (FW) or boiler (P5), highlighting flow issues visually (e.g., red for low pressure) (P1), and creating an extra panel for the electrician with alarms relevant to them (P4), which also received two dots.

Lastly, it was suggested to show important alarms for a system directly at that system's operating panel (P2).

User Interface (UI) design and visual feedback ideas included using a slightly different color for buttons, such as the reset button, once they have been pressed and executed (P4), red or green indicators on filter symbols to show their status (P4), and creating a more intuitive and visually improved interface for the systems (P1).

Ideas for system structuring and startup support were proposed by participant 4, suggesting the organization of system structures by machinery type, system type, or priority type, along with a checklist for the starting process of generators or the main engine. This checklist would include parameters with either indication ranges or tick boxes (P4).

4.2.1.3 Workshop Results Phase 3

In the final phase of the workshop, participants created paper prototypes in small groups based on the ideas developed during the ideation phase and focused on prototyping those ideas that were most important to them. They were divided into two groups of three, ensuring a mix of backgrounds by assigning one Nautical student to each group. The goal was to design HMI concepts that would support the scenario experienced in the simulation. To represent their ideas, participants used materials such as paper, cardboard, and precut UI elements.

After the prototyping, participants evaluated the functionality and usability of their prototypes through a scenario walkthrough.

Results of the prototyping phase from Group 1 (P3, P4, P5) can be seen in Figure 4.2 and Figure 4.3.

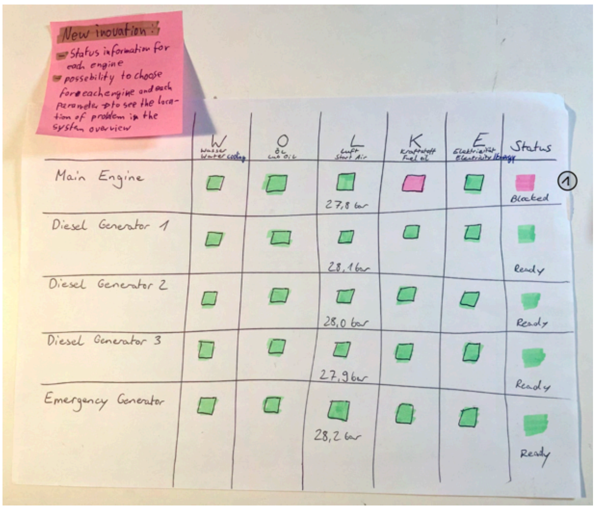


Figure 4.2: Prototype Part 1 from Group 1: Overview panel showing the WOLKE diagram

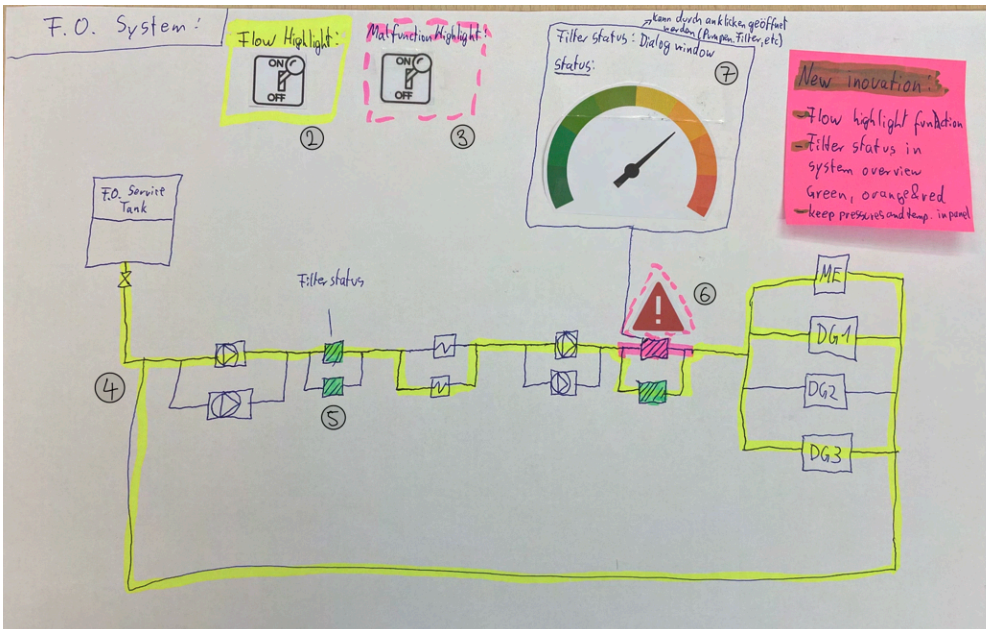


Figure 4.3: Prototype Part 2 from Group 1: System overview of the Fuel Oil System

The paper prototype in Figure 4.2 represents a panel for overviewing the WOLKE diagram. The WOLKE diagram displays the status information for each engine. In a table format, the horizontal headings include *Water Cooling*

(Wasser), *Lub Oil (Öl)*, *Start Air (Luft)*, *Fuel Oil (Kraftstoff)*, *Electricity (Elektrizität)*, and *Status* (blocked or ready), while the vertical axis lists the engines: *main engine (ME)*, *diesel generator 1 (DG1)*, *diesel generator 2 (DG2)*, *diesel generator 3 (DG3)*, and the *emergency generator*. Each cell in the table contains a green or red light indicator, green meaning the component is available and functioning correctly, red indicating a problem or that the component is blocked or not ready. This is a concept presented by P5 during phase 2 of the workshop.

To assess engine readiness, users must scan the row for each engine: if all lights are green, the engine is ready to operate, whereas any red light indicates that a specific system is not functional, and the engine may not be ready.

Numbers have been added to the image to explain elements in more detail. When the user clicks on the "Blocked" status, they are guided to the system overview (see number 1 in Figure 4.2) to see directly why the engine is blocked.

Figure 4.3 shows the system overview for the Fuel Oil System. In this overview, the user has two switches: one switch turns on a flow path highlight (see number 2 in Figure 4.3), which also puts all unused components in the background. The other switch activates a malfunction highlight (see number 3 in Figure 4.3), showing which filter is blocked.

Below the switches is the system overview (see number 4 in Figure 4.3) of the fuel oil service tank. The flow highlight switch is turned on, and a yellow highlight shows the flow path. Boxes (see number 5 in Figure 4.3) represent the filters, when highlighted green, they signal that everything is in order. An alert symbol and pink highlight (see number 6 in Figure 4.3) signal that a filter is blocked. The flow line is also highlighted pink due to the activated malfunction highlight.

A dialogue window can be opened (see number 7 in Figure 4.3) by clicking on the alert symbol; it shows the status of the filter. If the gauge pointer is in the green zone, the filter is ready or in use; if in the orange zone, it can be used for a limited time; and if in the red zone, the filter is blocked.

Results of the prototyping phase from Group 2 (P1, P2, P6) can be seen in Figure 4.4.

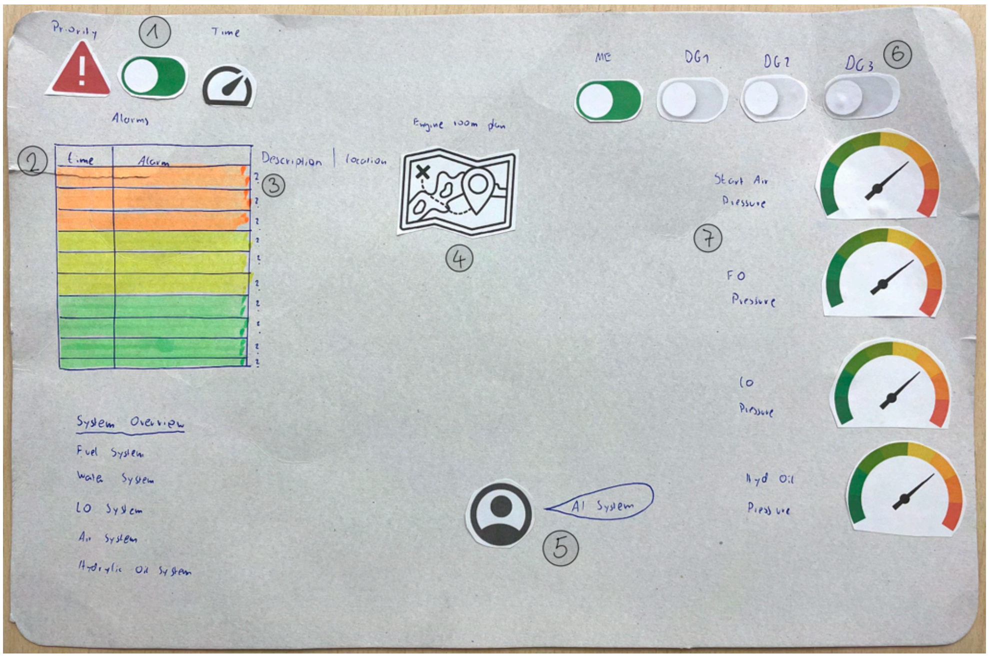


Figure 4.4: Prototyping results from Group 2

With the switch (see number 1 in Figure 4.4), the user can choose to sort the alarm listing by either priority or the time the alarm occurred. In the alarm listing (see number 2 in Figure 4.4), the color of the highlight indicates the priority: orange for high, yellow for medium, and green for low.

Next to each alarm, a question mark icon is shown (see number 3 in Figure 4.4); clicking it provides a more detailed description of the alarm and its location. Furthermore, Group 2 implemented an interactive engine room plan (see number 4 in Figure 4.4), which, when clicked, presents a visual model of the ship's layout and guides the user to the location of the issue causing the alarm.

Their paper prototype also includes an AI assistant (see number 5 in Figure 4.4) that users can contact for guidance and support. Number 6 in Figure 4.4 indicates Group 2's interpretation of the WOLKE principle. When the switches for ME, DG1, DG2, and DG3 are turned on, the user can view the state of start air pressure, fuel oil pressure, lub oil pressure, and hydraulic oil pressure on a gauge (see number 7 in Figure 4.4) for each engine.

After each group presented their prototype to the others, a semi-structured group interview was conducted. The analysis of the transcripts will be presented in the following section.

4.2.2 Workshop Analysis

The transcripts of the workshop, the observer notes, and all materials produced by participants during the workshop were coded per phase in stage 1. These codes were then grouped into categories in stage 2 of the analysis (see full analysis in Appendix B.8). An example of this categorization is visualized in Figure 4.5, which shows part of the categories and codes from phase 1 that were developed during stage 1 and grouped in stage 2.

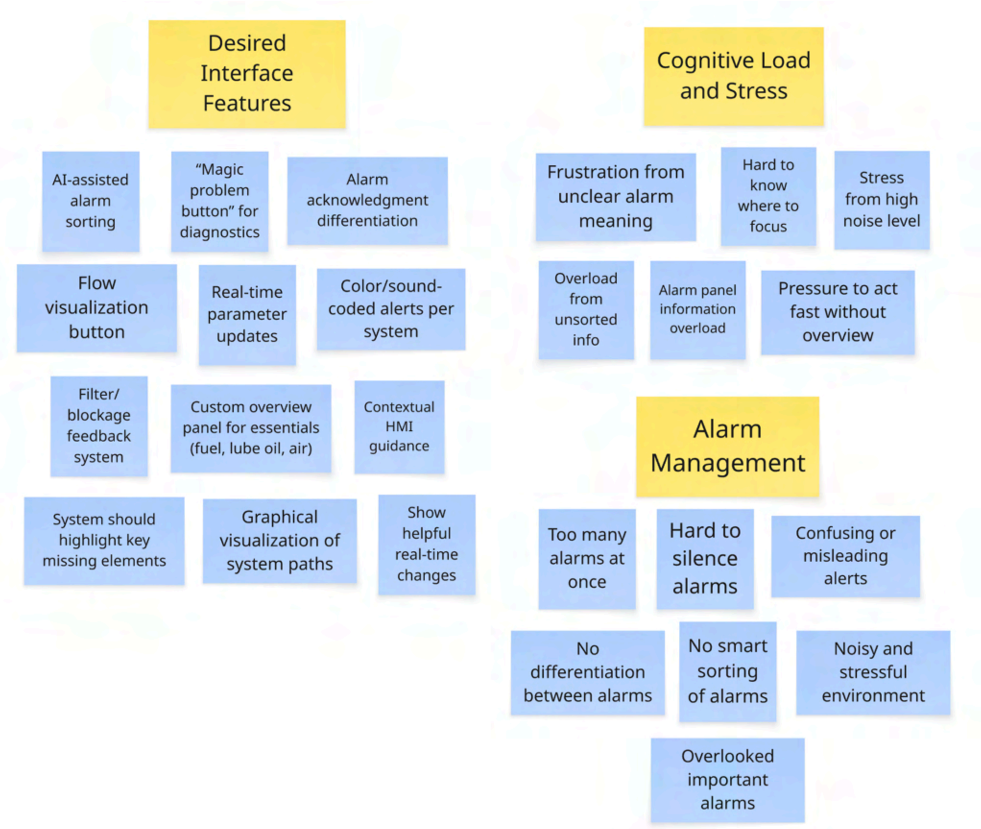


Figure 4.5: Example of analysis from stage 1 and 2

Based on the categories from stage 2 and the research question, the following assessment criteria were derived:

- Usability & Interface Clarity
- Cognitive Load
- Operational Performance Support

- Standardization & Consistency
- Modularity & Customization
- Alarm Handling & Information Management
- Feedback Workshop

The codes were grouped into these criteria. An example of this grouping is visualized in Table 4.2 (see full analysis of stage 3 in Appendix B.9). If it was unclear whether a code referred to a designed feature or an existing problem, the phrasing "wishing for" or "should" was added to the code for clarification.

Table 4.2: Example of the codes grouped into the assessment criteria

Assessment criteria	**Code**	**Phase**
Alarm Handling & Information Management	Wishing for alarm acknowledgment differentiation	1
Alarm Handling & Information Management	Wishing for detailed alarm information view	2
Cognitive Load	Wishing for "Magic problem button" for diagnostics	1
Cognitive Load	Hard to find cause of problem	1
Modularity & Customization	Retrofitting engine and pipes to implement sensors for displaying flow	3
Modularity & Customization	Implementing a system plan seems possible only on newer systems	3
Operational Performance Support	Wishing for fuel flow visualization, switchable between overview and detail	2

In stage 4, themes were developed by going through each *assessment criterion* and reviewing all the codes and sub-themes grouped under that criterion. Then, the **main insight** was identified, a summarizing statement or central idea that captures participants' perception.

Alarm Handling & Information Management

From the assessment criteria codes of *Alarm Handling & Information Management*, the following theme was identified (see all codes in Table 4.3).

Theme: Participants experienced the alarm system as confusing and poorly organized. They wanted smarter, AI-based sorting, clearer visibility of important alerts, and consistent controls across panels, including differentiated alarm acknowledgment and detailed alarm information views. They also emphasized that an alarm list where the alarms are sorted by priority would improve their reaction time and overall awareness.

Table 4.3: Codes grouped under the assessment criterion "Alarm Handling & Information Management"

Code	Phase
Lack of alarm prioritization	1
Unclear alarm source	1
Overlooked important alarms	1
Hard to silence alarms	1
No smart sorting of alarms	1
Confusing or misleading alerts	1
Wishing for AI-assisted alarm sorting	1
Alarms should be sorted by priority	2
Alarms should stay visible until addressed	2
Confusion due to silencing alarms from different panels	2
Important alarms should be displayed prominently (e.g., at system panel/switchboard)	2
Wishing for alarm acknowledgment differentiation	1
Wishing for detailed alarm information view	2

Cognitive Load

From the assessment criteria codes of *Cognitive Load*, the following theme was identified (see all codes in Table 4.4).

Theme: Participants experienced high cognitive load due to alarm overload, unclear priorities, and lack of guidance. They expressed a need for AI-driven support systems that assist in diagnosis, guide attention, and simplify decision-making, while still allowing human control. Visual clarity, contextual pre-alarms, and checklists were emphasized to reduce mental load and support quicker, more confident action. The WOLKE diagram was emphasized a lot because it provides a quick visual overview of the operational readiness of each engine on the ship. Furthermore, visualization of the fuel flow allows users to see where filters are blocked.

Table 4.4: Codes grouped under the assessment criterion “Cognitive Load”

Code	**Phase**
Wishing for “Magic problem button” for diagnostics	1
Hard to find cause of problem	1
Overwhelming alarm lists	1
Noisy and stressful environment	1
Overload from unsorted info	1
Hard to know where to focus	1
Stress from high noise level	1
Frustration from unclear alarm meaning	1
Pressure to act fast without overview	1
Wishing for flow path backgrounding of unused components	3
Wishing for AI assistant provides explanations	3
Too much alarm info leads to overload	3
Skepticism about AI prioritization accuracy	3
Different combinations of alarms change context	3
Wishing for guided attention to next relevant system screen	3
Clear overview reduces time spent searching	3
System should support, not replace, human judgment	3
Too much info on one panel is counterproductive	3
Valuing clear prioritization in critical situations	3
AI that searches the manuals to suggest possible causes of alarms for solving them	3
WOLKE diagram helps quick thinking	3
Wishing for AI system for diagnosing and suggesting solutions	2
Wishing for checklists linked to alarms	2
System should suggest causes and next steps	2
Wishing for pre-alarms based on data trends (e.g., slow pressure drop)	2
Wishing for contextual HMI guidance	1
Wishing for flow visualization button	1
Wishing for real-time parameter updates	1
Alarm panel information overload	1

Feedback Workshop

From the assessment criteria codes of *Feedback Workshop*, the following theme was identified (see all codes in Table 4.5).

Theme: Participants experienced high cognitive load due to alarm overload, unclear priorities, and lack of guidance. They expressed a need for AI-driven support systems that assist in diagnosis, guide attention, and simplify decision-making, while still allowing human control. Visual clarity, contextual pre-alarms, and checklists were emphasized to reduce mental load and support quicker, more confident action. The WOLKE diagram was emphasized a lot because it provides a quick visual overview of the operational readiness of each engine on the ship. Furthermore, visualization of the fuel flow allows users to see where filters are blocked.

Table 4.5: Codes grouped under the assessment criterion “Feedback Workshop”

Code	Phase
Group discussion boosts creativity and idea quality	3
Prototypes increase problem identification	3
Appreciating realistic scenario-based designing	3
Recognizing enhanced results from group interaction	3

Modularity & Customization

From the assessment criteria codes of **Modularity & Customization** the following theme was identified (see all codes in Table 4.6).

Theme: Participants strongly valued interfaces that can be adapted to different roles, preferences, and experience levels. They emphasized the need for customizable system views, sortable and clickable content, and interactive visual tools to support learning, task performance, and scalability across ship types and scenarios.

An interactive map of the ship was suggested to display the exact location of the machines and highlight where problems occur. This would allow users to quickly identify where they need to go. The map should be updatable to reflect changes on board and would significantly support faster orientation and familiarization, especially when working on a new ship.

Table 4.6: Codes grouped under the assessment criterion "Modularity & Customization"

Code	Phase
Custom overview panel for essentials (fuel, lube oil, air)	1
Wishing for option to switch alarm list sorting (e.g., time vs. priority)	2
Wishing for Contextual system overview on alarm → On-click access to detailed system data	2
Dedicated panel for electricians	2
Wishing for sorting systems by machinery type, priority, or function	2
Interactive engine room plan	3
Wishing for click-through from overview to system detail	3
Need for updatable digital system plans	3
Interface should support both novices and experts	3
Interactive maps would improve onboarding and training	3
One design can support multiple scenarios	3
User should be able to update system content	3
Retrofitting engine and pipes to implement sensors for displaying flow	3
Implementing a system plan seems possible only on newer systems	3

Operational Performance Support

From the assessment criteria codes of **Operational Performance Support** the following theme was identified (see all codes in Table 4.7).

Theme: Participants stressed the importance of real-time feedback, system overviews, and intelligent support tools to enhance situational awareness and decision-making. They highlighted the need for visual and searchable access to system status, fault locations, and procedural knowledge, while emphasizing the value of human oversight in complex or variable scenarios.

They emphasized the need for startup checklists with indicators, a real-time system flow overview, clear visual links from blocked statuses to root causes, and engine state gauges per subsystem (e.g., start air, oil) for visualizing pressure. Participants also suggested switchable fuel flow visualization, toggling between overview and detail, to immediately detect blocked filters.

Table 4.7: Codes grouped under the assessment criterion "Operational Performance Support"

Code	Phase
Wishing for fuel flow visualisation, switchable between overview and detail	2
Sorting filters and flow visualization would help workflow	3
Missing real-time feedback	1
System should highlight key missing elements	1
Filter/blockage feedback system	1
Show helpful real-time changes	1
Overview screens would help chiefs gain fast situational awareness	1
Wishing for search engine for manuals	2
Wishing for database system for context-specific help (e.g., "what should I do?") based engine manual	2
Wishing for Integrated technical knowledge database	2
Wishing for Wolke system overview, shows readiness to start (fuel, air, lube, etc.)	2
Wishing for startup checklists with indicators	2
Wishing for real-time system flow overview	2
Filter blockages and pump problems should be visible and traceable	2
Display component status (e.g., pressure, mode)	2
Better search engine for technical manuals	2
Chief needs clear overview for delegation	2
Maintenance time slots should be trackable and acknowledged via UI	2
Wishing for quick visual access to component status	3
Alarm overview would improve reaction time	3
Wishing for Wolke for start-readiness overview	3
Wolke would help fast decision-making in stressful situations	3
Chief engineer needs fast situational overview	3
Training AI for alarm priority could take a lot of time	3
Skepticism towards accurate Alarm priority list made by AI	3
Alarm priorities change with different combinations of alarms	3
To identify problems, a system plan of the area where the problem originates would help	3
Wishing for blocked status links to root cause	3
Wishing for engine state gauges per subsystem (start air, oil, etc.)	3

Standardization & Consistency

From the assessment criteria codes of **Standardization & Consistency**, the following theme was identified (see all codes in Table 4.8).

Theme: Participants emphasized the need for consistent alarm structures, including color and sound coding, to improve clarity and reduce ambiguity. They advocated for standardized procedures and system indicators to support quick understanding across teams and systems. Also, wishing for dependency recognition among systems.

Table 4.8: Codes grouped under the assessment criterion "Standardization & Consistency"

Code	**Phase**
Lack of structure in alarm display	1
No differentiation between alarms	1
Wishing for Color/sound-coded alerts per system	1
Wishing for different sounds for different alarm types	2
Wishing for consisted procedure for silencing alarms	2
Wishing for color-coded system indicators (green/red, slight blink feedback for order acknowledgment)	2
Audible alerts should be accessible to all	2
Wishing for color-coded component states (green/orange/red)	3
Wishing for indication lights linked to Wolke status	3
Wishing for color-coded alarm priority	3
Wishing for red/green indicators for engine readiness	3
Warning against over-reliance on automation	3
Wishing for dependency recognition among systems	2

Usability & Interface Clarity

From the assessment criteria codes of **Usability & Interface Clarity**, the following theme was identified (see all codes in Table 4.9).

Theme: Participants emphasized the need for clear, intuitive, and interactive interfaces. Visual clutter, unclear status indicators, and non-intuitive navigation slowed users down. They wished for improved graphical system maps, clickable elements, and minimalist design to support fast interpretation and action by all roles on board, not just senior operators.

Table 4.9: Codes grouped under the assessment criterion "Usability & Interface Clarity"

Code	Phase
Confusing visual overview	1
No confirmation after actions	1
No clear status information (e.g. filters)	1
UI not intuitive for fuel paths	1
Wishing for Graphical visualization of system paths	1
Valve operation interface was easy	1
General satisfaction with system layout (from some)	1
Difficult visibility of key alarms	1
Critical information not prominent	1
Wishing for digital plan of the engine room with alarm location highlighted	2
Wishing for valves and system status should be visually clear	2
Cluttered interface hinders quick action	2
More intuitive UI design needed	2
Information flow should reach everyone, not just chief	2
Switchable alarm sorting (priority/time)	3
Wishing for highlighted flow path with color	3
Wishing for malfunction highlight switch	3
System map would help orientation on unfamiliar ships	3
Wishing for clickable alarm descriptions	3
Clear diagrams and symbols aid interpretation	3
Clickable interactions would improve usability	3
Importance of visual clarity and minimalism	3
Clear Interface would reduce time to action through interface design	3
Wishing for engine status overview via traffic-light system	3
Wishing for clickable help icons for alarm explanations	3

4.3 Summary of Key Findings

The results indicate that standardized HMI concepts have the potential to reduce cognitive load and improve usability in maritime engine control rooms. Across all expert interviews and the co-design workshop, participants highlighted that current control systems are often fragmented, inconsistent, and overloaded with information.

The findings suggest that ergonomic and functional grouping, could be a promising direction to support situation awareness, task efficiency and reduction of cognitive load. In addition, the study shows that end users prefer HMIs that reflect their mental models and that flexibility, consistency and physical separation of functions are important factors for usability and trust in maritime environments.

The findings emerged from a combination of the interviews and the co-design workshop. Through RTA of the interviews, six core themes were identified: (1) experimental knowledge, referring to the reliance on hands-on familiarity with systems for decision-making; (2) visual clarity, highlighting the importance of clean, readable displays for situational awareness; (3) automation, which was seen as helpful but only when it remains transparent and controllable; (4) communication, emphasizing the need for clear exchanges, especially in multicultural crews; (5) information overload, pointing to the negative impact of excessive or poorly structured data; and (6) lack of standardization reflecting frustrations with inconsistent interfaces across different systems and vessels. The co-design activities not only confirmed these themes but extended them by proposing practical design ideas, such as priority-based alarm sorting, AI-assisted alarm management, role-specific panels, visualizations of the fuel flow and WOLKE diagram, and interactive maps of the engine room. Together, these data sources offer a complementary understanding of both existing pain points and future design directions.

Chapter 5

Design concepts

5.1 UI Design Solutions

The following shows the illustrative design proposals based on user input from the workshop. The mockups are building on the OpenBridge Design System which is a free, open-source framework created to improve the design, implementation, and certification of industrial work environments and equipment. It is grounded in modern UI principles, industry standards, and human-centered design methodologies. While initially developed for maritime applications, the system has since been adapted to support a broader spectrum of industrial contexts [62].

The mockups in Figure 4.4 and Figure 5.2 illustrate an alarm sorting layout inspired by Group 2's proposal for prioritizing alarms. A switch allows the user to change between alarms sorted by priority (see Figure 5.1) and alarms sorted by time (see Figure 5.2). The need for prioritized alarm sorting was highlighted by all participants. Also, emphasizing the filtering and prioritization of critical versus non-critical information aligns with the ISO 9241-112 principles [47]. This visual structuring is supposed to address user concerns about alarm flooding and cognitive overload, providing clearer situational cues and supporting more efficient decision-making.

Alarms are color-coded using red, orange, and yellow to indicate their severity, red for critical, orange for moderate, and yellow for low-priority alarms. This visual encoding is based on the suggestions from Group 2 and aligns with ISO 11064-5 by emphasizing prioritization and layout clarity [45]. Furthermore, it supports alarm differentiation and prevents alarm flooding by allowing users to expand, locate, and interpret alarms with clarity which aligns with signal prioritization and visual accessibility.

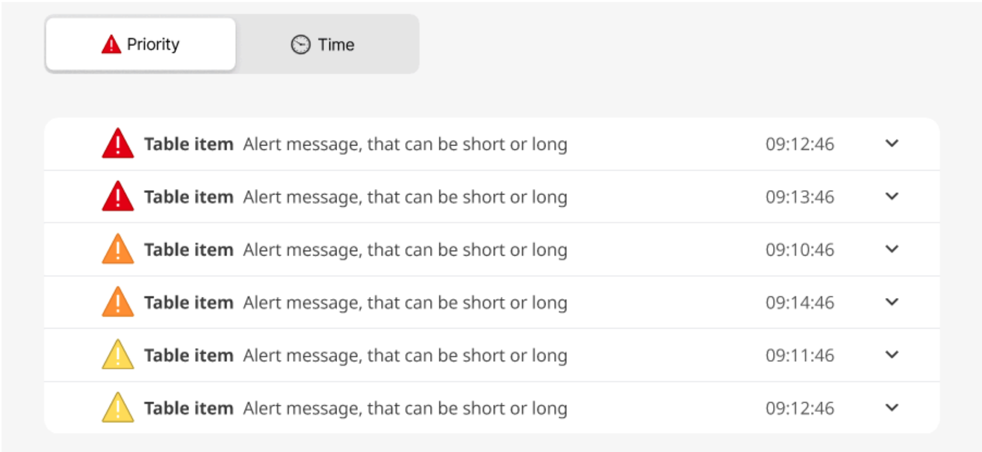


Figure 5.1: Mockup for alarms sorted by priority

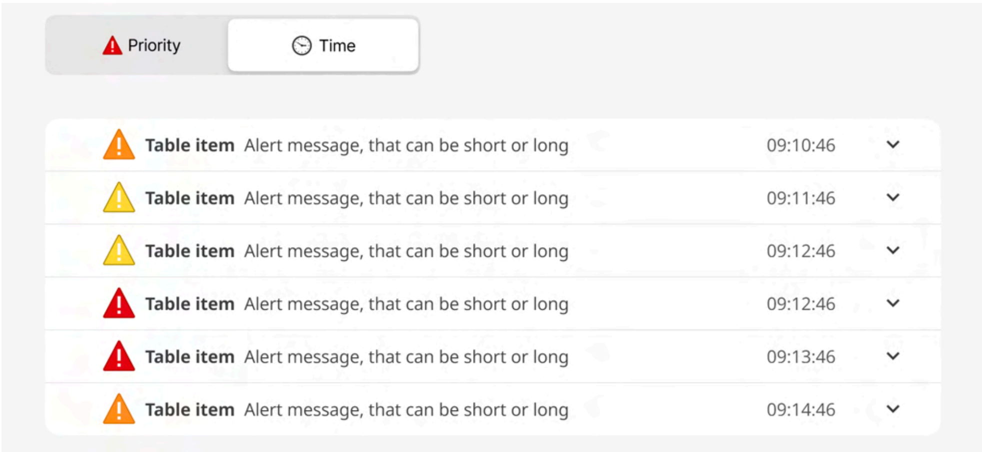


Figure 5.2: Mockup for alarms sorted by time

To access more detailed alarm information, the user can expand individual entries using the arrow icon (see Figure 5.3). By clicking the magnifier icon within an expanded alarm, the user is taken to a location map indicating where the issue occurred (see Figure 5.4). This design is also based on the concept developed by Group 2.

Figure 5.3: Mockup for expanding alarm description

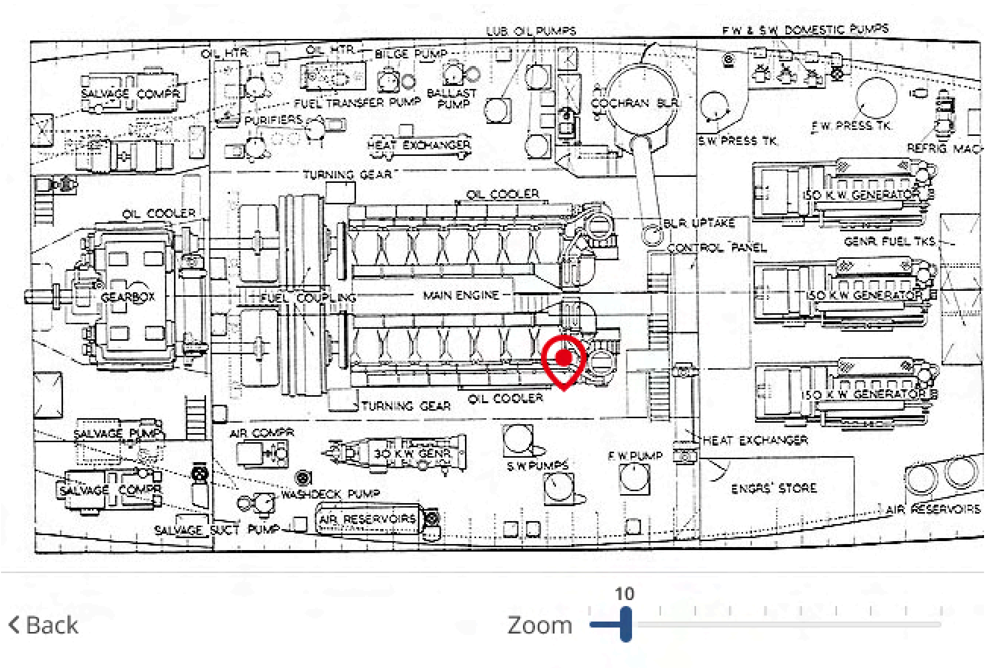


Figure 5.4: Mockup of the interactive map

The interactive map mockup (Figure 5.4) shows the location of an alarm within the engine room. The user can zoom in and out of the map and, by clicking on the red location icon, the user can access a 3D visual model of the engine room (see Figure 5.5). This idea originated from Group 1.

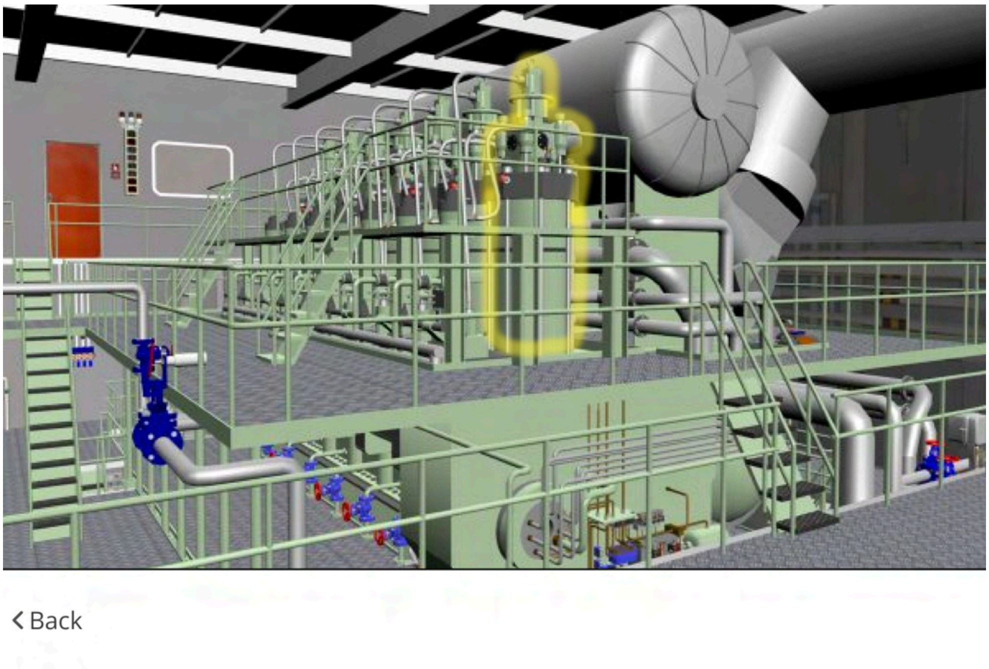


Figure 5.5: Mockup of 3D engine room

The mockup in Figure 5.6 is based on Participant 5's idea to visualize the WOLKE diagram. It provides a quick overview of the status of the Main Engine, Diesel Generators, and the Emergency Generator. Clicking the "blocked" icon leads the user to the flow overview of the issue, which is based on Group 1's prototype (see Figure 5.7).

	WATER COOLING	LUB OIL	START AIR	FUEL OIL	ELECTRICITY	STATUS
Main Engine	Ready	Ready	Ready	Ready	Ready	Ready
Diesel Generator 1	Ready	Ready	Ready	Ready	Ready	Ready
Diesel Generator 2	Ready	Ready	Ready	Ready	Ready	Ready
Diesel Generator 3	Ready	Ready	Ready	Blocked	Ready	Blocked
Emergency Generator	Ready	Ready	Ready	Ready	Ready	Ready

Figure 5.6: Mockup of the WOLKE diagram

Figure 5.7 shows the fuel oil system flow visualization. Users can activate two types of highlights: the malfunction highlight (which emphasizes any flow interruptions) and the flow highlight (which makes the direction and path of the fuel flow visible). This design builds on the prototype developed by Group 1 (see Figure 5.8).

Furthermore, the design implements ISO 9241-112: Information presentation by visualizing the fuel flow with highlights for malfunctions and direction [47]. These context-sensitive visualizations can improve cognitive clarity and reduce overload.

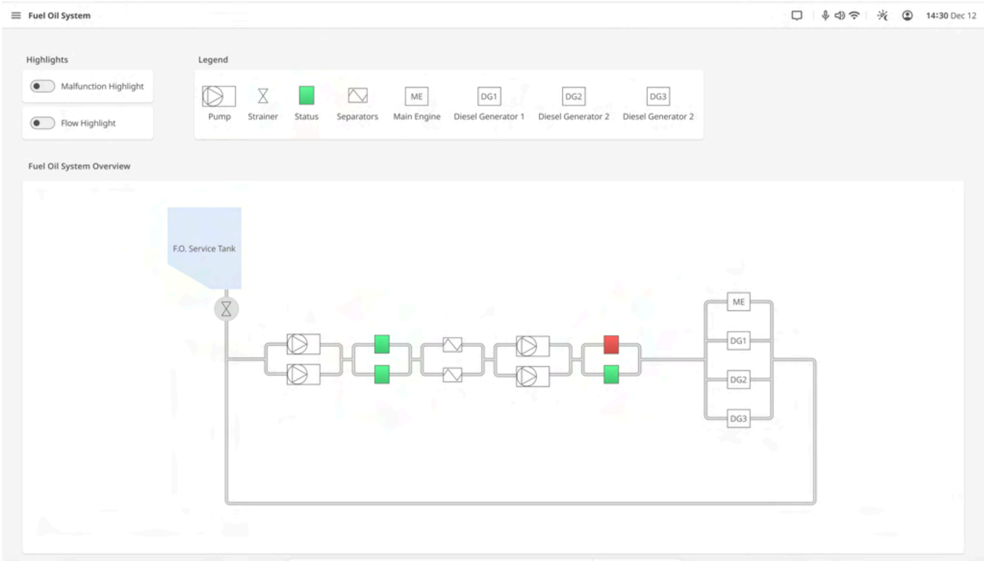


Figure 5.7: Mockup of fuel oil system flow

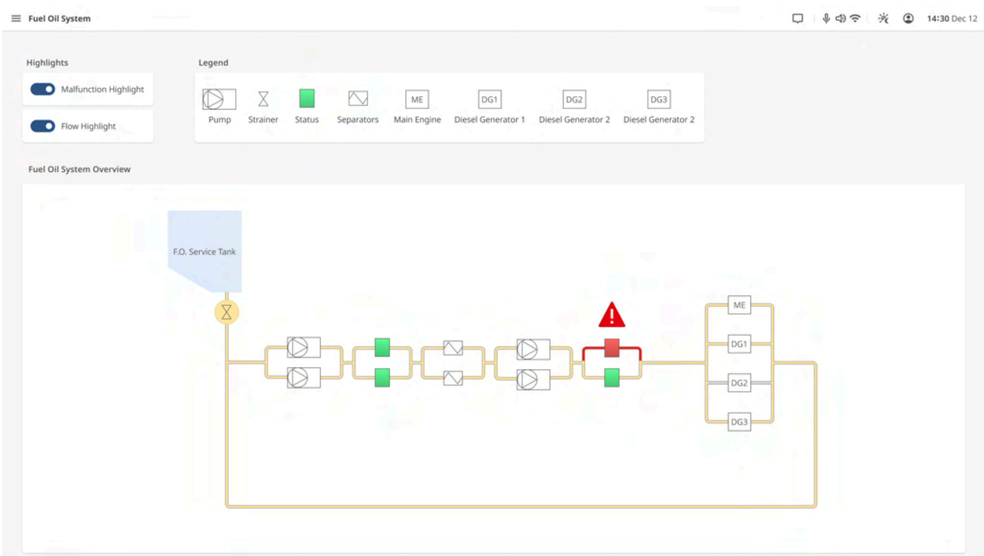


Figure 5.8: Mockup of fuel oil system flow with highlights

When the user clicks on the red alert symbol, a pop-up window appears with specific information about the issue disrupting the fuel flow (see Figure 5.9). This functionality was also proposed by Group 1.

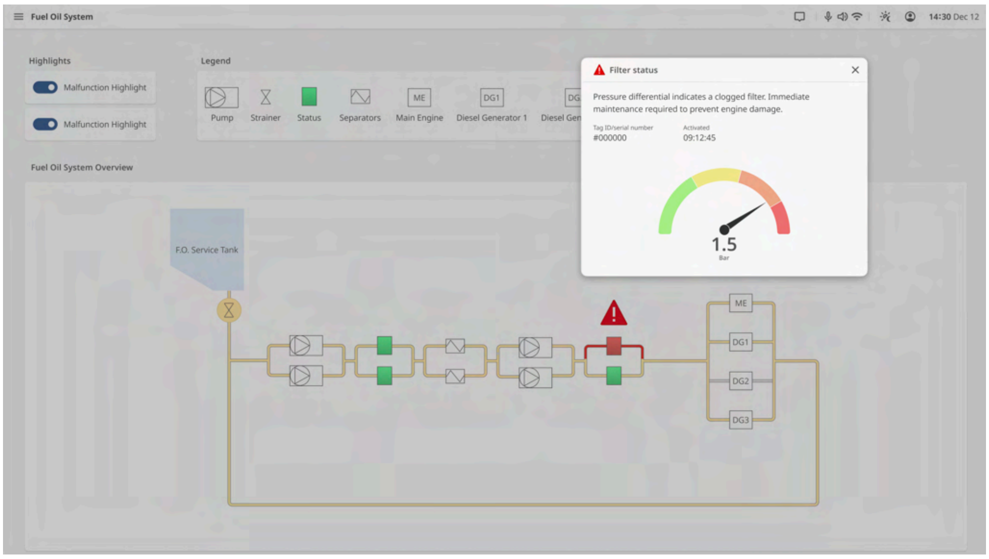


Figure 5.9: Mockup of fuel oil system flow alarm pop-up

Grouped layouts and logically presented data in the mockups (e.g., block-based alarm views, visualization of the machine room) can support spatial memory and efficient scanning, which are key points of the ISO 9241-125 and 161 standards [48, 49].

In addition, the mockups align with the ISO 9241-110 dialogue principles which promote usability principles such as suitability for the task, error tolerance, and learnability [46]. They follow these principles through intuitive icons, role-specific overviews in Figure 5.6, and interactive maps in Figure 5.4, all of which help reduce complexity and support error management.

5.2 Multimodal Design Solutions

This section presents three multimodal design solutions developed in response to the user needs and challenges identified during interviews and workshops. These concepts aim to enhance situational awareness, reduce cognitive load, and support clear communication in ECRs. Each design integrates multiple sensory channels and interactive modalities to improve the effectiveness and reliability of alarm handling and maintenance tasks.

Figure 5.10 illustrates a design solution that provides engineers with haptic and visual feedback confirming successful task completion. Feedback is delivered both locally, to the on-site engineer, and remotely, to the ECR. It is designed for a scenario were an alarm in the ECR indicates for example a blocked filter. A crew member is dispatched to the engine room to clean it. The engineer wears a smart wristband with a proximity sensor. Upon completing the task, the wristband vibrates and a green light is displayed. This provides immediate haptic and visual feedback, reinforcing task closure. Simultaneously, the system in the ECR detects the resolved status, highlights the resolved alarm in green, plays a confirmation sound ("ping"), and logs the event. The design supports shared situational awareness between ECR and field engineers. This design reduces misunderstandings about task completion, strengthens team feedback loops and prevents redundant or missed actions.

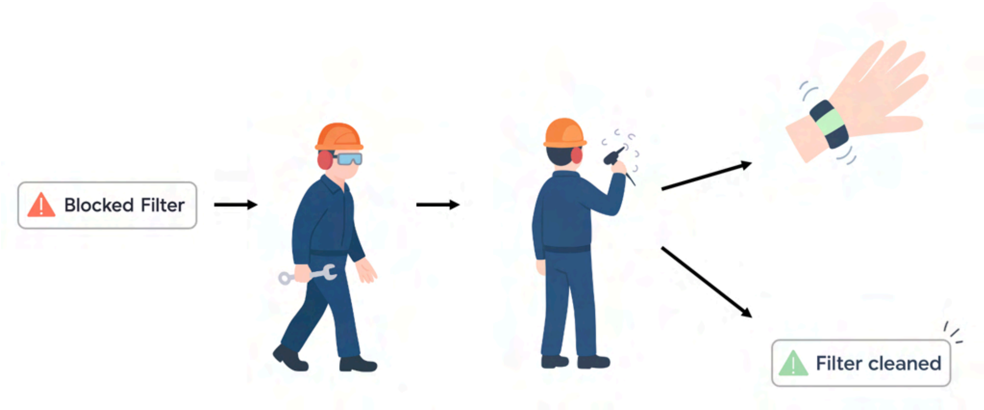


Figure 5.10: Mulitmodual confirmation

To reduce search time and cognitive load, Figure 5.11 shows a design concept for augmented reality (AR) safety glasses. These glasses provide real-time visual guidance and system status information directly in the engineer's field of view. The design addresses the context of an alarm triggered in the ECR (e.g., overheating generator or blocked filter). Instead of consulting static maps, the dispatched engineer puts on AR safety glasses. These glasses overlay directional arrows in the real-world environment to guide the engineer toward the fault location, using contextual layout data, like "Google Maps for ships". When the faulty component is in sight, it is visually highlighted, and the interface displays key system diagnostics (e.g., pressure, temperature, error codes). Once the task is completed, the engineer confirms completion via a gesture, triggering a synchronized update in the ECR. It benefits trough reduced search time and stress during time-critical tasks. It keeps both hands free for physical interaction, provides intuitive and context-sensitive support.

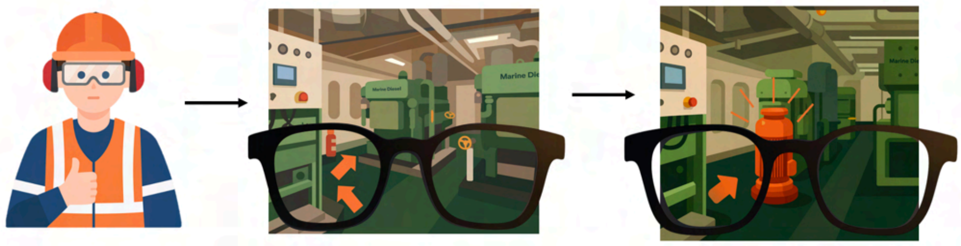


Figure 5.11: Augmented Reality Glasse

Figure 5.12 presents a voice-interactive AI assistant that could reduce cognitive load and enhance decision-making by offering verbal explanations, suggestions, and system context. An engineer in the ECR faces multiple alarms, including cascading effects. Instead of searching through menus or manuals, the engineer verbally asks the assistant for help (e.g., "What caused the fuel pressure alarm?" or "How do I fix this blocked filter?"). The system uses causal reasoning and sensor data to identify probable root causes and distinguish primary from secondary alarms. Spoken answers are also mirrored visually on a nearby side display. The assistant is activated with a trigger phrase such as "Hey Engine Assist". The design reduces time spent interpreting alarms and searching for documentation, helps less experienced crew members handle unfamiliar situations and keeps hands free for actions.

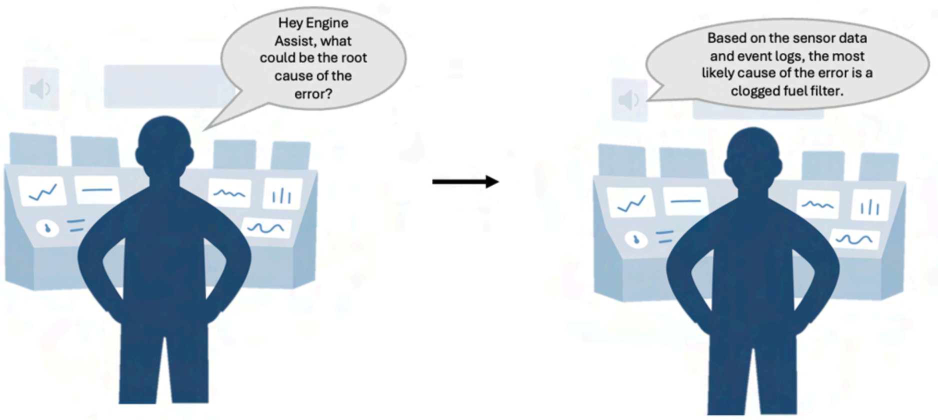


Figure 5.12: Audio Assistant

5.3 How User Insights Shaped the Design Concepts

Operators reported being overwhelmed by excessive and poorly structured information, particularly during emergencies (e.g., Interviewee 1: "*Most of the time, you ignore 20,000 alarms and look for the first error.*"). To address this, alarm sorting views (by time or priority) were developed (see Figure 5.1, 5.2). Color-coded alarm severity levels (red/orange/yellow) support faster scanning and reduce cognitive load, as requested by participants who emphasized simplicity and speed (e.g., Interviewee 5: "*How many clicks do I need?*"). These solutions address the themes "Information Overload" & "Visual Clarity" from the interviews.

Participants described interface inconsistency as a major problem when moving between vessels. By integrating the OpenBridge Design System, the prototypes promote standardized interface logic, iconography, and navigation across systems [62]. This reduces learning effort and aligns with interviewee concerns about heterogeneous HMI layouts (Interviewee 3:"*Every ship is different, every system looks different.*") addressing the theme "Lack of Standardization" from the interviews.

Interviewees repeatedly stressed that digital displays often fail to convey the embodied cues (vibrations, smells, temperature) used for fault detection (e.g., Interviewee 2: "*You feel it at first, because it vibrates.*"). The 3D engine room visualization (see Figure 5.5) and interactive alarm map (see Figure 5.4) attempt to preserve spatial awareness and link abstract digital alarms with real-world locations. Similarly, the visualized flow diagrams (see Figures 5.7, 5.8) make interdependencies and system behaviors more accessible and transparent. This designs addresse the interview themes "Experiential Knowledge" and "Automation".

The flow-based alarm interface (see Figure 5.9) enables users to trace causes and effects. This meets the needs expressed by interviewees for alarm structures that go beyond symptom reporting to root cause indication. As Interviewee 2 said, "*With a chain of errors like that, it's difficult to pinpoint the actual cause of this system error*". This design supports alarm causality and system transparency.

Furthermore, interview participants expressed mixed feelings about automation, they want support, but not loss of control. The designs maintain manual inspection options and make automation transparent, by showing why a generator shut down. Pop-up windows explaining alarm details provide feedback without hiding logic, building trust.

Visual tools like the WOLKE diagram (see Figure 5.6) present a fast system overview that supports shared mental models across team members and allows quicker decision-making in complex scenarios. Redundancy through multiple views (alarm list, location map, flow diagram) enhances reliability. Designing for operational resilience.

The theme "Experiential knowledge" from the interviews showed that engineers rely on sensory confirmation, the illustrated wearable feedback system (see Figure 5.10) delivers vibratory and visual cues upon successful maintenance actions. Workshop participants also explained that current systems do not clearly indicate when a task (like filter cleaning) is completed or acknowledged by the system. The wristband and ECR confirmation give tactile and visual cues that are perceivable even in loud environments. This design supports multisensory awareness and embodied interaction, visual clarity, trust and transparentcy and clear communication in multinational teams.

To address spatial disorientation and reduce search time during fault responses, AR glasses provide navigation cues and component highlights (see Figure 5.11). This concept reflects interviewee requests for tools that help locate issues faster and reduce information fragmentation across multiple displays. Furthermore it addresses the workshop participants concern about struggling to locate components and understand the system layout when getting familiar with a new ship.

Interviewees described difficulties in interpreting layered alarm structures and requested more support for root cause identification. The audio assistant concept (see Figure 5.12) allows engineers to verbally query alarm origins and consequences. It enhances cognitive relief and bridges the knowledge gap for less experienced crew, another key concern highlighted in the interviews. Moreover, the voice-assistant directly addresses workshop feedback where participants expressed the need for support in interpreting complex alarm chains and identifying root causes. This reflects suggestions such as a "magic problem-solving button" or a smart assistant that explains alarms and guides action.

Chapter 6

Discussion

6.1 Interpretation of Results

In line with the research questions, the results reveals that inconsistent interface layout, fragmented information, and lack of standardization are primary contributors to cognitive overload in maritime ECRs. Participants emphasized that these factors impair situational awareness and hinder effective decision-making, especially under time pressure or stress. This supports earlier findings by Wagner et al. (2008), who reported usability problems in ECRs due to inconsistent instrumentation and layout [3]. Furthermore, Man et al. (2018) emphasized how environmental stressors and legacy systems exacerbate operator workload [1]. The results in this thesis echo these concerns but also demonstrate that designs, if aligned with operators' mental models, could mitigate many of these issues. This finding supports prior work by Wu et al. (2017), who showed that cognitive misalignment between interface structure and user expectations negatively impacts decision-making performance [22].

The co-design workshop further validated these insights. Notably, the main user struggles that emerged, such as alarm flooding, excessive interface complexity, and cognitive overload, were directly addressed through co-design generated interface concepts. For instance, suggestions like smart alarm prioritization and confirmation feedback aimed to resolve user frustrations about unclear menu structures, too many clicks, and missing situational support. The workshop thus translated mentioned frustrations into concrete design ideas, illustrating the value of co-design in uncovering and solving domain-specific challenges. A recurring theme in the interviews was the lack of trust in current levels of automation. While participants expressed openness to digital assistance, they warned against over-automation that reduces transparency or removes operator control. This reinforces that trust depends on the system's ability to provide clear, contextual feedback and enable timely operator intervention.

Engineers often relied on informal, experience-based adaptations "what works on our ship" to manage usability. This indicates a persistent gap between formal design guidance and real-world implementation, suggesting that standards either lack clarity, reach, or perceived relevance among practitioners.

The design concepts developed in this study translate operator needs into concrete visual and interactive design solutions that respond directly to user-identified challenges.

For instance, the alarm sorting interface in Figure 5.1 and Figure 5.2 exemplifies the application of ISO 9241-112, which emphasizes the filtering and prioritization of critical versus non-critical information [47]. By allowing users to toggle between priority- and time-based sorting, these mockups address concerns about alarm flooding and cognitive overload, offering clearer situational cues and improving response efficiency. Color-coded alarms, red for critical, orange for moderate, and yellow for low-priority, further support quick visual differentiation, aligning with ISO 11064-5 principles on layout clarity and signal prioritization [45].

In addition, the integration of contextual visualizations, such as the interactive map (Figure 5.4) and the 3D engine room (Figure 5.5), helps operators understand alarm locations within physical space, supporting situational awareness and decision-making. These features implement ISO 9241-110 dialogue principles by promoting suitability for the task and reducing interaction complexity through intuitive, role-specific overviews and visual feedback [46].

The fuel system flow mockups (Figure 5.7–5.9) demonstrate how ISO 9241-112 is applied to visualize complex engine processes. The use of malfunction highlights and flow direction indicators provides cognitive framework for users, enabling quicker problem detection and resolution. These designs also draw on ISO 9241-125 and 161 standards by presenting grouped and logically structured visual data, which enhances readability and supports efficient scanning [48, 49].

Crucially, these designs reveal a broader issue: the gap between what is technically feasible in modern HMI design and what is currently addressed by maritime standards. Participants expressed a desire for more tactile and multisensory feedback. In this regard, ISO 9241-920 becomes particularly relevant. It outlines the importance of haptic feedback (e.g., vibration, force feedback) for enhancing interaction when visual or auditory channels are compromised [51]. The findings suggest that maritime HMI standards need to evolve to better support such multimodal interaction possibilities.

Multimodal solutions are addressed in the designs for multimodal confirmation feedback (see Figure 5.10), AR glasses for guided maintenance (see Figure 5.11) and in the voice-interactive AI assistant (see Figure 5.12). These concepts respond to interview insights highlighting the importance of embodied interaction and the sensory awareness engineers use in practice, such as detecting faults through vibration or sound.

By integrating visual, tactile, and auditory modalities, the designs support task feedback, spatial orientation, and verbal communication in high-pressure and noisy environments. They reduce cognitive fragmentation and address user demands for intuitive access to system knowledge.

Finally, the methodological structure of this study reflects ISO 9241-210 by embedding user needs and contextual insights across the design lifecycle [57]. The co-design workshop not only validated interview-derived themes but also translated them into design concepts grounded in real-world operations. By involving end users in ideation and early-stage prototyping, the approach reduced the risk of misaligned design assumptions and ensured that developed concepts aligned with actual work practices.

In sum, both the process and the design outcomes underscore the critical role of user-centered and ergonomically informed design in shaping future maritime HMIs. They highlight the potential of aligning ISO standards with domain-specific realities and demonstrate how collaborative methods can generate context-aware, operationally robust design solutions.

The central insight emerging from this study is that cognitive overload in maritime ECRs stems less from system complexity alone, and more from inconsistent visual organization and insufficient standardization. Among various proposed design features, ergonomic grouping and alignment with user mental models stood out as most promising for future implementations.

6.2 Implications for Design and Practice

This study reinforces the importance of user-centered design for maritime ECRs. The findings point to visual clarity, task alignment, and ergonomic grouping as the most critical levers for reducing cognitive load and improving usability.

While modular HMIs were introduced as a potential future direction and echoed in related domains like nuclear energy or industrial automation [8, 28], the results of the interviews and co-design workshop do not give empirical evidence to support modularity as a tested or validated design solution. Instead, the co-design process revealed that end users seek interfaces that feel intuitive, reduce friction, and support quick, confident action.

Looking to related domains, however, modular HMIs have been shown to support interface scalability and consistency. For instance, the "plug-and-display" concept discussed by Shakil et al. (2020) offers a technical pathway for integrating new system modules over a ship's lifespan without requiring complete redesigns [63]. User-generated ideas such as role-based panels, confirmation prompts, and visual data flow tools offer additional paths to making complex HMIs more usable and cognitively manageable.

At the regulatory and organizational level, the study highlights the need for stronger guidance and enforcement of HMI standards in the engine room, similar to those already in place for ship bridges [33]. Mallam and Lundh (2013) already pointed out the lack of ergonomic regulation in ECRs, and this gap remains evident today [36]. Without clearer targets, design quality is left to vendor discretion, risking variability across vessels.

Beyond the scope of this thesis, future development of maritime HMIs should consider user-centered design as a continuous process throughout the system lifecycle. As Squire (2004) notes, poor ergonomics and inadequate consideration of real-world usage can lead to fatigue, stress, and critical human error [64]. ECR design must reflect operational realism, accommodate demographic diversity among users, and maintain feedback loops from end-users such as seafarers to remain adaptive and effective over time.

The study also provides methodological insight. The qualitative interviews were analyzed using RTA, which emphasizes context-sensitive, subjective meaning-making, appropriate for uncovering experiential and systemic patterns in operator feedback. In contrast, the co-design workshop was analyzed in a more goal-oriented and structured way: data were sorted by workshop phase, linked to assessment criteria, and grounded in the blackout scenario. This approach proved more suitable for integrating multi-modal outputs such as participant drawings, task-based insights, and observer notes.

Finally, the co-design format of the workshop was deliberately designed to reflect best practices in focus group composition. Baxter et al. (2015) recommend six to eight participants to ensure balanced participation and dynamic interaction, noting that groups with more than ten become difficult to manage [9]. The six-person group in this study allowed for rich exchange, and participants actively built on one another's contributions. To further strengthen these results, repeating the workshop under different scenarios is recommended to capture a broader range of user needs and stress responses.

In conclusion, as maritime automation and system complexity increase, this study underscores the importance of adaptable, transparent, and operator-centric HMIs. Only by integrating both expert insight and user-driven design can ECR interfaces evolve toward improved safety, usability, and operational trust.

Chapter 7

Conclusions and Future work

7.1 Conclusions

This thesis explored how user-centered design can improve human-machine interfaces in maritime engine control rooms by reducing cognitive load and supporting usability. Through expert interviews and a scenario-based co-design workshop, it identified critical interface problems and proposed design strategies grounded in real user needs.

The central finding is that cognitive overload in ECRs is primarily driven by poor visual organization and inconsistent information presentation, rather than system complexity alone. Design solutions that prioritize clarity, simplicity, and task-relevance are most effective in supporting operator performance.

While modularity was identified early by DLR as a promising concept for standardization, this thesis did not implement or evaluate modular systems. Instead, it explored how modular ideas might align with user preferences, an approach that could best be pursued in future high-fidelity prototypes.

This work provides practical design guidance and a methodological template for involving users in the early phases of HMI development. The methodological approach demonstrates how HCD can be effectively applied to the maritime domain, offering initial guidance for future projects in this field.

Furthermore, the HMI design principles derived from the interview findings provide the first set of guidelines for HMI designers and researchers aiming to create new user-centered HMIs for maritime ECRs. It shows that small improvements in layout, feedback, and prioritization can significantly enhance user experience and reduce risk.

7.2 Limitations

While this study offers valuable insights into the development of user-centered HMI systems for maritime engine control rooms, several limitations must be acknowledged.

The generalizability of the results is limited by the composition of the participant group. All interviewees and workshop participants were male and of German nationality. Moreover, the interview group was predominantly older and experienced, whereas the workshop involved younger participants, all students. A more diverse and representative sample in terms of age, professional background, and cultural context would be needed to fully capture the range of user needs in real-world engine control settings.

The co-design session was conducted in a simulated environment and focused on a single scenario, a blackout caused by a blocked filter. While this scenario was realistic, it does not reflect the full complexity of ECR operations.

The materials provided during the co-design workshop, primarily paper, pens, and pre-cut UI components, guided participants toward screen-based interface solutions. This may have constrained creativity and prevented the exploration of alternative modalities such as haptic, auditory, or embodied interactions, which emerged more strongly in the interview data. Future co-design sessions should incorporate multimodal prototyping tools (e.g., audio prompts, physical components, or wearable mockups) to support a broader range of ideas and interaction types.

Realism in the simulated setting of the co-design workshop lacked real operational stressors such as long working hours, environmental conditions, or communication with bridge personnel.

Furthermore, the study did not collect quantitative task performance data. As a result, the usability findings are based on qualitative insights rather than measurable improvements in operational performance.

Despite these limitations, the study provides a credible foundation for further research and design in the field. The findings are valid within the exploratory scope of the project and offer a useful starting point for developing modular HMI systems that are more adaptable, user-centered, and aligned with the needs of maritime professionals.

7.3 Future work

Due to the breadth and complexity of the research topic, only some of the initial goals of this study could be fully addressed. While the findings offer a strong foundation for the design of user-centered HMIs in maritime ECRs, several options remain open for further investigations.

First, the co-design workshops should be repeated with different maritime scenarios to capture the full spectrum of user needs. These needs, along with participant-generated concepts, can then be translated into design solutions, prototyped, and tested with end users. Testing is recommended through longitudinal studies in real-world or high-fidelity simulation environments. Iterative feedback and evaluation cycles should follow until the interface effectively supports situational awareness, manages cognitive load, and enhances operational efficiency.

Second, studying usability and cognitive load across multinational and multicultural crews remains a critical step toward broader applicability. As ECR teams often consist of individuals from diverse linguistic and cultural backgrounds, future work should examine how design elements, such as iconography, alarm hierarchy, and navigation logic, are interpreted and acted upon across such settings.

A further direction involves the development of intelligent systems capable of assisting operators in prioritizing alarms. Integrating AI-driven models that can analyze contextual data and recommend appropriate actions based on procedural manuals would enhance situational awareness and reduce cognitive overload during complex operations.

Future evaluations of new HMI designs should incorporate both subjective and objective workload assessments. Tools like NASA-TLX offer valuable insight into perceived workload across dimensions such as mental demand and frustration [65]. This is particularly important given the cognitive and communicative demands of ECR tasks, where interface complexity can directly affect operational safety and performance.

In addition to subjective scales, physiological metrics such as eye tracking offer complementary insights. Studies by Yan et al. (2019) demonstrate that pupil dilation and blink rate are highly sensitive to mental workload in HMI interactions [66]. Integrating such measurements in simulator-based usability testing can reveal workload patterns not captured through questionnaires alone. Simulation environments remain a practical and safe setting to observe user interaction under varied conditions, offering repeatability and realism for evaluating human factors in safety-critical contexts [66].

Furthermore, creating practical design guidelines or standardized frameworks for modular HMIs in ECRs would support system developers, shipyards, and equipment manufacturers in adopting user-centered approaches. These frameworks should align with international safety, training, and usability standards to facilitate broader industry adoption.

Finally, collaboration with industry stakeholders is essential to validate these concepts under real operating conditions. Partnerships with shipbuilders, shipping companies, or maritime training centers could enable iterative testing, refinement, and eventual implementation of modular HMIs in vessel design and retrofitting projects.

Collectively, these directions would not only strengthen the empirical foundation of user-centered interface design in the maritime domain but also support a safer and that is adaptable to future technological and operational developments.

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Appendix A

Interview materials

A.1 Interview Guide English

Interview Guide - English

Introduction

My name is Malin Brilon and I'm a Master Student in Human-Computer Interaction and Design at KTH University. Thank you for agreeing to meet today! I really appreciate your time. This interview aims to understand how human-machine interfaces in engine control rooms impact cognitive load, especially during high-stress scenarios. We want to explore where the interfaces help and where they could be improved. If you do not mind—I would like to make a recording. This allows me to go back at a later time and review your comments so that I am not distracted from our conversation by taking notes. I am a neutral evaluator, so nothing you say today will hurt my feelings. Your honest opinions can only help me. If you do not have an opinion or cannot answer any of the questions I ask, please feel free to say so. Everything shared in this interview will remain confidential. If you prefer not to answer any question, feel free to skip it. You are free to leave at any time. Please stop me at any point if you have questions.

Interview

Ice breaker	Get participant talking, put participants at ease, create rapport	Can you briefly tell us something about your professional background? How old are you?
Introduction	Bring up topic, shift focus toward product	Can you give me a typical example of your day-to-day work as a technical watch officer/engineer/ship mechanic?
Key	Gather insight on areas of primary interest; achieve study goals	**Information flows & data interaction** How do you currently receive information on machine data, e.g. displays, alarms? Which systems or interfaces do you mainly use? Are there situations in which the interface has hindered you? **Workload & stressful moments** Were there situations where working in the control room was particularly stressful Were there situations where you were inundated with data and processing it was overwhelming or stressful What role does the presentation of information (e.g. alarm systems, displays) play in stressful moments? **Areas for improvement** Are there any specific functions or display modes that you would like to see? How would you describe ideal technology support in the control room?
Summary	Consider key questions within a broader perspective	Thinking about all your experience - what do you think is the biggest problem with using tech systems in the control room? What do you think would be the most important improvement to reduce the workload?
Wrap-up	Bring closure to discussion	Is there anything else you think is particularly relevant to working in the machine control room that we haven't discussed? Is there anything else you would like to share with me?

A.2 Interview Guide German

Interview Guide - German

Einleitung

Mein Name ist Malin Brilon und ich studiere Human Computer Interaction and Design im Master an der KTH Universität. Vielen Dank, dass du dir heute Zeit genommen hast! In diesem Interview geht es darum zu verstehen, wie Mensch-Maschine-Schnittstellen in Engine controll room die kognitive Belastung beeinflussen. Wir wollen ebenfalls untersuchen, wo die Schnittstellen hilfreich sind und wo sie verbessert werden könnten.

Wenn du nichts dagegen haben, würde ich gerne eine Aufnahme machen. So kann ich zu einem späteren Zeitpunkt zurückgehen und Ihre Kommentare durchsehen, ohne dass ich durch Notizen von unserem Gespräch abgelenkt werde.

Ich bin ein neutraler Beobachter, daher wird nichts, was Sie heute sagen, meine Gefühle verletzen. Ihre ehrliche Meinung kann mir nur helfen. Wenn Sie keine Meinung haben oder keine der von mir gestellten Fragen beantworten können, sagen Sie es mir bitte. Alles, was Sie in diesem Gespräch sagen, wird vertraulich behandelt.

Wenn du es an einem Punkt vorziehst, eine Frage nicht zu beantworten, können wir sie auch überspringen. Es steht dir jederzeit frei, das Gespräch zu verlassen. Bitte sprich mich an, wenn du Fragen hast.

Interview

Ice breaker	Teilnehmer zum Reden bringen, sich wohlfühlen, eine Beziehung aufbauen	• Kannst du kurz etwas über deinen beruflichen Hintergrund erzählen? • Wie alt bist du? • Was hat dich ursprünglich motiviert, in der Schifffahrt zu arbeiten?
Einführung	Thema ansprechen, Fokus auf das Produkt lenken	• Kannst du mir ein typisches Beispiel aus deinem Arbeitsalltag als *Technischer Wachoffizier/* ***Ingenieur/***Schiffsmechaniker schildern? • Wie sah Ihr Arbeitsumfeld im Maschinenkontrollraum aus?
Key	Einblicke in Bereiche von primärem Interesse gewinnen; Studienziele erreichen	**Informationsflüsse & Dateninteraktion** • Wie hast du aktuell Informationen zu Maschinendaten also z. B. Anzeigen, Alarme erhalten? • Welche Systeme oder Interfaces nutzt du dabei hauptsächlich? • Gibt es Situationen, in denen das Interface dich behindert hat? **Arbeitsbelastung & Stressmomente** • Gab es Situationen, indem die Arbeit im Kontrollraum als besonders belastend war?- • Welche Rolle spielt die Informationsdarstellung (z. B. Alarmsysteme, Anzeigen) in stressigen Momenten? **Verbesserungsmöglichkeiten** • Gibt es bestimmte Funktionen oder Darstellungsweisen, die du dir wünschen würdest? • Wie würden Sie eine ideale Unterstützung durch Technik im Kontrollraum beschreiben?
Zusammen-fassung	Schlüsselfragen in einer breiteren Perspektive betrachten	• Wenn du an all deine Erfahrung denkst – was ist deiner Meinung nach das größte Problem bei der Nutzung technischer Systeme im Kontrollraum? • Was wäre aus deiner Sicht die wichtigste Verbesserung, um die Arbeitsbelastung zu reduzieren?
Wrap-up	Diskussion zum Abschluss bringen	• Gibt es noch etwas, das du im Zusammenhang mit der Arbeit im Maschinenkontrollraum für besonders relevant hältst und das wir noch nicht besprochen haben? • Möchtest du mir sonst noch etwas mit auf den Weg geben?

A.3 Participant Information Sheet

Participant information sheet for an Interview

Modular Human-Machine Interfaces for Maritime Engine Control Rooms: A User-Centered Design to Minimize Cognitive Load and Improve Performance

I would like to invite you to participate in a research study as part of my master's thesis at KTH Royal Institute of Technology. Before you make your decision, it is important that you understand the purpose of the research and what your involvement would entail. Please take your time to read the following information carefully. If anything is unclear or if you would like further details, feel free to ask questions. Take your time to decide whether or not you wish to participate.

WHO I AM AND WHAT THIS STUDY IS ABOUT

My name is Malin Brilon, and I am conducting this research as part of my master's thesis in Human-Computer Interaction and Design, a double degree program at KTH Royal Institute of Technology and the University of Twente. The purpose of this study is to explore how **Human-Machine Interfaces (HMIs)** in **maritime engine control rooms** can be improved through **modular design** and **user-centered principles** to reduce **cognitive load** and enhance **operational efficiency**. I aim to understand how HMI design affects decision-making in high-stress scenarios and identify areas where improvements can be made.

WHAT WILL TAKING PART INVOLVE?

You are invited to participate in a **semi-structured interview** where you will be asked to share your experiences and insights about **Human-Machine Interfaces** (HMIs) in the context of **maritime engine control rooms**. The interview will last approximately **30-60 minutes**. Questions will focus on your experience in **high-stress situations**, the cognitive load you experience, and how **HMI designs** support or hinder your ability to make quick, accurate decisions.

WHY HAVE YOU BEEN INVITED TO TAKE PART?

You have been selected because of your **experience in maritime operations**, specifically working with **engine control rooms**, or expertise in **HMI design** or **maritime technologies**. Your insights will be valuable in understanding the practical issues and potential solutions related to improving **HMI systems** in the maritime sector.

DO YOU HAVE TO TAKE PART?

No, your participation is **completely voluntary**. You can choose not to take part, or withdraw at any time during the interview, without any consequence. You may also refuse to answer any specific question during the interview if you do not feel comfortable.

WHAT ARE THE POSSIBLE RISKS AND BENEFITS OF TAKING PART?

The primary benefit of participating is that your feedback will help improve HMI design in maritime operations, contributing to safer, more efficient engine control rooms. Possible risks would be a hacking of the private computer or data leaks within the personal Microsoft office 365 programs. Therefore, no personal data (e.g., name, age, nationality) will be collected during the study unless explicitly consented to by the participant. The information and notes will be linked to the participant number. In case of a data leak, I will inform every participant about the possibility of the data being illegally publicized.

WILL TAKING PART BE CONFIDENTIAL?

Yes, all information collected will be **confidential**. The interview will be recorded only for transcription purposes, and no personal identifiable information will be linked to your responses in the final thesis. You may request to review any direct quotes used from the interview before they are included in the final project.

HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED AND PROTECTED?

The interview will be **audio-recorded for transcription purposes only**, with your prior consent. The recording will be stored exclusively on a private mobile device that is not synced to any cloud services. The audio files will be deleted within 48 hours after transcription is completed. Only the researcher will have access to the recordings during this short period. All research data will be stored securely on a private, password-protected device. The transcripts will be used for analyzing the interview content, following a thematic analysis approach to identify patterns and insights relevant to the research questions. All personal identifiers will be removed during transcription, and the data will be fully anonymized in any reporting or publications.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

The results will be used to write my master's thesis and will be published. The data will be analyzed to identify insights on HMI design**,** cognitive load reduction, and usability improvements in maritime systems. Only anonymized data will be used in for the thesis unless otherwise explicitly consented to by the participant.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

If you have any questions about this study, please feel free to contact me:

Malin Brilon
Email: brilon@kth.se

If you have questions about your rights as a participant or would like to discuss any concerns about the study, you may contact my **thesis supervisor**:

Rey Rémy	**Jan Oberhagemann**	**Andrea Papenmeier**
(Project Supervisor KTH)	**(DLR Supervisor)**	**(Critical observer Utwente)**
rey.remy@kth.se	jan.oberhagemann@dlr.de	a.papenmeier@utwente.nl

Additionally, you can contact the Secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente through ethicscommittee-cis@utwente.nl

THANK YOU!

A.4 Informed Consent Form

Consent Form for Modular Human-Machine Interfaces for Maritime Engine Control Rooms: A User-Centered Design to Minimize Cognitive Load and Improve Performance - an Interview

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [__/__/____], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that participating in the study involves an audio-recorded interview, which will be transcribed into text. The audio recording will be securely deleted once the transcription is completed.	□	□
Use of the information in the study		
I understand that the information I provide will be used for the master's thesis, as part of the research conducted at KTH Royal Institute of Technology, and within the ongoing DLR research on Human-Machine Interfaces for Maritime Engine Control Rooms. The data may be included in reports, academic publications, and potentially shared with DLR for internal research purposes. Furthermore, I understand that the thesis will be published. The findings may also be disseminated through conferences, workshops, or publications in relevant maritime technology and human-computer interaction journals, with all personal identifying information being anonymized.	□	□
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	□	□
I agree that my information can be quoted in research outputs	□	□
I agree that my real name can be used for quotes	□	□
Consent to be Audio/video Recorded		
I agree to be audio recorded.	□	□

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Signatures

Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Malin Brilon		
Researcher name	Signature	Date

Study contact details for further information:

If you have any questions or concerns regarding this interview or the study, please feel free to contact us:

Malin Brilon
brilon@kth.se

Rey Rémy (Project Supervisor KTH)
rey.remy@kth.se

Jan Oberhagemann (Supervisor at DLR)
jan.oberhagemann@dlr.de

Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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Appendix B

Co-design workshop materials

B.1 Participant Information Sheet

Participant information sheet

Co-Designing Human-Machine Interface Workflows in Maritime Engine Control Rooms

I would like to invite you to participate in a **co-design workshop** as part of my master's thesis in Human-Computer Interaction and Design at KTH Royal Institute of Technology. Before you make your decision, it is important that you understand the purpose of the research and what your involvement would entail. Please take your time to read the following information carefully. If anything is unclear or if you would like further details, feel free to ask questions. Take your time to decide whether or not you wish to participate.

WHO I AM AND WHAT THIS STUDY IS ABOUT

My name is Malin Brilon, and I am conducting this research as part of my master's thesis in Human-Computer Interaction and Design, a double degree program at KTH Royal Institute of Technology and the University of Twente. The purpose of this study is to explore how **Human-Machine Interfaces (HMIs)** in **maritime engine control rooms** can be improved through **modular design** and **user-centered principles** to reduce **cognitive load** and enhance **operational efficiency**. I aim to understand how HMI design affects decision-making in high-stress scenarios and identify areas where improvements can be made.

WHAT WILL TAKING PART INVOLVE?

You are invited to take part in a **3.5–4 hour in-person workshop** on **June 11th**, which will include:

- A **simulator session** where you experience an emergency scenario in an ECR
- **Group discussions**, idea generation, and hands-on **paper prototyping**
- **Audio and video recordings** of group activities
- A **semi-structured group interview** at the end to reflect on insights and outcomes
- Snacks and drinks will be provided, and there will be one break during the session.

WHY HAVE YOU BEEN INVITED TO TAKE PART?

You have been selected because of your **experience in maritime operations**, specifically working with **engine control rooms**, or expertise in **HMI design** or **maritime technologies**. Your insights will be valuable in understanding the practical issues and potential solutions related to improving **HMI systems** in the maritime sector.

DO YOU HAVE TO TAKE PART?

No, your participation is **completely voluntary**. You can choose not to take part, or withdraw at any time during the interview, without any consequence. You may also refuse to answer any specific question during the interview if you do not feel comfortable.

WHAT ARE THE POSSIBLE RISKS AND BENEFITS OF TAKING PART?

The primary benefit of participating is that your feedback will help improve HMI design in maritime operations, contributing to safer, more efficient engine control rooms. Possible risks would be a hacking of the private computer or data leaks within the personal Microsoft office 365 programs. Therefore, no personal data (e.g., name, age, nationality) will be collected during the study unless explicitly consented to by the participant. The information and notes will be linked to the participant number. In case of a data leak, I will inform every participant about the possibility of the data being illegally publicized. The simulator scenario may feel overwhelming, as it simulates emergency scenario You may feel mild discomfort due to the stress of the situation. Support is available if needed.

WILL TAKING PART BE CONFIDENTIAL?

Yes, all information collected will be **confidential**. The interview will be recorded and filmed only for transcription purposes, and no personal identifiable information will be linked to your responses in the final thesis.

HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED AND PROTECTED?

The interview will be **audio and video recorded for transcription purposes only**, with your prior consent. The recording will be stored exclusively on a private mobile device that is not synced to any cloud services. The audio files will be deleted within 48 hours after transcription is completed. Only the researcher will have access to the recordings during this short period. All research data will be stored securely on a private, password-protected device. The transcripts will be used for analyzing the interview content, following a thematic analysis approach to identify patterns and insights relevant to the research questions. All personal identifiers will be removed during transcription, and the data will be fully anonymized in any reporting or publications.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

The results will be used for my master's thesis, as part of the research conducted at KTH Royal Institute of Technology, and within the ongoing DLR research on Human-Machine Interfaces for Maritime Engine Control Rooms. The data may be included in reports, academic publications, and potentially shared with DLR for internal research purposes. The thesis will be published. The findings may also be disseminated through conferences, workshops, or publications in relevant maritime technology and human-computer interaction journals, with all personal identifying information being anonymized.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

If you have any questions about this study, please feel free to contact me:
Malin Brilon: brilon@kth.se

If you have questions about your rights as a participant or would like to discuss any concerns about the study, you may contact my **thesis supervisor**:

Rey Rémy	**Jan Oberhagemann**	**Andrea Papenmeier**
(Project Supervisor KTH)	**(DLR Supervisor)**	**(Critical observer Utwente)**
rey.remy@kth.se	jan.oberhagemann@dlr.de	a.papenmeier@utwente.nl

Additionally, you can contact the Secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente through ethicscommittee-cis@utwente.nl

THANK YOU!

B.2 Informed Consent Form

Consent Form for Co-Designing Human-Machine Interface Workflows in Maritime Engine Control Rooms

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [__/__/____], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves taking part in a co-design workshop, which will include audio/video recordings, design activities, and simulator interaction. The audio and video recording will be securely deleted once the transcription is completed.	□	□
Risks associated with participating in the study		
Participation in the simulator-based scenario may cause temporary mental discomfort or stress due to the simulated emergency (e.g., flooding on board). Some participants may feel overwhelmed by the situation. However, the simulation is non-harmful, and support will be available if needed.	□	□
Use of the information in the study		
I understand that the information I provide will be used for the master's thesis, as part of the research conducted at KTH Royal Institute of Technology, and within the ongoing DLR research on Human-Machine Interfaces for Maritime Engine Control Rooms. The data may be included in reports, academic publications, and potentially shared with DLR for internal research purposes. Furthermore, I understand that the thesis will be published. The findings may also be disseminated through conferences, workshops, or publications in relevant maritime technology and human-computer interaction journals, with all personal identifying information being anonymized.	□	□
I understand that personal information that could identify me (e.g., name or location) will not be shared beyond the study team.	□	□
I agree that anonymized quotes from the workshop discussions may be used in publications.	□	□
I agree to be audio and video recorded during the workshop.	□	□
Future use and reuse of the information by others		
I agree that anonymized transcripts and artifacts from this workshop may be archived securely for future academic research.	□	□

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Signatures

Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Malin Brilon		
Researcher name	Signature	Date

Study contacts details for further information:

If you have any questions or concerns regarding this interview or the study, please feel free to contact us:

Malin Brilon
brilon@kth.se

Rey Rémy (Project Supervisor KTH)
rey.remy@kth.se

Jan Oberhagemann (Supervisor at DLR)
jan.oberhagemann@dlr.de

Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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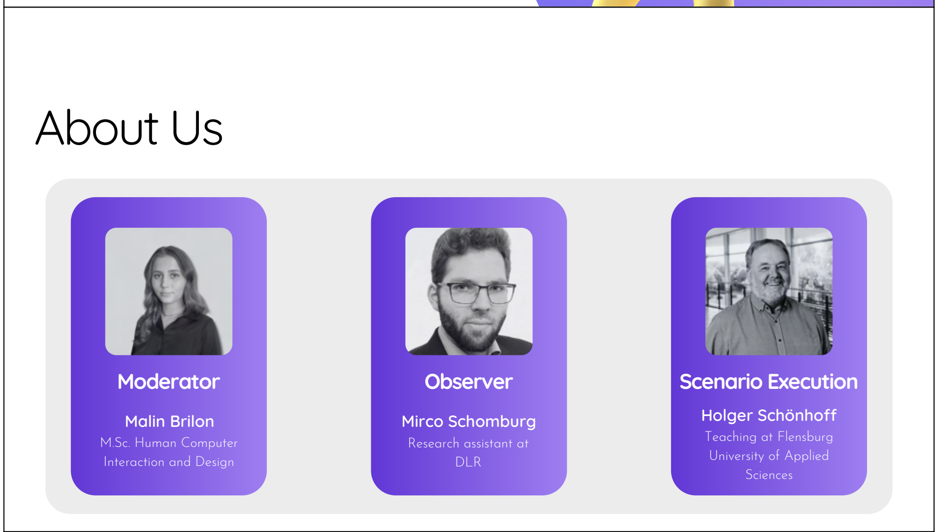
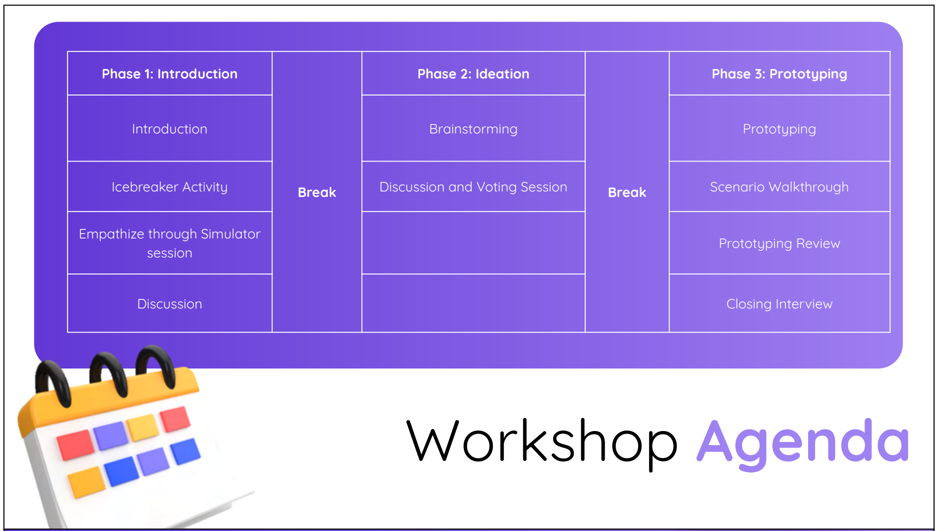
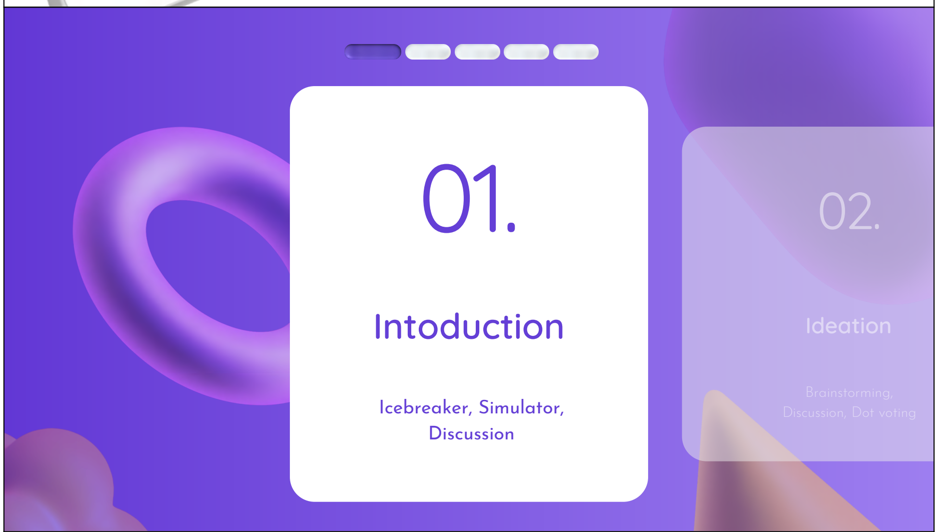
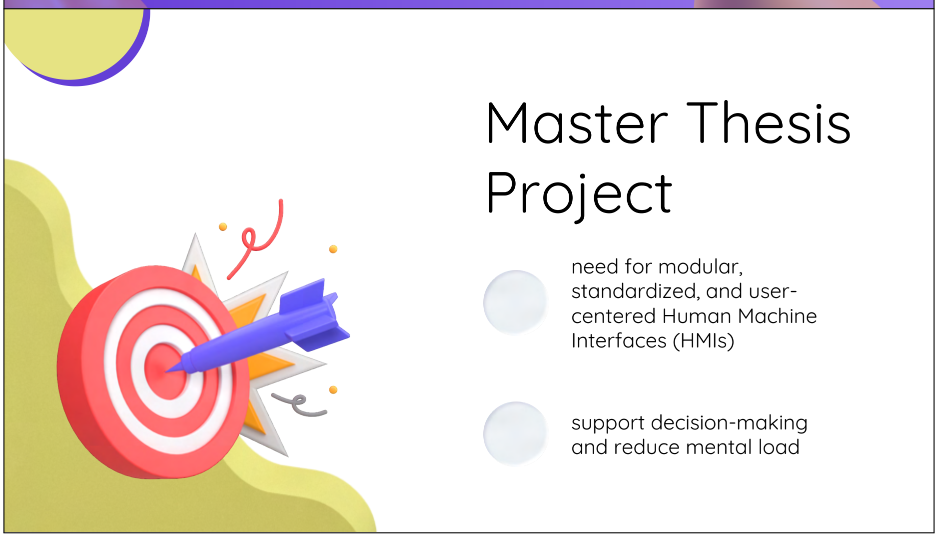
B.3 Co-design Workshop PowerPoint

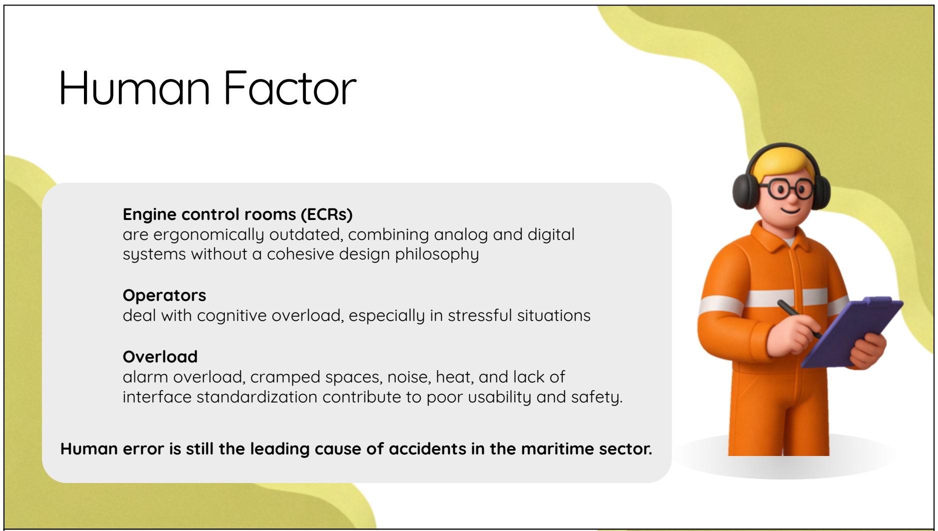


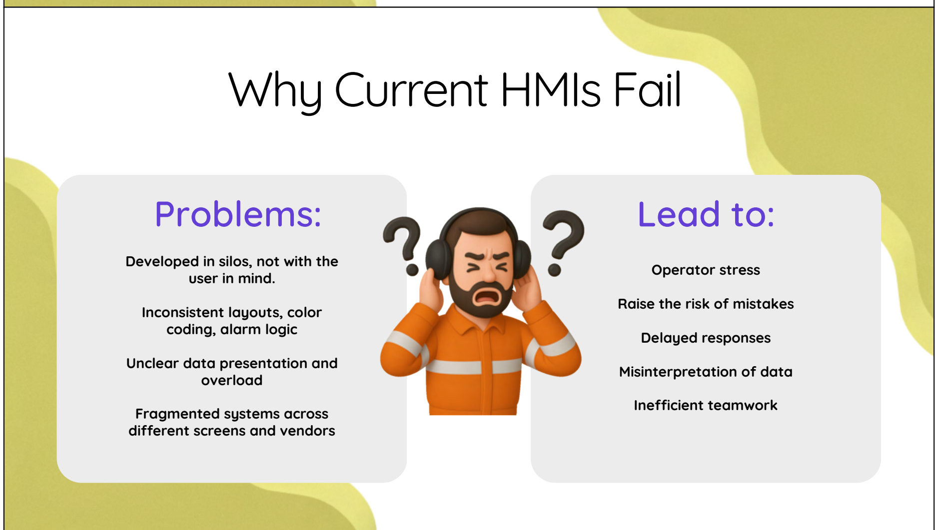


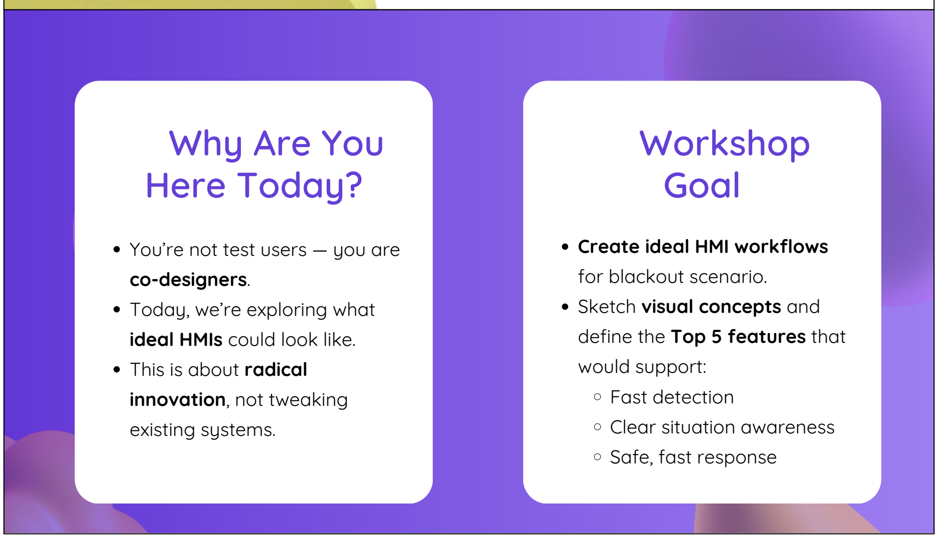
Phase 1: Introduction		Phase 2: Ideation		Phase 3: Prototyping
Introduction	Break	Brainstorming	Break	Prototyping
Icebreaker Activity		Discussion and Voting Session		Scenario Walkthrough
Empathize through Simulator session				Prototyping Review
Discussion				Closing Interview

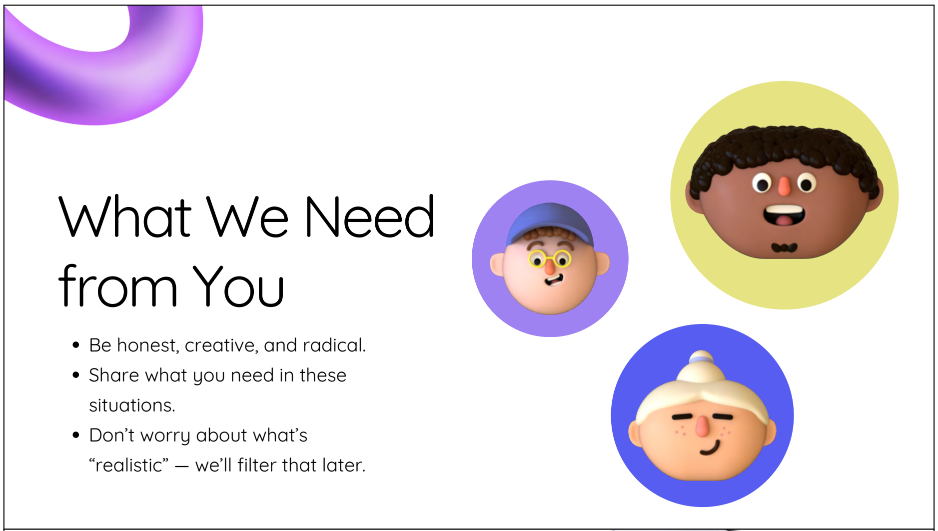


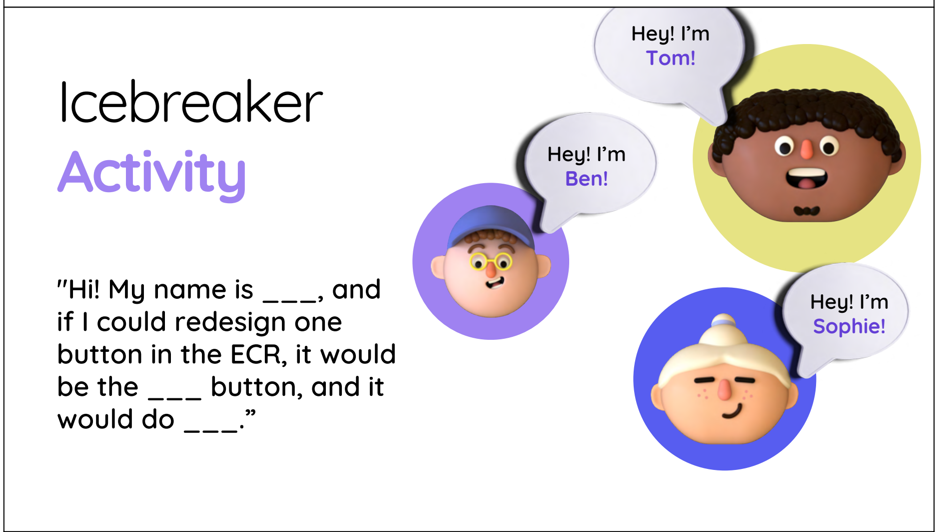


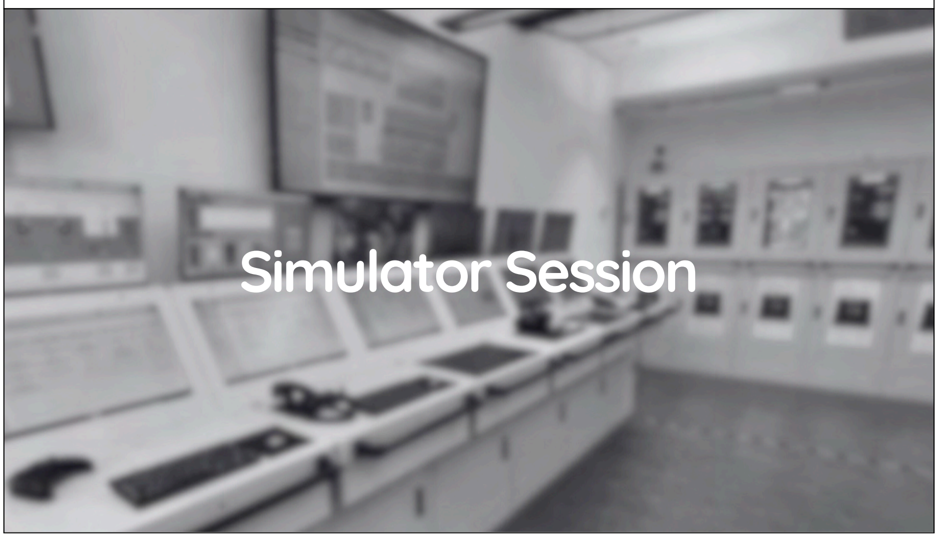

Human Factor
Engine control rooms (ECRs)
are ergonomically outdated, combining analog and digital systems without a cohesive design philosophy
Operators
deal with cognitive overload, especially in stressful situations
Overload
alarm overload, cramped spaces, noise, heat, and lack of interface standardization contribute to poor usability and safety.
Human error is still the leading cause of accidents in the maritime sector.

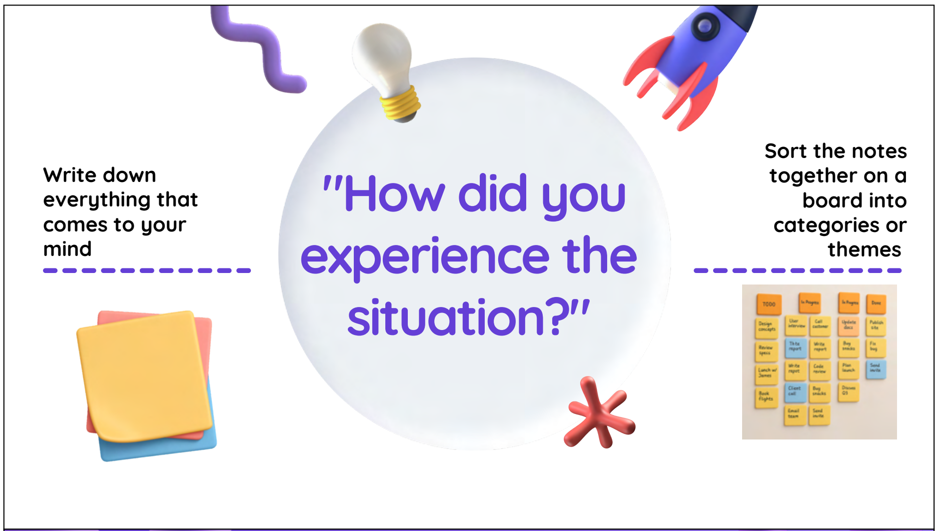

Why Current HMIs Fail
Problems:
Developed in silos, not with the user in mind.
Inconsistent layouts, color coding, alarm logic
Unclear data presentation and overload
Fragmented systems across different screens and vendors
Lead to:
Operator stress
Raise the risk of mistakes
Delayed responses
Misinterpretation of data
Inefficient teamwork

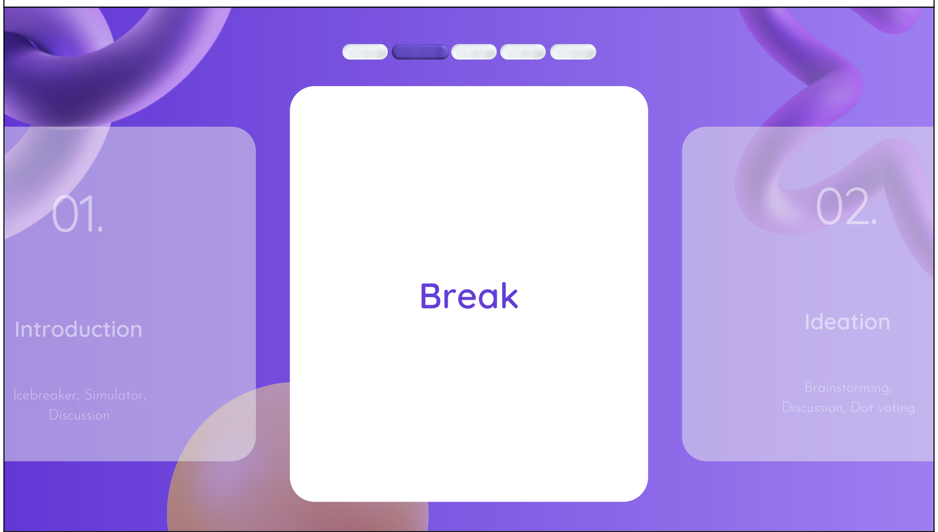

Why Are You Here Today?
• You're not test users — you are co-designers.
• Today, we're exploring what ideal HMIs could look like.
• This is about radical innovation, not tweaking existing systems.
Workshop Goal
• Create ideal HMI workflows for blackout scenario.
• Sketch visual concepts and define the Top 5 features that would support:
◦ Fast detection
◦ Clear situation awareness
◦ Safe, fast response

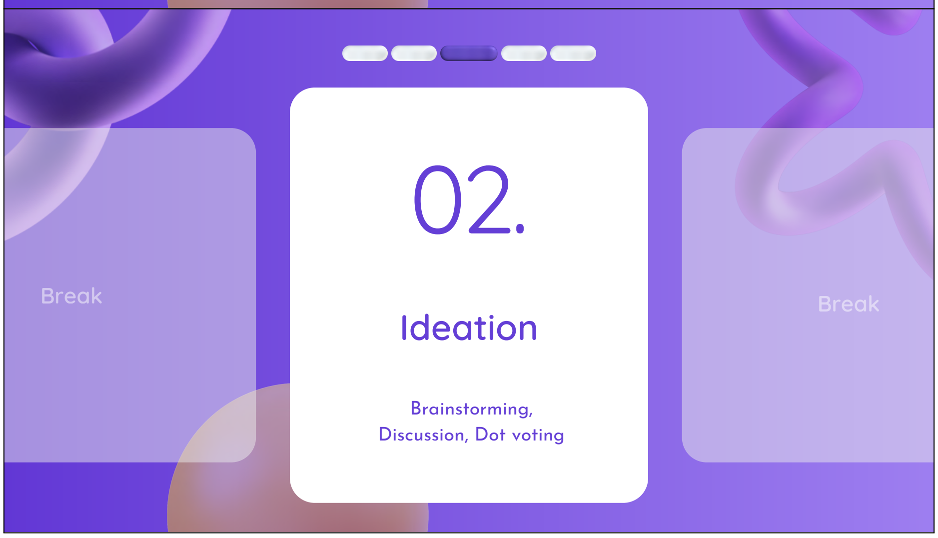

What We Need from You
• Be honest, creative, and radical.
• Share what you need in these situations.
• Don't worry about what's "realistic" — we'll filter that later.


Icebreaker
Activity
"Hi! My name is ___, and if I could redesign one button in the ECR, it would be the ___ button, and it would do ___."
Hey! I'm Tom!
Hey! I'm Ben!
Hey! I'm Sophie!

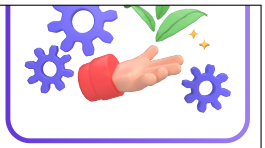

Simulator Session


Write down everything that comes to your mind
"How did you experience the situation?"
Sort the notes together on a board into categories or themes


01.
Introduction
Icebreaker, Simulator, Discussion
Break
02.
Ideation
Brainstorming, Discussion, Dot voting


Break
02.
Ideation
Brainstorming, Discussion, Dot voting
Break

Crazy 8

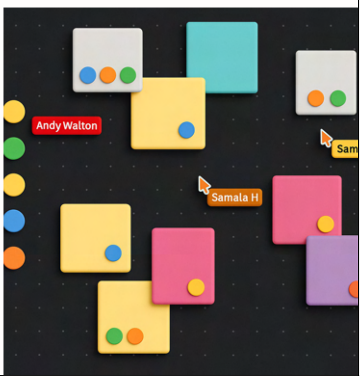


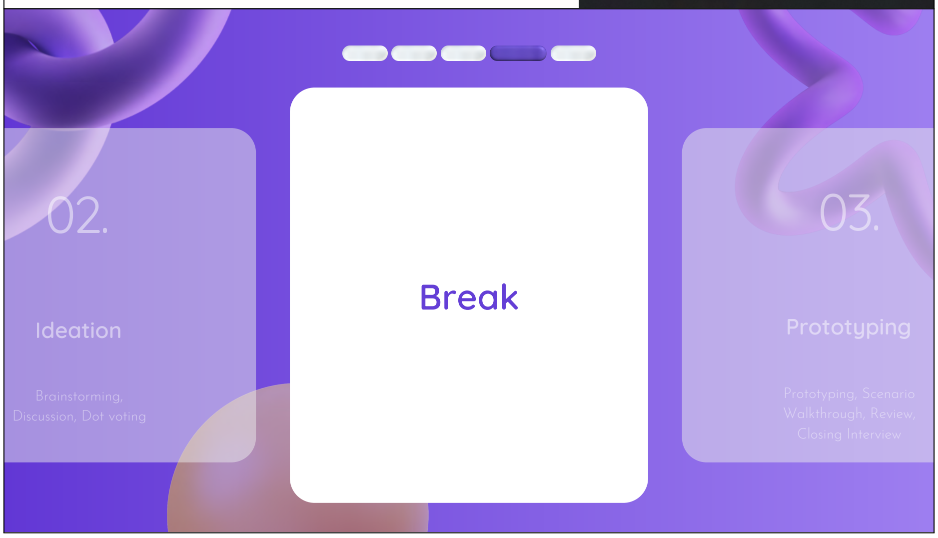
Visualizes eight possible solutions in eight minutes and eight fields

"In this scenario, what would a perfect workflow look like?"
"What information would you want instantly? What controls would you want immediately available?"
"What controls or actions should be at hand right away?"

Discussion & Dot Voting

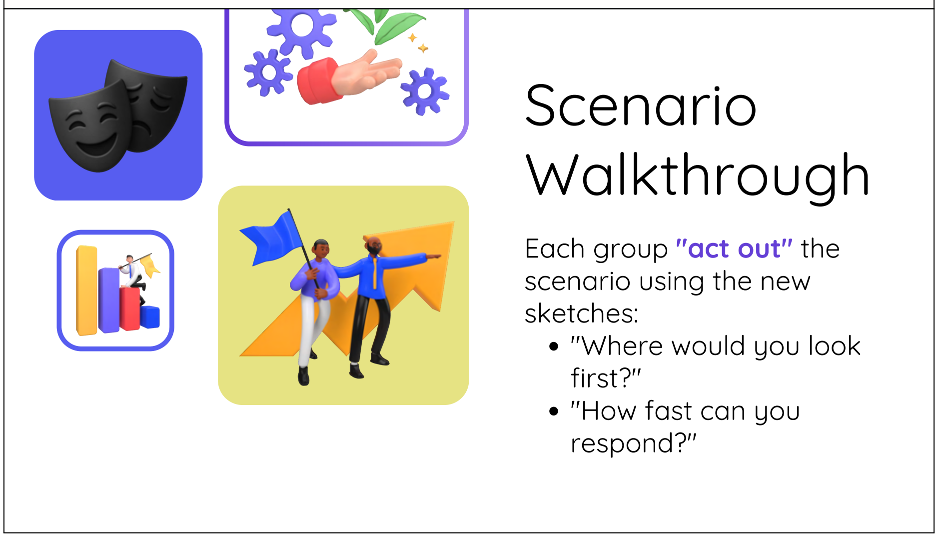
Vote 3 dots on features or elements you find most valuable.






Break
03.
Prototyping
Prototyping, Scenario Walkthrough, Review, Closing Interview

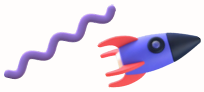

Prototyping
Build groups of 2-3 people
Develop visual and haptic prototypes of ideal HMI concepts.
40 minutes


Scenario Walkthrough
Each group "act out" the scenario using the new sketches:
• "Where would you look first?"
• "How fast can you respond?"

Prototyping
Review

Group discussion
- "What works?"
- "What could be improved?".

Closing
Interview

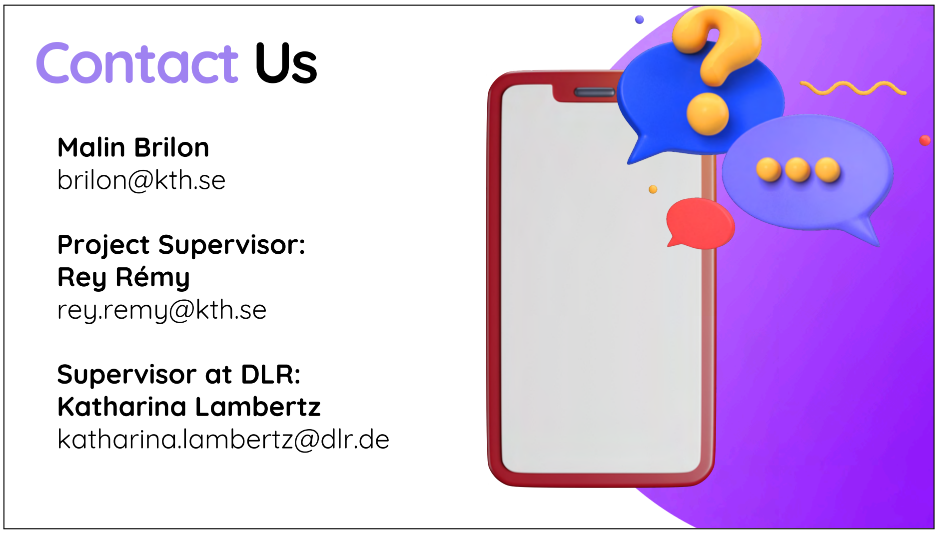


What HMI features would improve safety or efficiency most?

What worket well & what didnt?

What was surprising?

Thank You So Much!


Contact Us
Malin Brilon
brilon@kth.se
Project Supervisor:
Rey Rémy
rey.remy@kth.se
Supervisor at DLR:
Katharina Lambertz
katharina.lambertz@dlr.de

B.4 Screening questioner

Co-Design Workshop Registration Survey

* Gibt eine erforderliche Frage an

Co-Design Workshop

Welcome to the Co-Design Workshop on Maritime HMIs!

This short form is to register your interest in participating in a co-design workshop focused on improving Human-Machine Interfaces (HMIs) in ship engine control rooms (ECRs).

What it's about

We're exploring how modular and user-friendly interfaces can help engineers work more efficiently in high-stress environments like the ECR. The workshop will be hands-on, using real scenarios and prototyping methods.

Duration

Approximately 4 hours, including breaks.

Why I'm doing this

This workshop is part of my Master's thesis at KTH Royal Institute of Technology, conducted in collaboration with the German Aerospace Center (DLR). Your insights will help shape safer, more ergonomic future systems in maritime technology.

Contact

Malin Brilon (m.brilon@kth.se)
Project Supervisor: Rey Rémy (rey.remy@kth.se)

1. **What is your age?** *

   ____

2. **What is your gender?** *

   Markieren Sie nur ein Oval.

   - ◯ Male
   - ◯ Female
   - ◯ Non-binary
   - ◯ Prefer not to say

3. **Have you completed training in the maritime sector?** *

   Wählen Sie alle zutreffenden Antworten aus.

   - ☐ Training as a ship mechanic
   - ☐ Studies in the field of marine technology / marine engineering
   - ☐ Training as a technician (e.g. electrical engineering, mechanical engineering)
   - ☐ No training in the maritime sector
   - ☐ Sonstiges: ____________________

4. **What is your current role or status?** *

   Markieren Sie nur ein Oval.

   - ◯ Marine engineering student
   - ◯ Marine technician
   - ◯ Maritime professional
   - ◯ Sonstiges: ____________________

5. **Have you already worked at sea?** *

   Markieren Sie nur ein Oval.

   - ◯ No
   - ◯ Yes

6. **If yes:** How many months or years did you work at sea in total? *
   Please state the duration as precisely as possible (e.g. "approx. 3 years" or "18 months").

   ____

7. **How many months or years of experience do you have working in an engine control room (ECR)?** *

   ____

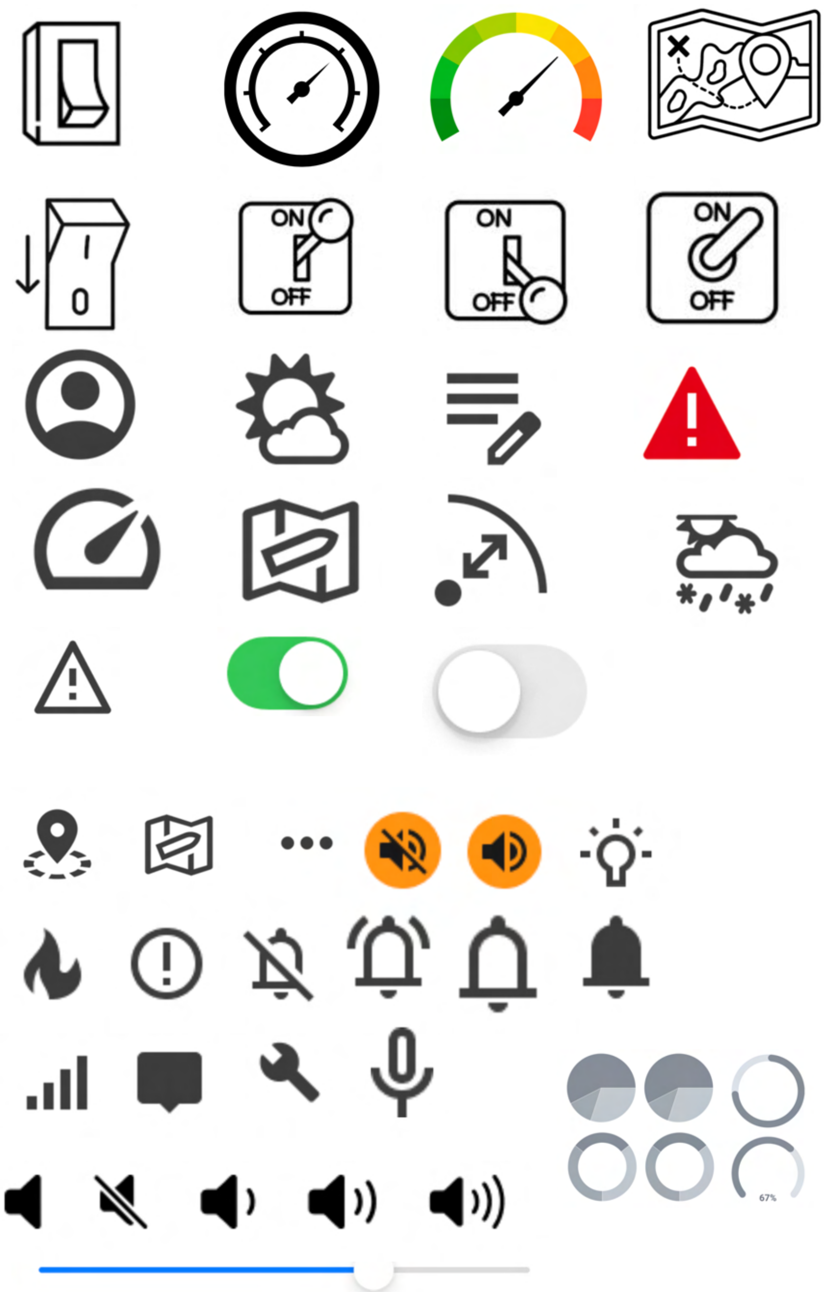
8. **Have you participated in usability testing or design workshops before?** *

Markieren Sie nur ein Oval.

- Yes
- No
- Not sure

9. **Do you have any dietary or accessibility needs for the workshop?**

B.5 UI Elements

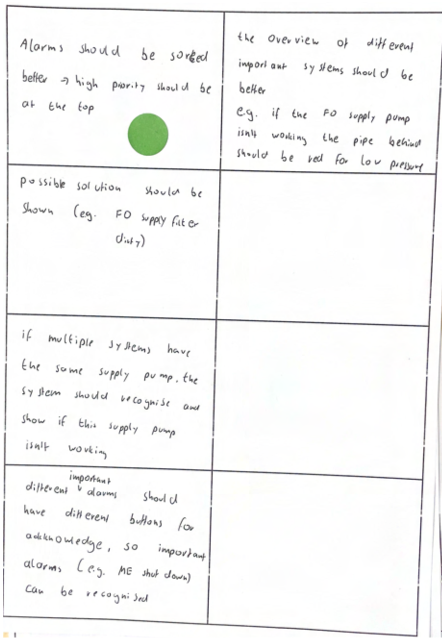


B.6 Screening questioner results

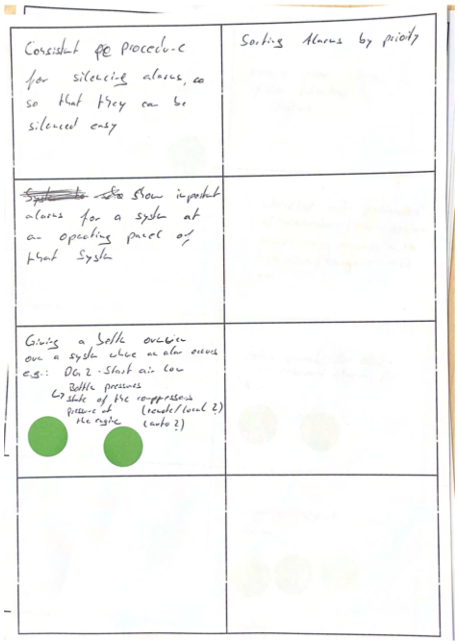
Table B.1: *Overview of the participants' answers to the screening questionnaire.*

What is your age?	What is your gender?	Have you completed training in the maritime sector?	What is your current role or status?	Have you already worked at sea?	If yes: How many months or years did you work at sea in total? Please state the duration as precisely as possible (e.g., "approx. 3 years" or "18 months").	How many months or years of experience do you have working in an engine control room (ECR)?	Have you participated in usability testing or design workshops before?	Do you have any dietary or accessibility needs for the workshop?
25	Male	Training as a ship mechanic	Marine engineering student	Yes	3 years apprenticeship and 1 year as ship mechanic	0	No	-
25	Male	Training as a ship mechanic	Marine engineering student	Yes	19 months	2	No	-
26	Male	Training as a ship mechanic	Nautical student	Yes	2 years	1 year	No	No
23	Male	Training as a ship mechanic	Nautical science student	Yes	19 months	10	No	-
34	Male	Ship Operations Assistant	Marine engineering student	Yes	17 months	2 months	No	-
25	Male	Training as a ship mechanic	Marine engineering student	Yes	2 years	1 year	No	-

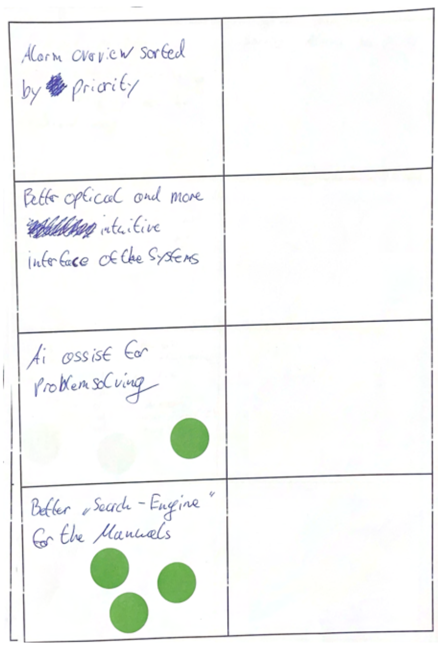
B.7 Co-design Workshop Results



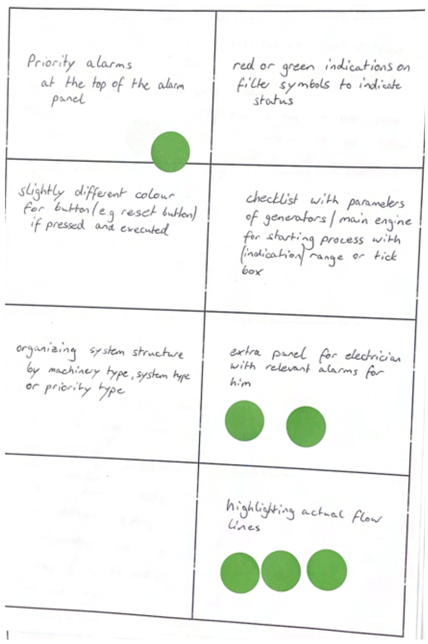
Participant 1



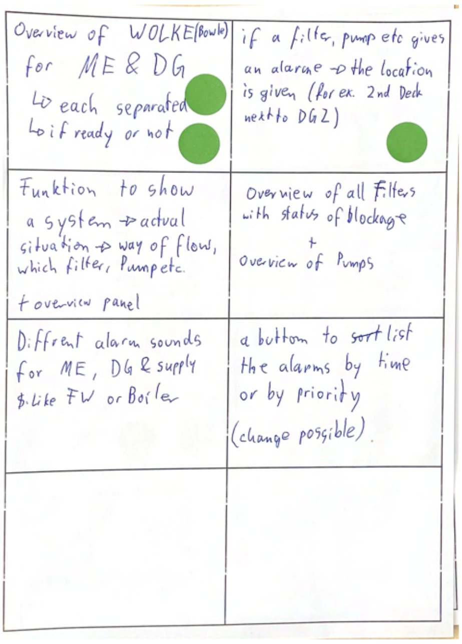
Participant 2



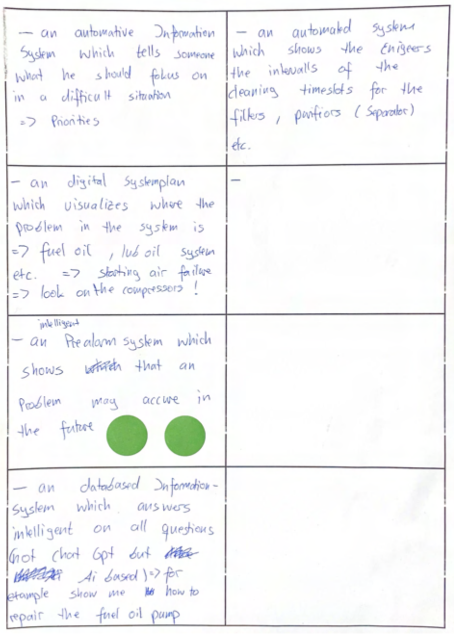
Participant 3



Participant 4



Participant 5



Participant 6

B.8 Analysis Workshop Stage 1 and 2

This list shows the identified codes grouped into categories for each workshop phase.

Phase 1

Interface Design and Usability

- Lack of alarm prioritization
- Confusing visual overview
- Unclear alarm source
- Missing real-time feedback
- No confirmation after actions
- No clear status information (e.g., filters)
- Hard to find cause of problem
- UI not intuitive for fuel paths
- Lack of structure in alarm display
- Overwhelming alarm lists
- Difficult visibility of key alarms
- Critical information not prominent

Alarm Management

- Too many alarms at once
- Overlooked important alarms
- Noisy and stressful environment
- Hard to silence alarms
- No differentiation between alarms
- No smart sorting of alarms
- Confusing or misleading alerts

Cognitive Load and Stress

- Overload from unsorted info
- Hard to know where to focus
- Stress from high noise level
- Frustration from unclear alarm meaning
- Pressure to act fast without overview
- Alarm panel information overload

Desired Interface Features

- AI-assisted alarm sorting
- “Magic problem button” for diagnostics
- Graphical visualization of system paths
- System should highlight key missing elements
- Color/sound-coded alerts per system
- Custom overview panel for essentials (fuel, lube oil, air)
- Filter/blockage feedback system
- Show helpful real-time changes
- Alarm acknowledgment differentiation
- Contextual HMI guidance
- Real-time parameter updates
- Flow visualization button

Positive Feedback

- Overview screens help chiefs gain fast situational awareness
- Valve operation interface was easy
- General satisfaction with system layout (from some)

Phase 2

Alarm Management

- Alarms should be sorted by priority
- Different sounds for different alarm types
- Alarms should stay visible until addressed
- Option to switch alarm list sorting (e.g., time vs. priority)
- Confusion due to silencing alarms from different panels
- Important alarms should be displayed prominently (e.g., at system panel/switchboard)
- Consistent procedure for silencing alarms
- Search function for manuals
- Dependency recognition among systems
- Detailed alarm information view

Cognitive Support & Problem Solving

- AI system for diagnosing and suggesting solutions
- Checklists linked to alarms
- System should suggest causes and next steps
- Pre-alarms based on data trends (e.g., slow pressure drop)
- Database system for context-specific help (e.g., "what should I do?") based on engine manual
- Integrated technical knowledge database

System Overview and Visualization

- Fuel flow visualisation, switchable between overview and detail
- Digital plan of the engine room with alarm location highlighted
- Wolke system overview, shows readiness to start (fuel, air, lube, etc.)
- Color-coded system indicators (green/red, slight blink feedback for order acknowledgment)
- Valves and system status should be visually clear
- Filter blockages and pump problems should be visible and traceable
- Contextual system overview on alarm → On-click access to detailed system data
- Display component status (e.g., pressure, mode)
- Startup checklists with indicators
- Real-time system flow overview

Interface Design and Usability

- Cluttered interface hinders quick action
- More intuitive UI design needed
- Better search engine for technical manuals
- Dedicated panel for electricians
- Sorting systems by machinery type, priority, or function

Role Support and Workflow

- Chief needs clear overview for delegation
- Information flow should reach everyone, not just chief
- Audible alerts should be accessible to all
- Maintenance time slots should be trackable and acknowledged via UI

Phase 3

System Overview & Visualization

- Highlight flow of fuel path with color
- Flow path backgrounding of unused components
- Quick visual access to component status
- Malfunction highlight switch
- Color-coded component states (green/orange/red)
- Interactive engine room plan
- Indication lights linked to Wolke status
- Click-through from overview to system detail
- System map helps orientation on unfamiliar ships
- Need for updatable digital system plans
- Retrofitting engine and pipes to implement sensors for displaying flow
- Importance of visual clarity and minimalism
- Implementing a system plan seems possible only on newer systems
- To identify problems, a system plan of the area where the problem originates would help
- Engine status overview via traffic-light system
- Blocked status links to root cause

Alarm and Information Handling

- Switchable alarm sorting (priority/time)
- Color-coded alarm priority
- Clickable alarm descriptions
- AI assistant provides explanations

- Alarm overview improves reaction time
- Too much alarm info leads to overload
- Skepticism about AI prioritization accuracy
- Different combinations of alarms change context
- Valuing clear prioritization in critical situations
- AI that searches the manuals to suggest possible causes of alarms for solving them
- Training AI for alarm priority could take a lot of time
- Skepticism towards accurate alarm priority list made by AI
- Alarm priorities change with different combinations of alarms
- Clickable help icons for alarm explanations
- Engine state gauges per subsystem (start air, oil, etc.)

Cognitive Support & Problem Solving

- Wolke for start-readiness overview
- Red/green indicators for engine readiness
- Guided attention to next relevant system screen
- Clear overview reduces time spent searching
- Helps fast decision-making in stressful situations
- Prototypes increase problem identification
- Reduced time to action through clear interface design
- Wolke diagram helps quick thinking

Role Support and Learning

- Chief engineer needs fast situational overview
- System should support, not replace, human judgment
- Interface should support both novices and experts
- Interactive maps improve onboarding and training
- Group discussion boosts creativity and idea quality
- One design can support multiple scenarios
- Warning against over-reliance on automation
- Valuing collaborative idea generation
- Appreciating realistic scenario-based designing
- Recognizing enhanced results from group interaction

Usability & Design Preferences

- Clear diagrams and symbols aid interpretation
- Clickable interactions improve usability
- Too much info on one panel is counterproductive
- User should be able to update system content
- Sorting filters and flow visualization helps workflow

B.9 Analysis Workshop Stage 3

Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase.

Assessment criteria	Code	Phase
Alarm Handling & Information Management	Lack of alarm prioritization	1
Alarm Handling & Information Management	Unclear alarm source	1
Alarm Handling & Information Management	Overlooked important alarms	1
Alarm Handling & Information Management	Hard to silence alarms	1
Alarm Handling & Information Management	No smart sorting of alarms	1
Alarm Handling & Information Management	Confusing or misleading alerts	1
Alarm Handling & Information Management	wishing for AI-assisted alarm sorting	1
Alarm Handling & Information Management	Alarms should be sorted by priority	2
Alarm Handling & Information Management	Alarms should stay visible until addressed	2
Alarm Handling & Information Management	Confusion due to silencing alarms from different panels	2
Alarm Handling & Information Management	Important alarms should be displayed prominently (e.g., at system panel/switchboard)	2
Alarm Handling & Information Management	Wishing for alarm acknowledgment differentiation	1
Alarm Handling & Information Management	Wishing for detailed alarm information view	2
Cognitive Load	wishing for “Magic problem button” for diagnostics	1

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	Code	Phase
Cognitive Load	Hard to find cause of problem	1
Cognitive Load	Overwhelming alarm lists	1
Cognitive Load	Noisy and stressful environment	1
Cognitive Load	Overload from unsorted info	1
Cognitive Load	Hard to know where to focus	1
Cognitive Load	Stress from high noise level	1
Cognitive Load	Frustration from unclear alarm meaning	1
Cognitive Load	Pressure to act fast without overview	1
Cognitive Load	Wishing for flow path backgrounding of unused components	3
Cognitive Load	Wishing for AI assistant provides explanations	3
Cognitive Load	Too much alarm info leads to overload	3
Cognitive Load	Skepticism about AI prioritization accuracy	3
Cognitive Load	Different combinations of alarms change context	3
Cognitive Load	Wishing for guided attention to next relevant system screen	3
Cognitive Load	Clear overview reduces time spent searching	3
Cognitive Load	System should support—not replace—human judgment	3
Cognitive Load	Too much info on one panel is counterproductive	3
Cognitive Load	Valuing clear prioritization in critical situations	3
Cognitive Load	AI that searches the manuals to suggest possible causes of alarms for solving them	3
Cognitive Load	Wolke diagram helps quick thinking	3
Cognitive Load	Wishing for AI system for diagnosing and suggesting solutions	2
Cognitive Load	Wishing for checklists linked to alarms	2
Cognitive Load	System should suggest causes and next steps	2

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	Code	Phase
Cognitive Load	Wishing for pre-alarms based on data trends (e.g., slow pressure drop)	2
Cognitive Load	Wishing for contextual HMI guidance	1
Cognitive Load	Wishing for flow visualization button	1
Cognitive Load	Wishing for real-time parameter updates	1
Cognitive Load	Alarm panel information overload	1
Feedback Workshop	Group discussion boosts creativity and idea quality	3
Feedback Workshop	Prototypes increase problem identification	3
Feedback Workshop	Appreciating realistic scenario-based designing	3
Feedback Workshop	Recognizing enhanced results from group interaction	3
Modularity & Customization	Custom overview panel for essentials (fuel, lube oil, air)	1
Modularity & Customization	Wishing for option to switch alarm list sorting (e.g., time vs. priority)	2
Modularity & Customization	Wishing for Contextual system overview on alarm → On-click access to detailed system data	2
Modularity & Customization	Dedicated panel for electricians	2
Modularity & Customization	Wishing for sorting systems by machinery type, priority, or function	2
Modularity & Customization	Interactive engine room plan	3
Modularity & Customization	Wishing for click-through from overview to system detail	3
Modularity & Customization	Need for updatable digital system plans	3
Modularity & Customization	Interface should support both novices and experts	3

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	Code	Phase
Modularity & Customization	Interactive maps would improve onboarding and training	3
Modularity & Customization	One design can support multiple scenarios	3
Modularity & Customization	User should be able to update system content	3
Modularity & Customization	Retrofitting engine and pipes to implement sensors for displaying flow	3
Modularity & Customization	Implementing a system plan seems possible only on newer systems	3
Operational Performance Support	Wishing for fuel flow visualization – switchable between overview and detail	2
Operational Performance Support	Sorting filters and flow visualization would help workflow	3
Operational Performance Support	Missing real-time feedback	1
Operational Performance Support	System should highlight key missing elements	1
Operational Performance Support	Filter/blockage feedback system	1
Operational Performance Support	Show helpful real-time changes	1
Operational Performance Support	Overview screens would help chiefs gain fast situational awareness	1
Operational Performance Support	Wishing for search engine for manuals	2
Operational Performance Support	Wishing for database system for context-specific help (e.g., “what should I do?”) based engine manual	2

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	Code	Phase
Operational Performance Support	Wishing for Integrated technical knowledge database	2
Operational Performance Support	Wishing for Wolke system overview – shows readiness to start (fuel, air, lube, etc.)	2
Operational Performance Support	Filter blockages and pump problems should be visible and traceable	2
Operational Performance Support	Display component status (e.g., pressure, mode)	2
Operational Performance Support	Better search engine for technical manuals	2
Operational Performance Support	Chief needs clear overview for delegation	2
Operational Performance Support	Maintenance time slots should be trackable and acknowledged via UI	2
Operational Performance Support	Wishing for quick visual access to component status	3
Operational Performance Support	Alarm overview would improve reaction time	3
Operational Performance Support	Wishing for Wolke for start-readiness overview	3
Operational Performance Support	Wolke would help fast decision-making in stressful situations	3
Operational Performance Support	Chief engineer needs fast situational overview	3
Operational Performance Support	Training AI for alarm priority could take a lot of time	3
Operational Performance Support	Skepticism towards accurate Alarm priority list made by AI	3

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	**Code**	**Phase**
Operational Performance Support	Alarm priorities change with different combinations of alarms	3
Operational Performance Support	To identify problems, a system plan of the area where the problem originates would help	3
Operational Performance Support	Wishing for startup checklists with indicators	2
Operational Performance Support	Wishing for real-time system flow overview	2
Operational Performance Support	Wishing for blocked status links to root cause	3
Operational Performance Support	Wishing for engine state gauges per subsystem (start air, oil, etc.)	3
Standardization & Consistency	Lack of structure in alarm display	1
Standardization & Consistency	No differentiation between alarms	1
Standardization & Consistency	Wishing for Color/sound-coded alerts per system	1
Standardization & Consistency	Wishing for different sounds for different alarm types	2
Standardization & Consistency	Wishing for consisted procedure for silencing alarms	2
Standardization & Consistency	Wishing for color-coded system indicators (green/red, slight blink feedback for order acknowledgment)	2
Standardization & Consistency	Audible alerts should be accessible to all	2
Standardization & Consistency	Wishing for color-coded component states (green/orange/red)	3

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	**Code**	**Phase**
Standardization & Consistency	Wishing for indication lights linked to Wolke status	3
Standardization & Consistency	Wishing for color-coded alarm priority	3
Standardization & Consistency	Wishing for red/green indicators for engine readiness	3
Standardization & Consistency	Warning against over-reliance on automation	3
Standardization & Consistency	Wishing for dependency recognition among systems	2
Usability & Interface Clarity	Confusing visual overview	1
Usability & Interface Clarity	No confirmation after actions	1
Usability & Interface Clarity	No clear status information (e.g., filters)	1
Usability & Interface Clarity	UI not intuitive for fuel paths	1
Usability & Interface Clarity	Wishing for Graphical visualization of system paths	1
Usability & Interface Clarity	Valve operation interface was easy	1
Usability & Interface Clarity	General satisfaction with system layout (from some)	1
Usability & Interface Clarity	Wishing for digital plan of the engine room with alarm location highlighted	2
Usability & Interface Clarity	Wishing for valves and system status should be visually clear	2

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	**Code**	**Phase**
Usability & Interface Clarity	Cluttered interface hinders quick action	2
Usability & Interface Clarity	More intuitive UI design needed	2
Usability & Interface Clarity	Information flow should reach everyone, not just chief	2
Usability & Interface Clarity	Switchable alarm sorting (priority/time)	3
Usability & Interface Clarity	Wishing for highlighted flow of fuel path with color	3
Usability & Interface Clarity	Wishing for malfunction highlight switch	3
Usability & Interface Clarity	System map would help orientation on unfamiliar ships	3
Usability & Interface Clarity	Wishing for clickable alarm descriptions	3
Usability & Interface Clarity	Clear diagrams and symbols aid interpretation	3
Usability & Interface Clarity	Clickable interactions would improve usability	3
Usability & Interface Clarity	Importance of visual clarity and minimalism	3
Usability & Interface Clarity	Clear Interface would reduce time to action through interface design	3
Usability & Interface Clarity	Difficult visibility of key alarms	1
Usability & Interface Clarity	Critical information not prominent	1

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Table B.2: Assessment criteria, associated codes, and their corresponding workshop phase (continued).

Assessment criteria	**Code**	**Phase**
Usability & Interface Clarity	Wishing for engine status overview via traffic-light system	3
Usability & Interface Clarity	Wishing for clickable help icons for alarm explanations	3

Appendix C

Use of Generative AI Tools

This thesis has made limited use of the generative AI tool ChatGPT to support the writing process. Specifically, the tool was used for:

Refurbishing sentence structure to enhance clarity and coherence,

Detecting and correcting spelling and grammatical errors,

Paraphrasing and polishing sections of the text to improve academic tone and readability.

At no point was sensitive personal data or confidential research content submitted to the AI tool. Use was limited to non-personal, non-sensitive content in compliance with the General Data Protection Regulation (GDPR). The AI assistance was employed as a writing aid only and did not contribute to the content generation, data analysis, or scientific conclusions of the thesis.

This statement is made to meet the transparency requirements of the EU AI Act (Regulation 2024/1689), ensuring both human and machine-readable documentation of AI use.

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