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Status Monitoring in Multivessel MASS Operations

Designing for Shared Situational Awareness

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Abstract

Autonomous maritime shipping operations, where vessels are controlled from land-based operation centers, will dramatically change maritime officer's work. In remote and autonomous operations, multiple ships will likely be operated simultaneously. This gives rise to the need for new types of control tools. Specifically this study looks at the user interfaces of the technical systems in remote maritime operations.

Related research is done on shared situational awareness and interface design that could enhance it. There are very few research papers that would address this issue in the context of remote and autonomous maritime operations. The research question in this study is what new requirements does the changing working context bring for designing the status monitoring tools for remote and autonomous maritime operations.

A human-centred design process forms the core of the study. User requirements for a status monitoring tool were refined through expert participation, and a clickable prototype with multiple novel features that were inspired by the expert's insights was designed and evaluated. The prototype featured for instance the alarm aggregation principle for the remote and autonomous maritime context. Contextually new designs proved to be effective tools in eliciting user requirements in this emerging field.

The study contributes to the body of knowledge about future remote maritime officers' requirements concerning system status monitoring.

Keywords autonomous ships, alert management, MASS, remote maritime operation, requirements gathering, shared situational awareness, status monitoring

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Työn nimi Käyttöjärjestelmän tilan valvonta autonomisessa monen laivan operaatiossa

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Tiivistelmä

Autonominen merenkulku, jossa aluksia valvotaan ja ohjataan maissa sijaitsevista keskuksista käsin, tulee muuttamaan merenkulkijoiden työtä merkittävästi. Etä- ja autonomisissa operaatioissa tullaan todennäköisesti liikennöimään useita aluksia samanaikaisesti. Tämä tuo esiin uudentyyppisten hallintatyökalujen tarpeen. Erityisesti tässä tutkimuksessa tarkastellaan autonomisen, etänä valvottavan merenkulun teknisten järjestelmien käyttöliittymiä.

Aiempi aiheeseen liittyvä tutkimus on käsitellyt jaettua tilannetietoisuutta ja käyttöliittymäsuunnittelua, joka voisi edesauttaa jaetun tilannetietoisuuden muodostumista. Etänä valvottaviin, autonomisen merenkulun sovelluksiin liittyen tutkimusta näistä aiheista on tehty toistaiseksi vain vähän. Tämän tutkimuksen tutkimuskysymys on se, millaisia uusia vaatimuksia muuttuva työn viitekehys tuo autonomisen merenkulun tilavalvontajärjestelmien suunnittelulle.

Tämän tutkimuksen keskeisin osa on ihmislähtöinen suunnitteluprosessi, johon alan erityisasiantuntijat ottivat osaa. Tilanvantojärjestelmän käyttäjävaatimuksia kerättiin ja tarkennettiin tämän prosessin kuluessa. Prosessissa myös toteutettiin toiminnallinen käyttöliittymän malli, joka sisälsi monia uudentyyppisiä, käyttäjien tarpeisiin perustuvia ominaisuuksia. Mallin sisäältämät, viitekehykselle uudentyyppiset ominaisuudet osoittautuivat tehokkaaksi tavaksi tuoda esiin käyttäjien tarpeita alalla, jonka keskeiset piirteet on vasta muovautumassa.

Tutkimus lisää tietoa tulevaisuuden meriliikenteen operaattoreiden käyttäjävaatimuksista liittyen tilavalvontajärjestelmiin

Avainsanat autonomiset laivat, hälytysten hallinta, MASS, laivojen etäohjaus, käyttäjävaatimusten kerääminen, jaettu tilannetietoisuus, automaatiojärjestelmän tilavalvonta

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1 Introduction

The maritime industry is well underway in developing the technology needed to start autonomous cargo shipping operations on a commercial scale. Several trial projects in the emerging field of maritime autonomous surface ships (MASS) have been executed since 2010s, such as the cargo ship Yara Birkeland by Kongsberg and Yara, and the MUNIN research project coordinated by Fraunhofer and funded by the European Commission (Kaarstad and Braaseth, 2020).

The developers of MASS technologies expect multiple benefits of autonomous shipping. Among these are for instance increased safety at sea due to less human navigational errors and not having a crew on board. Emissions and fuel costs are expected to be lower due to route optimization, the possibility of lower cruising speed, and more economical ship design. Fully autonomous vessels do not need for instance crew accommodation, crew safety equipment, sanitary systems, air conditioning, or bridge, thus the investment costs are lower (Negenborn, 2023, Massterly 2023).

MASS operation may mean ships that have different levels of automation, from systems that assist human onboard crew, to systems that are able to carry out a whole operation without human intervention (IMO, 2021). The ship could also be operated remotely, but still have crew on board who are able to control the ship if needed. Different levels of vessel autonomy could also take place within the same operation.

Before remote and autonomous, unmanned operations are possible, except in limited, national-level test settings, the adjacent technologies and operational procedures need to be first verified by the International Maritime Organization (IMO). Thereafter the legislation based on these can be implemented by each country.

It is widely noticed that the concept of remote and autonomous maritime operation leads to many challenges. The Norwegian DNV, one of the maritime certification bodies that has implemented a preliminary class guideline for autonomous ships, states that the introduction of novel technologies shall not impair the safety of people or the environment or bear a negative impact on other societal aspects. DNV states that the new remote and autonomous operational concepts shall have equivalent or better safety when compared to conventional vessel operations (DNV, 2021).

Even for unmanned, autonomous ships, there will be a human in the loop securing safe operation, capable of intervening in unexpected scenarios. Problems that operators of highly reliable systems may face have been widely discussed in automation studies. Bailey and Scerbo showed that when an operator highly trusts the system being monitored, their monitoring performance is low (Bailey and Scerbo, 2007).

It is timely to research how the work of these future operators is best designed. In the context of conventional shipping, Margareta Lützhöft found that mariners prefer to take over work from the automation, to be something else than a spectator onboard. She also proposes that the focus of research in the maritime domain should be in cognitive and social tasks, not engineering and devices. (Lützhöft, 2004).

The future remote operators of MASS will be similarily highly trained and skilled maritime experts as the officers today on conventional ships. Hanna Koskinen points out how in development of tools for safety-critical systems the opinions and concerns of the main users should be heard early on in the design process to ensure suitability of the tools for the task. (Koskinen, 2023). This is an excellent starting point for this study, which involves the expert users in the development of a novel system, in a human-centred design process.

1.1 Motivation of the Study

Kongsberg Maritime (KM) is developing solutions for managing multiple vessels and the Remote Operation Centre's (ROC) systems in a multivessel, remote and autonomous operation.

I had the chance to take part in the project as a master's thesis worker. I was presented with a topic concerning the future remote engineering officer's alarm management.

Typical for highly automated systems is that they are capable of producing formidable amounts of data and also system alarms. This is the case also for maritime automation systems. Alarms and alarm management are known to be central to usability of highly automated systems. Poor alarm system and alarm management design can lead to issues such as alarm fatigue, automation misuse, disuse or abuse, eventually leading to possible catastrophic consequences (Parasuraman and Riley, 1997; Lee and See, 2004).

Autonomy involving Artificial Intelligence (AI) is gradually entering the maritime scene. For mariners, the introduction of autonomous systems means significant changes in work. Skill and competency requirements will change, too. Veitch et. al. found navigators on a ferry with autonomous navigation and docking capability feeling a shift to a backup role, a “button presser”, possibly leading to boredom, degrading skills and stretched resources (Veitch et al., 2022).

1.2 Research Aims and Research Question

Introduction of remote and autonomous, multivessel shipping operations brings in new types of challenges for mariners. High situational awareness in an environment that is more complex than in conventional shipping is required among the operating team. This calls for new tools that help the team to respond quickly and adequately when unexpected situations emerge.

KM has identified that an alert management system through which the future remote engineering officers can handle the multiple vessel systems involved in a MASS operation is needed.

This study takes the view of a future remote maritime engineering officer to a multivessel MASS operation. Central in the study is to look at the topic through the lenses of system status monitoring, shared situational awareness and team communication in the future ROC’s. It is important to study how the increasing automation with more complex and intelligent systems changes the user requirements. The identified requirements in this study may lead to a better working environment for the future remote operators and may also inform designing similar monitoring systems in other domains.

This study aims to come up with an early phase design for an alarm management tool for remote and autonomous, multivessel shipping operations.

This is done in a human-centred design process that seeks to understand the context and user requirements of the future operators.

Research question is: **What types of new requirements the change in the working context of maritime engineering officers will bring?**

The study aims to add to the body of knowledge of user requirements for developing human-centred solutions for remote MASS operations.

1.3 Research Method

The main part of this study describes a human-centred design process that was carried out in September–December 2023. The standard HCD framework as described in ISO 9241-210 guided the process.

Informants of the study are Finnish and Norwegian maritime experts from Kongsberg Maritime and their customers specialising in short sea shipping, and maritime experts and teachers from Novia University of Applied Sciences.

The qualitative data in the study was collected in semi-structured expert interviews, workshops, brainstorming sessions and expert evaluations of the prototype. Data was extracted from audio recordings of these, and thematically analysed. Data is anonymised and used with the participants explicit consent.

The prototype was developed collaboratively with user experience designers from Kongsberg Maritime and evaluated by three maritime experts with substantial knowledge and personal experience of MASS systems.

1.4 Structure of the Thesis

Chapter 1. described the context and motivation of the study and introduced the aims of the research, research question and research method. In the next Chapter 2., existing research relevant for this study and relating theoretical frameworks are presented. Chapter 3. presents the human-centred design process that leads to development and evaluation of an early stage prototype for a status monitoring system. Chapter 4. presents the findings from the design process. In Chapter 5. the results are discussed. Chapter 6. is my personal reflection of a master's level design student on the work process.

2 Related Research and Theoretical Frameworks

The evolution of maritime technology is closely connected to the four industrial revolutions. After the renaissance, with the first industrial revolution that started around 1750, steam engines became an alternative for sails. With the second industrial revolution that introduced electrical production a hundred years later around 1850, steel hulls became possible to build, ships grew in size and became more durable, allowing larger cargo capacity. Third industrial revolution in the 20th century saw the emergence of electronics and electronic navigation devices, such as radar and GPS (Hattendorf, 2007; Kumar et al., 2019).

The so-called fourth industrial revolution is signified by smart technologies that make use of the capabilities of general digitalization and AI-driven technologies (Breque et al., 2021; Kumar et al., 2019). Possibly due to the safety critical and highly regulated nature of maritime operations, the maritime sector has not been among the first to adopt cutting edge smart technologies. One field expert in my study stated that “in the maritime world, things change slowly”. But now with the advent of autonomous shipping, it seems that the maritime world will soon be in the vanguard of smart technologies.

2.1 Situational Awareness in MASS Operations

Remote operator’s situational awareness (SA) in MASS operations, and specifically in the light of teamwork, has not been yet widely studied. Veitch & Alsos included 42 studies in a systematic review about human supervision and control of autonomous ships. Of these, in 9 papers situation awareness was referred to, being the most common Human-Computer Interaction (HCI) paradigm among them. (Veitch and Alsos, 2022).

Kari and Steinert point out that situational awareness in the context of MASS is often discussed based on human-machine interactions, but could also be researched based on interactions within the operation team. They conclude that SA should be considered from both perspectives for adequate levels of overall SA to be achieved (Kari and Steinert, 2021).

An early paper for this new domain by Porathe et. al. highlights how operators in future ROCs will lack many physical cues that mariners on traditional ships are used to. These are for instance for the navigators the movements of the ship caused by rough weather – something that is termed “ship sense” (Porathe et al., 2014; Prison et al., 2013).

Through an experiment that was carried in a simulator setting, Man et. al. found working from a ROC posing multiple challenges for the operator to develop adequate SA. They state for instance that a ROC alert system should have “proactive”, forward-looking capabilities, as they found it likely that the remote operating team will need more time to react in a problem scenario than on conventional ships. Adequate team communication, and acknowledging and making efficient use of different team member’s expertise was found to be crucial. They also stress the importance of appropriate working procedures that take into account the maritime regulations (Man et al., 2015).

2.2 Theoretical Frameworks

How to design usable and safe interactive tools for operators of safety critical systems – such as for remote operators of ships – is a question that touches a vast amount of academic research fields. Under the umbrella of human factors/ergonomics are an array of research topics. Of primary interest for this study are those that concern situational awareness (SA).

In the following, I will present academic research approaches from the field of human factors that are considered relevant for this study. The well known framework of human-centred design that is included in this same field is introduced in Chapter 3. and not dicussed here.

According to ISO 9241-210 (2019), human factors/ergonomics is a scientific approach that is concerned with the interactions between humans and other elements of a system.

Wickens et. al. define the goal of human factors engineering to be making human interaction with systems so that it reduces error, increases productivity and enhances safety and comfort (Wickens et al., 1998).

In literature, the terms “human factors/ergonomics” and “human factors engineering” are often used interchangeably. Whichever is used, the driver in human factors seems to be optimization of use in terms of effectiveness, efficiency, well-being, user satisfaction, accessibility and sustainability.

This optimization is far from being an easy task. With advancements in technologies, new challenges emerge perpetually. Hollnagel and Woods describe how the increasing potential of technology is invariably put to use to meet performance goals or efficiency pressures. This in turn, according to Hollnagel and Woods, generally leads to increased system complexity which then invariably leads to increased task complexity (Hollnagel and Woods, 2005). The same logic is reflected by the basic “irony of automation” described by Lisanne Bainbridge, which is that the more complex the automated system is, the more crucial can the operator’s role be (Bainbridge, 1983).

From a designer’s point of view, strictly abiding to human factors approaches in a design case might be challenging for the simple reason that many disciplines, especially the ones relating to psychology in this interdiscpliplinary field, may fall outside the core skill set of the designer. This idea is implictly brought up by Hannu Karvonen, who in his dissertation aims to bridge a gap between human factors methods and creative user experience (UX) design work (Karvonen, 2019).

2.1.1 Situational Awareness

Mica R. Endsley, a prominent scholar of situational awareness studies, points that genuine situational awareness is about more than being aware of multiple data points. It demands an elevated level of comprehension of the situation and the ability to anticipate the future states of a system based on the operator’s goals. SA involves a level of focus that is different from conventional information processing approaches when trying to understand how humans operate complex systems (Endsley, 1995).

Endsley and Garland note that ‘today’s systems are capable of producing a huge amount of data, both on the status of their own components, and on the status of the external environment’. Endsley sees that problem with today’s systems is finding the right information when it’s needed. She further states that technological systems are not able to provide SA in and of themselves, but a human operator is needed to perceive information to make it useful (Endsley and Garland, 2000).

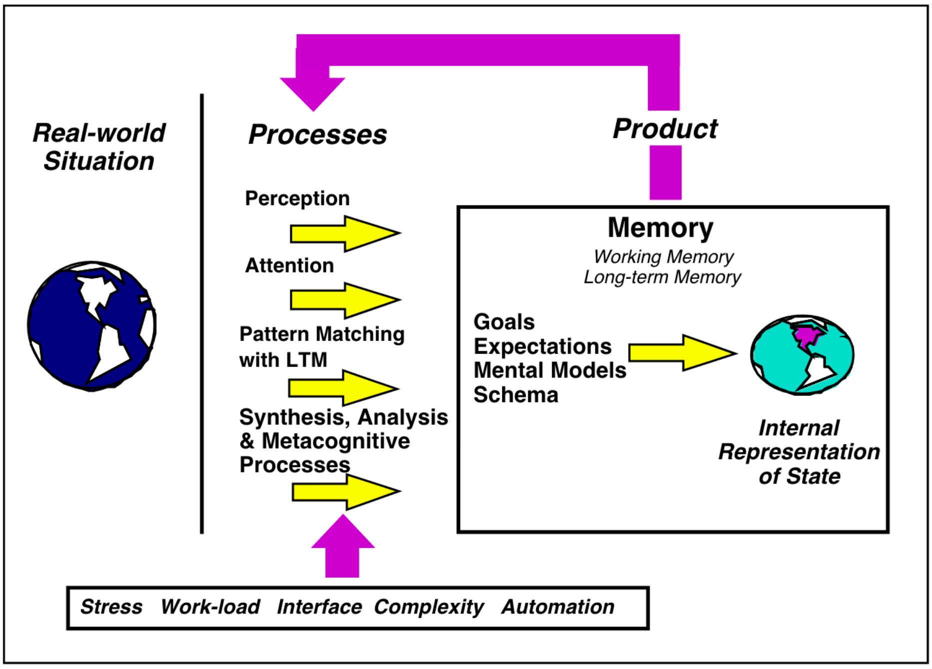
In an extremely apt way in the light of this study too, Endsley notes that the design goal and measure of accomplishment that is termed situation awareness is to know how well the system design aids the operator in acquiring essential information under changing operational constraints (Endsley and Garland, 2000).

Endsley defines situational awareness in a widely accepted way as ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future’ (Endsley, 1988). Endsley breaks SA to three levels. Level 1 SA, *perception* is fundamental. Without basic perception of important information, it becomes more likely that an incorrect picture of the situation will be formed. Level 2 SA, *comprehension*, includes integration of pieces of information and determining their relevance for the person’s goals. Level 3 SA, *projection* is the highest, which is the ability to forecast what the future situations will likely be (Endsley and Garland, 2000).

Simply put, SA is formed from a person’s various sources of information – human senses. Cues may be highly apparent such as a system alert, or subtle such as a slight change in a running machine’s sound (Endsley and Garland, 2000).

Based on Wickens’ information processing theory (see for instance Wickens, 2013), Endsley proposes a model of cognitive mechanisms that are important for the development of SA. In her model, Endsley includes concepts of: a) working memory and attention, b) long-term memory, c) mental models, d) pattern-matching, e) goals, f) expectations and g) automaticity, and the SA is developed through mechanisms and processes involving these (Endsley, 1988; Endsley and Garland, 2000). Endsley’s model is pictured in **Figure 1.**

Figure 1.
Mechanisms and processes involved in situational awareness.
(Endsley and Garland 2000)



2.1.2 Automation Awareness and SA

Mica R. Endsley presents the conundrum of automation being that the more the system is autonomous, trustworthy and robust, the lower the operator's SA is, and the less capable they will be to take control when it's needed (Endsley, 2017). This has been empirically proven for instance by Bailey and Scerbo (Bailey and Scerbo, 2007)

Parasuraman et. al. define automation as 'full or partial replacement of a function previously carried out by the human operator'. Their widely applied illustration of levels of automation is a 10-step scale where "10" is full automation ('computer decides everything') and "1" is no automation at all ('the computer offers no assistance: human must take all decisions and actions' (Parasuraman et al., 2000).

With intelligent, automated systems, it is essential that the operator understands what the automation is doing and is able to make a judgment call when it is necessary to take over. Karvonen et. al. define automation awareness as 'user's conception of the utilized automation system's state in such a manner that enables the user to observe, control, and anticipate the process events mediated by automation' and propose it to be seen as part of the situation awareness (Karvonen et al., 2015).

Endsley points out as a problem, if the automation interface does not provide the operator information on the state of the automation. (Endsley, 2017).

2.1.3 Joint Cognitive Systems, Distributed Cognition and Distributed SA

Significant paradigm shifts in human factors research have happened through multidisciplinary approaches. Cognitive Systems Engineering introduced by Hollnagel & Woods is an approach that combines principles from cognitive psychology, human factors engineering, and systems engineering to improve the interaction between humans and complex systems. In CSE, according to Hollnagel & Woods, the 'focus of investigation and analysis is the Joint Cognitive System rather than human-machine interaction or human-machine system'. They state that control is accomplished by the JCS and 'depends on human-machine co-agency rather than on human-machine interaction'. According to Hollnagel & Woods, 'focus should not only be on cognition and the internal mechanisms and processes of the components, but also on how they interact and co-operate.' (Hollnagel & Woods, 2005)

Edwin Hutcins' concept of distributed cognition challenged the traditional view of cognition as an individual and internal process. Hutchins sees that cognition extends beyond an individual's mind, encompassing external tools, artifacts, and social interactions. The same line of thought is seen in the CSE approach. In the context of naval navigation, Hutchins examined how mariners coordinate their actions and use various external resources, such as maps, charts, instruments, and communication protocols, to achieve effective problem-solving and decision-making. (Hutchins, 1990, 1995)

Distributed SA or shared SA are terms that are not very common in literature. Stanton et. al. assume that 'in distributed team work, cognitive processes occur at a systems, rather than individual level.' They show how Endsley's three-stage SA model is possible to linearly map to a system consisting of machine and human agents. Their description of Distributed Situation Awareness is system-oriented rather than individual-oriented, and bears a strong relationship to JCS approach and Hutchin's findings. (Stanton et al., 2006)

2.1.4 Interfaces, Displays and SA

The interfaces and displays between a human operator and the automated system can be a source of problems according to many researchers. (Parasuraman et al., 2000, Endsley, 2017). Endsley sees that automation that gathers and presents needed information (Level 1 SA), integrates the information to support comprehension and projection needs (Level 2 an 3 SA) can reduce workload and enhance both SA and performance. (Endsley 2017, p. 15)

The *Ecological Interface Design* framework developed by Jens Rasmussen and Kim Vicente is based on Rasmussen's studies on how expert workers reason about complex systems during problem solving (Naikar, 2017). The driving principles of the framework are to minimise interference and support recovery from errors (Rasmussen, 1999). Rasmussen states it being important to present the system's data in a way that integrates to higher level objects, states and events that match the conceptual language and the level of abstraction applied in the operator's causal reasoning (Rasmussen, 1999).

Rasmussen found the worker's reasoning happening at different abstraction levels while performing their tasks, and spontaneously shifting their view of the system from purposive properties to physical properties according to their task or situational demands. The workers also reason at different levels of decomposition, thus moving between coarse and fine-grained views of the system. **Figure 2.** shows an example of the abstraction-decomposition space.

To design an ecological interface, the abstraction–decomposition space is used to develop a model of a work domain and thus define what information is necessary on a display to support human problem-solving in that system (Naikar, 2017).

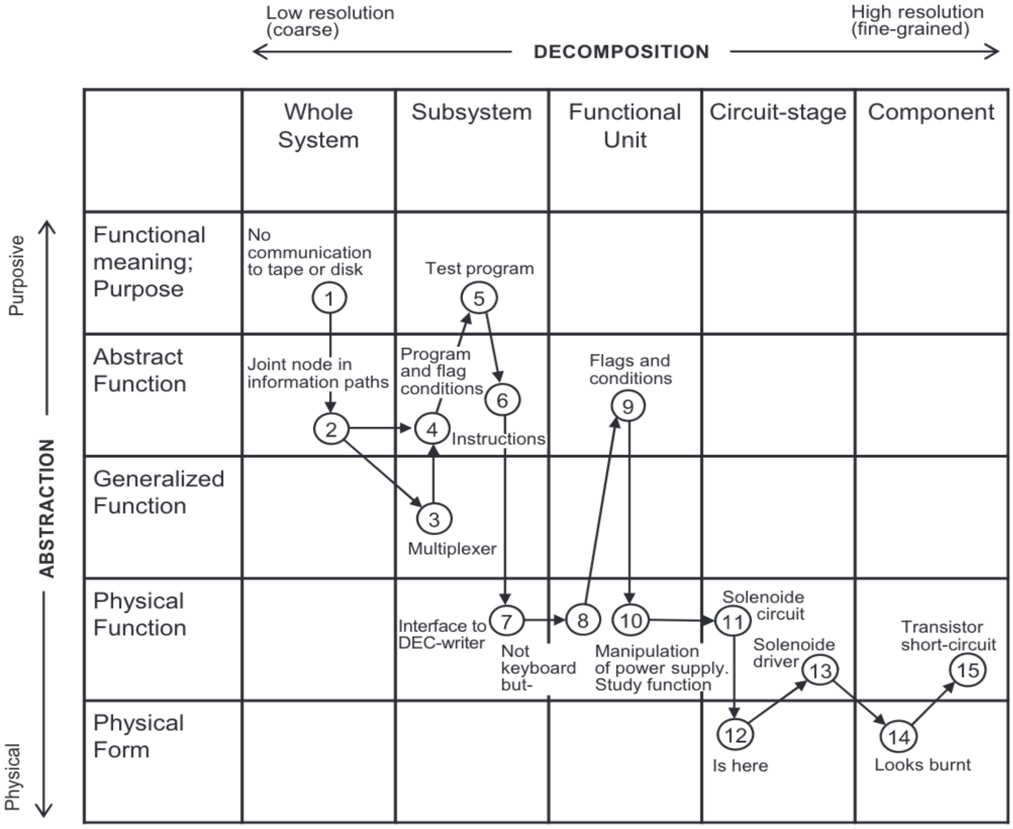
Vicente and Rasmussen organized human decision-making – or cognitive control – processes into three levels: a) skill-based, b) rule-based and c) knowledge-based (Vicente and Rasmussen, 1992).

In skill-based behaviour the environment and the observer are linked through continuous time-space properties (Bennett and Flach, 2011). An example of skill-based interaction could be a navigator following and responding to a live video feed in the ROC. Rasmussen states that 'the spatial-temporal control loop must remain intact through the interface mediation' (Rasmussen, 1999).

In rule-based behaviour the environment and the observer are linked through consistency. The learned conventions in rule-based behavior can involve fixed response sequences (Kevin Bennet and Flach, n.d.). Rasmussen states that an interface should provide all relevant attributes with respect to effective actions in a work situation and do it in a consistent manner (Rasmussen, 1999).

In knowledge-based behaviour the link between the observer and the environment is ambiguous or hypothetical and the subjective or objective meaning is not apparent unless some degree of analysis or problem solving takes place (Kevin Bennet and Flach, n.d.). Rasmussen states that in the case of unfamiliar situations, the interface should offer a ‘faithful, externalised symbolic model to support mental experiments’ (Rasmussen, 1999).

Figure 2.
Abstraction-decomposition space with the example of an electrician who is troubleshooting a tape recorder.



3 Human-Centred Design Process

This chapter describes the design process during which a status monitoring tool for an engineering officer supervising and controlling multiple vessels in a Remote Operation Centre was developed.

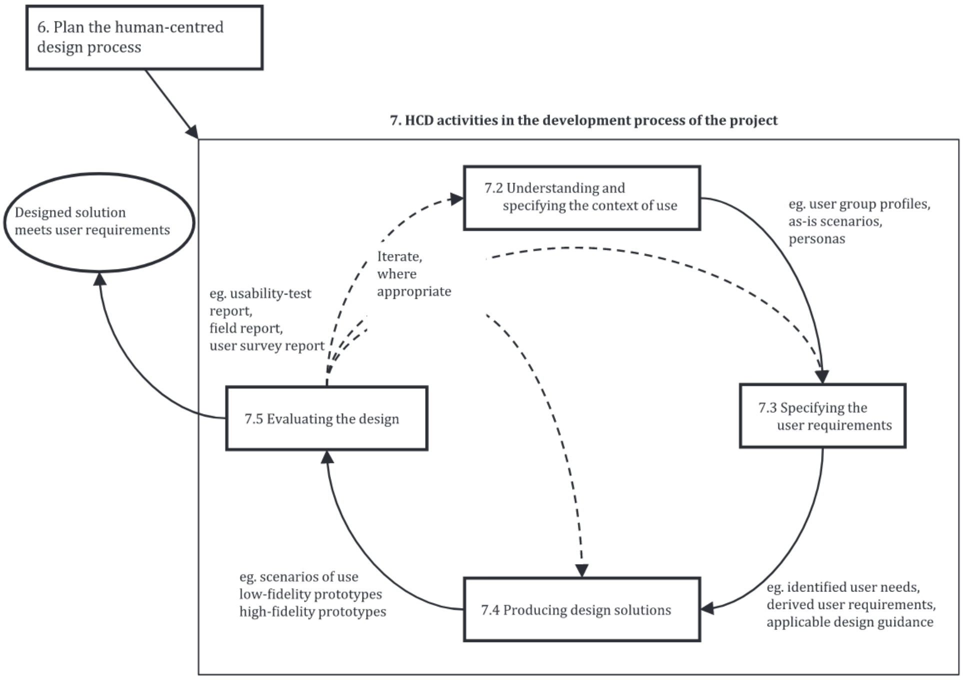
Human-centred design (HCD) is a widely applied approach for developing interactive systems. Primary concern of HCD is to incorporate the perspective of the users in the design process to produce systems that are usable (Maguire, 2001). It can be seen as an umbrella definition when considering software design that makes use of user experience, usability or human factors methods and involves users in the process (Karvonen, 2019).

The ISO standard 9241-210 on Ergonomics of human-system interaction (2019) states that the approach leads to designs that are more satisfactory, effective and efficient, accessible and sustainable and that support the user's well-being. The standard also states that adverse effects to health, safety and performance are mitigated by applying HCD. Moreover, economic and social benefits are mentioned in the standard.

As general principles on human-centred design, the ISO standard lists that:

- design should be based on explicit understanding of users, users tasks and environments
- users are involved throughout the design process
- design is driven and refined by user-centred evaluation
- design process is iterative
- design addresses the whole user experience
- design team includes multidisciplinary skills and perspectives

Figure 3.
Interdependence of human-centred design activities (ISO 9241-210:2019)



The practical design work in this thesis was carried out by following the processes that the ISO standard on human-centred design states as essential. These are:

1. Planning the human-centred design process
2. Understanding and specifying the context of use
3. Specifying the user and organisational requirements
4. Producing designs and prototypes
5. Carrying out user-based assessment

Steps 2.–5. are repeated until the desired usability goals are met. Figure 3. pictures the stadard human-centred design process.

3.1 Overview of the Design Activities

13 field experts took part in informing the design process and evaluating the iterations of the design ideas. As it was not possible to involve actual users of

a system that it still for a great part underway, the choice was to use the expertise of people who are knowledgeable with maritime control systems and also have good understanding on the prospects of MASS systems.

The participatory activities included semi–structured interviews, a group interview, workshops and participatory evaluation of designs. All activities except two design workshops with KM designers and one informal interview with an expert were audio recorded. Participatory evaluation of the final prototype that was carried online was also recorded on video. **Table 1.** summarises the activities involving participants.

Participant's insights were extracted from the audio recordings and thematically analysed following the method presented by Braun and Clarke (Braun and Clarke, 2006). Insights and other material such as visual sketches and infographics gathered from previous sessions were used for eliciting views in consecutive sessions.

I was responsible for producing the designs and the final prototype that was evaluated. A design lead and a senior UX/UI designer from Kongsberg Maritime were involved in three co-design workshops where design ideas were developed. Together we also planned the design process and selected the experts to be involved in the process.

3.2 Planning the Human-Centred Design Process and Scoping the Project

Preparatory planning of the design project took place in a series of meetings with various experts from the client's side. The insights I gathered from these first meetings also helped specify the context of use and user and organisational requirements. Due to the nature of this study as a master's thesis project, no strict business objectives or strict scoping of the deliverable design was set. In the following I will clarify the starting point and preliminary expectations from Kongsberg Maritime's side.

3.2.1 Why is the System Being Developed?

KM is developing a user interface for remotely operating multiple unmanned

Table 1. Participatory activities included in the human-centred design process of the study.

Phase	Activity	Duration	Participant	Data codes
Planning & Understanding the context of use	Semi-structured interview	45	Chief engineer	ENG01 / INT01
		45	Field expert	EXP04 / INT04
		45	Field expert	EXP06 / INT03
		45	Field expert	EXP05 / INT02
		120	Field expert	-
		45	Captain	NAV04 / INT05
		60	Chief engineer	ENG03 / INT06
	Workshop	180	Multiple participants	EXP03, ENG02, EXP04, EXP02 / MEET01
Specifying user requirements	Brainstorming	120	Chief engineer	ENG01 / WS01
			Field expert	EXP02 / WS01
			Field expert	EXP06 / WS01
			Field expert	EXP05 / WS01
	Group interview	120	Chief engineer	ENG02 / WS02
			Captain	NAV01 / WS02
			Captain	NAV02 / WS02
Producing designs and prototypes	Designer workshop	120	KM designers, author	-
	Designer workshop	120		-
Carrying out user-based assesments	Participatory evaluation	30	Chief engineer	EVAL01 / ENG01
		30	Chief engineer	EVAL01 / ENG02
		30	Captain	EVAL01 / NAV03

vessels from a land-based remote operation centre (ROC). In the general scenario of this study, the ships will be autonomous and unmanned: The operating system of the ship is able to make decisions and determine actions by itself. This is what IMO describes as level 4. autonomy (IMO 2021).

According to field experts interviewed for this study, it is most likely that though the vessels will be highly autonomous, legislation and maritime class guidelines will require that human operators supervise the operations and are able to take control if needed.

In this study, a basic assumption is that it will be possible to supervise maritime operations in such a manner that one remote navigational operator supervises 2–3 vessels and one remote technical operator supervises 3 or more vessels and also some aspects of the ROC's technical systems, such as functioning of the workstations and computers.

Operating multiple vessels simultaneously brings out the need for a system that gives the operator an overview of the status of all the systems that are crucial for a safe operation. Compared to conventional maritime operation, the amount of systems to be supervised by a remote operator increases multiple times as the number of vessels increases. Thus, solely relying on the existing maritime machinery automation control systems – though they are principally compatible with remote operations – is not an optimal solution in terms of usability.

Remote and autonomous maritime operation is also reliant on connectivity between the vessels and the ROC and functioning of the ROC technology. These shall be monitored as well.

So far, KM has been testing remote and autonomous operations so that the existing maritime automation monitoring systems have been used for each ship, and a separate development version of an interface that is giving information of the status of the ROC systems has been added.

To summarise, the vessel's autonomous functioning changes the maritime operator's information needs compared to traditional maritime operations.

3.2.2 Overall Objectives for the Design Case

An alert system is an essential component in all maritime operations. IMO has adopted performance standards for ship bridge alert management 2010 (IMO

2010). The purpose of this standardisation is to enhance handling and presentation of alerts. The IMO standard recommends a central alert management interface that supports the bridge team in identification of abnormal situations and supports the team in its decisions.

For remote and autonomous maritime operations, the legislation and guidelines are still underway for a great part. DNV class guideline for autonomous and remotely operated ships states that all navigation related alerts shall be managed in accordance with IMO's bridge alert management concept .

The final design output of this project in KM's view should be such that it is both worth developing further and has potential to fulfil the future maritime legal and classification requirements. It could preferably also drive and inspire the future development work of MASS interfaces.

3.2.3 Users, their Tasks and Expertise

A widely accepted understanding of the manning of the future MASS operations is that there will be officers at least in two distinct working roles in an operation: A navigator who is responsible for navigational safety, and an engineer who is the expert of the vessel's technical systems.

It is justified to expect that the operators in the ROC are trained and qualified maritime professionals who, in addition to having the training of navigating or engineering officers, will also have received training on technologies for remote maritime operations.

In the general scenario of this project, there is one technical officer and two navigation officers working in one ROC, supervising three autonomous vessels. The vessels are expected to be operating on short, point-to-point routes in coastal waters.

This project focuses primarily on the future remote engineering officer as the intended user, but also other members of the remote operator team, as well as for instance port side maintenance personnel are possible users of the system to be designed.

The engineering officer's tasks are to supervise the status of the technical systems on the ships, some supportive port systems such a charging system, and to some extent also the systems in the ROC. Their tasks include also managing the maintenance of the systems.

The navigator's task is to monitor the voyage of the ship and when necessary, drive the ship manually but remotely. Navigators also handle the needed communication with other ships and officials such as maritime traffic controllers. The whole operation team takes part in planning the operations.

Danish Maritime Authority foresees that the roles of the future operators will include elements of both the navigating officer's and the engineering officer's functions (DMA, 2017).

3.2.4 Why Will the System be Used?

According to the experts interviewed for this study, an integrated maritime automation system – the engineering officer's primary tool – will typically give a significant number of alerts during a working day, but only a fraction of these alerts are safety critical to the extent that they would call for immediate intervention. It takes the expertise of a trained professional to make the judgment call on the actual hazards that a certain alert could be indicative of.

Today's maritime machinery on the other hand is automated and reliable to such an extent that under certain conditions, according to the experts interviewed, it's legal to have the ship's engine room without direct supervision for 16 hours a day.

Moving to remote, autonomous multivessel operation brings out the need for a tool for the remote engineering officer which helps him/her to effectively judge the priority of the alerts coming from different ships and different systems.

3.2.5 Technical and Physical Aspects

The remote operation team will be working in a room equipped with specifically designed Remote Operation Workstations (ROWS). Each rows has multiple screens available for the systems, input devices, and audio devices.

Generally, the operators can customize the workspace layout in terms of what information is displayed on which of the multiple screens. A remote navigational officer would in a typical navigational scenario be using for instance live video feed from the vessels, ship's route display, conning display, information of the traffic around the vessel (AIS information), and radar display. This information may be combined to screens for instance in such a manner that both route display, radar view and AIS information are shown on a single screen.

3.2.6 General Usability Goals

For a great part, the users, as maritime experts, will already be familiar with the functionality and use of the software used in the ROC, such as maritime automation systems.

At the design stage, OpenBridge design system is used as a basis. OpenBridge is intended to achieve cross-vendor integration and consistent user interfaces for all maritime equipment on a ship's bridge (Nordby et al. 2019).

Obviously, new systems that are introduced should integrate to the existing systems so that they generally fit to the workspace, have similar work ergonomic properties as the existing systems and allow the above mentioned customisable layout.

3.3 Understanding and Specifying the Context of Use

A prominent challenge in carrying out a human-centred design process in the case at hand is that it is not possible to directly study a work context that does not yet exist: Remote shipping operations are not yet carried out in the manner described above. There is not a fully operating ROC that I could have visited. This means that many important aspects of the work are yet uncertain and left under speculation of different degrees.

I conducted a series of semi-structured expert interviews and a group interview to develop understanding about the context of use. I became familiar with demonstration and development versions of remote operation workstations at the KM premises and some parts of the expert interviews took place physically at these. I also visited the maritime school Novia in the city of Turku and was presented various maritime training simulators, including a ship machinery simulator. Furthermore, I was attending a development meet-

Figure 4.

Shipboard intelligent systems on a MASS vessel.

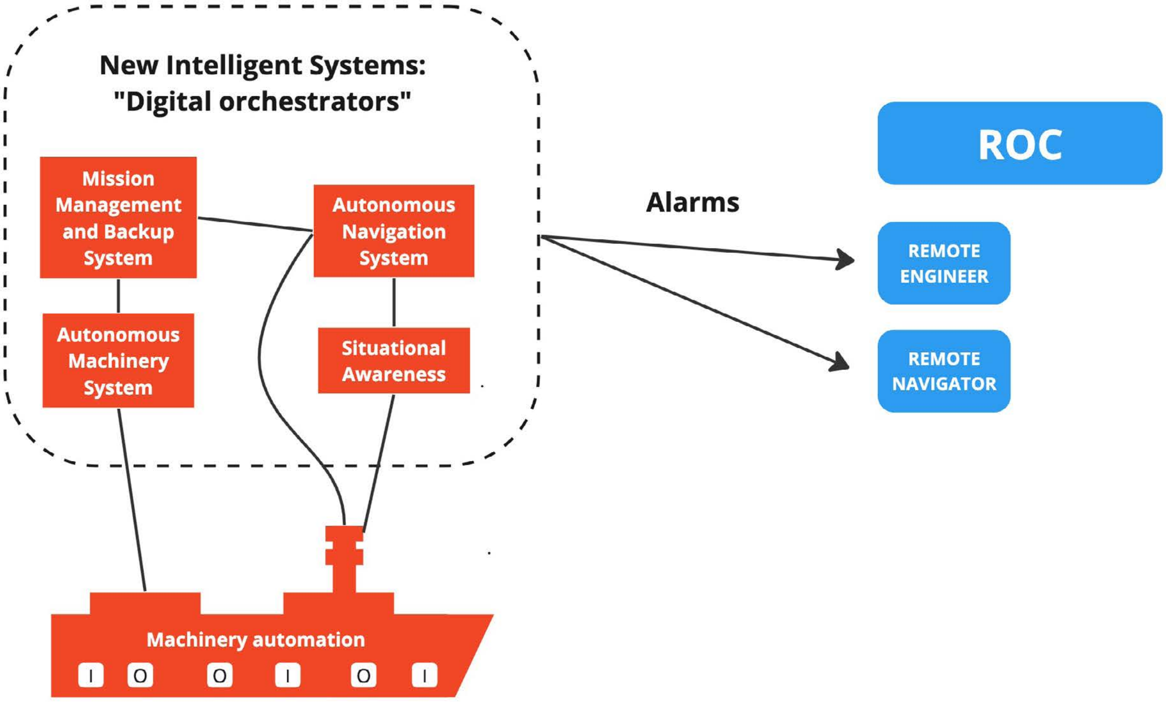
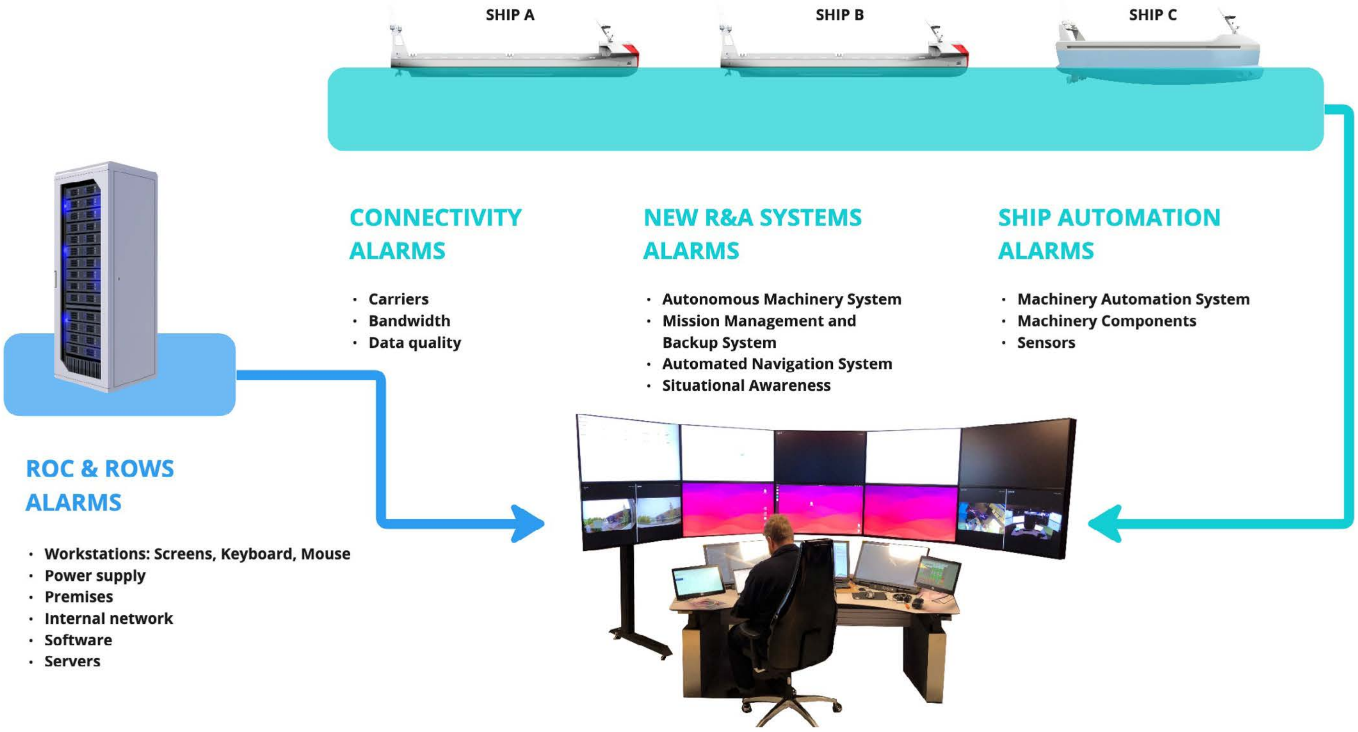


Figure 5.

Alarm sources in a remote MASS operation.



ing between KM and their customer.

To elicit participant's thoughts on the subject, I presented two simple diagrams of KM's current view on what the remote and autonomous system on a high level is. These are shown in **Figure 4.** and **Figure 5.**

For the maritime professionals with seafaring background who I interviewed, it seemed generally easy to put themselves in the shoes of future remote operators. All of them have been following the developments around remote and autonomous shipping, and most are also directly in contact with these developing technologies through their daily work. Every participant saw that following the current developments in the field, remote operations are possible in the future, as long as the adjacent legislative and certification processes are implemented.

Many obvious contextual factors in the case emerge from the existing reality of the maritime field, where technologies, operational models and workers competencies are highly regulated.

Regarding the uncertainties mentioned above, similar themes emerged in different interviews, discussions and workshops. These fall to following categories and will be discussed in detail below.

1. Remote operator's working role, responsibilities and team composition
2. Remote operator's skills, training & qualifications
3. Regulatory matters
4. Ship specifications
5. Autonomous system's performance
6. Task allocation in the team and between humans and the autonomous systems
7. Alerts
8. Responding to failures
9. Situational factors
10. Well-being at work

3.3.1 Remote Operator’s Working Role, Responsibilities and Team Composition

A central dilemma in defining the remote engineering officer’s work role emerges from that it is very hard with today’s knowledge to exactly define how much, what kind of and of which systems a remote operator can take responsibility for. Generally it is seen by the interviewed experts that the responsibilities of a remote engineering operator will be higher than when working onboard ships

The sailors I interviewed who have personal experience with MASS systems are confident to take on the role as remote operators with the added responsibilities. This approach is in line with what Margareta Lützhöft describes as a part of mariner culture where “anything can be handled”. The downside of this kind of attitude is that it can lead to too much burden added to the worker. (Lützhöft, 2004.)

For the remote engineering officer, in addition to the question on how many ships they can handle, it’s also about to which extent they are capable of maintaining the ROC’s systems.

In this study the assumption is that one remote engineering officer is capable of sufficiently managing the technical systems of at least three electrically powered ships and also basic level issues that the ROC’s systems might have. The latter brings forth needs for skills that have not traditionally been central for ship engineers.

An engineering teacher of a maritime school notes that basic IT skills such as managing software updates are required from engineers working on ships already.

At KM it has been identified that the IT knowledge and skills required from workers in the future ROCs could possibly be high. A systems engineer at KM notes that the ship and ROC systems form such a complex whole that thorough mastering of it would ask the operator expert level knowledge of multiple fields external to current maritime discipline. Many interviewees stated that the system supplier should be running a Service Operations Centre that is able to assist when technical problems concerning the ROC emerge.

Aside from actual seafaring, the operation team will also plan the operations and vessel maintenance. When asking mariners about how they see fitting route planning and maintenance management in the workflow a multivessel operation, it becomes obvious that primary attention of the operators would be directed to ships that might need focus because of their navigational situation. An ETO notes that for instance many testing procedures can be timed flexibly.

> *"I don't think I would direct my focus to the vessel*
> *in the harbor to carry out route planning. I think I will focus on the*
> *navigation part. And when that's safe or arrives at the port,*
> *then I will go to the next vessel."*
>
> *WS02 NAV01*

3.3.2 Remote Operator's Skills, Training & Qualifications

There is a common understanding in the maritime field that the future remote officers will have similar training and qualifications as currently is required from ship personnel.

A chief engineer with expertise on autonomous systems notes in an interview that for remote engineering operators, good understanding of the ship and sea environment is still needed, as well as qualifications to operate different kinds of vessels. He also sees that it would be beneficial for a remote engineer to have ship experience. He further notes that the physical fitness requirements will most certainly be different for remote operators, opening job opportunities for persons that would not qualify for working onboard because of physical limitations.

In Finland, maritime certifications of competence are issued by the Finnish Transport and Communications Agency Traficom. For Chief Engineers, these certifications expire in 5 years. For a certificate, the applicant must hold a watchkeeping engineer's certificate, have completed chief engineer officers training, and have completed seagoing service and practical training of approximately 3 years. In addition to certificates of competency, there are certifications of proficiency that show completion of safety training (Traficom website 2023).

Among possible future requirements could be for instance proficiency with data security. Cyber risks of MASS operations need to be seriously considered. A teacher of a maritime school notes that cyber security is already in the curriculum of today's engineering operator's training.

3.3.3. Regulatory Matters

To abide by the regulations is central for mariners, as the following quote from a chief engineer I interviewed pictures:

> *"The communication is ongoing. If there is a technological issue that can pose a risk for operating the ship, it is immediately communicated to the bridge. The ship might be in a critical position, such as being piloted or in a channel. It's in the regulations and laws that the communication must be there. Reporting the hazards from the machinery is expected to be communicated immediately, and I see no difference there for whether the ship is in remote operation or operated from onboard."*
>
> *ENG03 INT06*

The general maritime regulatory framework will not be described here. For understanding the context of use in the scope of this project it is maybe sufficient to note that mariners work and the technology used is governed with strict regulations.

Before the regulations that concern MASS operations are implemented, the developers of MASS systems need to use judgment on the likelihood of different future regulatory measures. Many central aspects concerning the regulations on autonomous ships capabilities, monitoring systems and manning of the ROCs are still to be clarified by the authorities (Kaarstad and Braaseth, 2020).

The first developers of autonomous systems are also in a position where they can propose solutions that become the base for the regulations. A field expert at KM notes that at the early stage of development, the existing regulations should not be in the way of innovative solutions.

3.3.4 Ship Specifications

Many interviewees bring forth how the specifications of different ships affect the work of both engineers and people who steer the ships.

According to one chief engineer, to learn a conventional ship well it takes 6–12 months, regardless of ship, because each ship has different types of control systems.

A navigator tells how he as a first task on a new ship learns about the ship's manouvering characteristics, which for each ship are different depending on the tonnage, propulsion and other specifications.

"Each ship is a prototype" is a notion that basically all the interviewees endorse. One engineer highlights how it can take a significant amount of time to "tune in" a newly delivered vessel.

3.3.5 Autonomous System's Specifications and Performance

Probably the aspect that causes most of the uncertainties in the project at hand is the performance of the autonomous systems as a whole. This was to a great extent also reflected in the expert interviews and discussions.

What does not yet exist is as an object that could be studied in the context of my thesis is a maritime "system of systems" – an operating system that is capable of independent decision-making even in safety critical situations. The performance of this kind of system is pivotal for MASS operations.

One expert at KM states that in the near future it is possible to carry out all the regular situations autonomously, but failure situations still need intervention from the human operator. He says that in the longer term, the intelligent operating system will be capable of managing failure states.

The interviewed expert's experiences with existing autonomous maritime systems are positive. Machinery automation and different types of remote monitoring systems have been commonplace in ships already for decades.

A maritime engineering teacher notes that it is commonplace that machinery manufacturers monitor the performance of their systems remotely, and are able to carry out adjustments and troubleshooting online.

Mariners with experience on KM's current autonomous navigation systems state that the operation of these is very reliable. At the moment, these systems are capable of autonomously manouvering and docking the ship. They state that the more they see these systems performing well, the more they trust them.

> *"If the ship has good automation capabilities,*
> *the operators should not necessarily intervene for instance*
> *in a blackout scenario."*
>
> *ENG01 WS01*

3.3.6 Task Allocation in the Team and Between Humans and the Autonomous Systems

The questions on how many ships and to which extent a remote operator is capable of monitoring relates closely to how the monitoring and control tasks can be allocated within the human team, and obviously, the autonomous system's performance.

When a situation calls for an operator's high attention, it seems crucial to have systems and work practices in place that support flexible task allocation, so that a colleague can take responsibility for the other ships. This view was repeated many times by different experts.

Handovers or shift changes are also seen by the experts as something that needs both support from the operational system and clear working procedures. It is stated that the handovers should preferably take place when ships are docked.

3.3.7 Alerts

As the focus of this study is the development of an alert management system, many insights collected were direct proposals for user requirements. These will be presented and discussed later in the user requirements section.

Regarding the uncertainties concerning alerts in MASS operations, it is for instance not yet fully clarified what types of new alerts will be coming from the "digital orchestrators", which are the intelligent shipboard operation systems that autonomously manage the ship's general mission, machinery automation, navigation, and the ship's [sic] situational awareness.

In a workshop with KM experts, some possible types of alerts were identified. The rough categorization of remote engineering officer's alarms was a) ROC system alerts, b) connectivity alerts, c) remote & autonomous systems alerts, and d) automation system alerts.

In the workshop, it was widely noticed that it is very difficult to yet predict the likelihood of different alerts.

3.3.8 Responding to Failures

How the remote operator responds to vessel side failures involves a lot of uncertainty and speculation. Obviously, the possibilities for troubleshooting and intervening in the event of failure of a vessel are very different from a conventional manned operation.

A central safety feature that the autonomous vessels will have is a safe mode, which KM terms as fall back state. At each time in a vessel's transit, there are at least two options for each vessel to pause the operation and for instance stop and hover on the spot, drive in a circle, or anchor. At the level of autonomy considered in this study, a fallback state would automatically follow for instance from total loss of connectivity between the ROC and the vessel. The operator will always have the option to initiate a fallback state, given that some connectivity to the vessel exists.

It was brought up in the interviews, that troubleshooting the autonomous vessel's failures calls for the operator's extensive understanding of the system. As one solution for this, the use of a digital twin was proposed.

3.3.9 Situational Factors

It was very easy for the participants with ship experience to come up with problematic scenarios that might take place for a single autonomous ship or in a fleet operation.

It was brought up, that for instance in rough sea conditions, the mariners with experience on an autonomous navigation system, prefer to take more control on ship's propulsion. This might be for instance to protect the machinery from overload and possible breakage. Moreover, in an emergency scenario, the mariners stated that it might be considered necessary to use all the propulsion there possibly is.

> *When it's bad weather and the vessel or the*
> *AI wants to use as much power as it wants, I think we need some*
> *sort of decision, human interaction in the future.*
>
> *WS02 NAV01*

This seems to imply that in the dynamic maritime context, also in the future and with autonomous vessels, in extreme conditions the officers will prefer to have the opportunity to take control of critical systems.

To a certain extent the situational factors were also seen to be possible to mitigate via mission planning. It was stated that the autonomous operations should be planned in such a manner that operational phases that possibly ask for high attention, such as sailing in congested waters, would not overlap.

3.3.10 Well-being at Work

There are understandable concerns around the possible well-being issues that might affect the future remote operators of MASS systems. There seems to be risks for both boredom and too high workload. Before larger scale MASS operations take place, the well-being aspect is left under speculation to a great extent.

Experienced chief engineers state in the interviews that low attention times are a regular feature of a mariner's work. It is also clear based on the interviews that future remote operators will have tasks other than monitoring the missions, such as planning the operations within the team and managing vessel maintenance.

Autonomous operations might also be carried out with a minimal crew on board. One chief engineer states that “psychologically it seems not viable to send 1-2 persons for a month’s trip on an autonomous ship”.

One central driver in the introduction of MASS is that the shipping industry is struggling to have enough trained workforce, especially officers (Negenborn, 2023). MASS operations can offer mariners work with regular hours in a safe environment.

> *“It’s a sure thing that in an emergency it’s much nicer*
> *to be in an office environment.”*
>
> *ENG01 INT01*

3.4 Specifying the user and organizational requirements

Requirements elicitation is generally seen as the most crucial part of a software development project. According to Martin Maguire, the success of a software development programme can greatly depend on how well this activity is executed (Maguire, 2001).

The ISO standard for Human Centered Design for Interactive systems notes as challenges that at the beginning of the project, the user requirements that can be captured are unlikely to be exhaustive and that some requirements may only emerge when a proposed solution is available. Moreover it states that user requirements can be diverse and potentially contradictory to each other. (ISO 2019)

I collected and refined the user requirements throughout the process, from literature, expert interviews and evaluation of the prototype. The array of stakeholders involved in the activities covers field experts, maritime system architects and designers, and active mariners with experience on autonomous navigation systems.

The activities included multiple semi-structured expert interviews, a group interview and a workshop where participants with multidisciplinary skills were present. (**Table 1.**) The experts were able to come up with various relevant scenarios for specifying user requirements.

All participants were aware of the potential risks that using highly automated systems in the maritime context may bring, such as boredom. For an engineering officer, a typical work situation is seen to be that everything in the operation is working as expected and nothing is calling for their direct attention.

Based on the interviews, engineering officers are accustomed to the fact that a significant portion of a working day may be such that no high attention is required by any system. For a non-expert this might sound like a possible source of problems regarding operator's alertness. A general understanding of the working culture and ethics of maritime engineering officers which is also supported by the insights I got from the interviews is that the engineers are accustomed to checking through the systems even when everything is working well.

3.4.1 User Needs for a Status Monitoring System in a Remote and Autonomous Operation of a Fleet of Ships

The general user need is stated as follows:

Remote engineering officers, who are responsible for keeping autonomous vessel systems, ROC systems and connectivity systems between the vessels and the ROC operable, need *means to effectively and without excessive workload, monitor the operational state of these systems. They also need to understand the provided information in the context of the operations. This is for them to gain sufficient situational awareness.* Other members of the remote operation team have the same needs occasionally.

3.4.2 User Requirements

User requirements derived from the user's needs and context of use are as follows. **Table 2.** maps the expert's insights to the requirements.

1. Status information is salient

As the systems in a MASS operation are capable of producing large amounts of system data and alert messages, the system to be designed must provide the operator with information that is relevant in the context of the overall operation.

2. Status information is contextual

The system must help the operator to understand the information provided in the context of the operation, for instance by providing information on a ship's mission.

3. Status information is transparent

Even though the system may be highly autonomous and present status information in a minimalistic manner, the operator must have visibility to the whole system, including the autonomous system's decisions.

4. Operator's active involvement is supported

The system must support the operator's active involvement both in normal operational states and failure states. The operator should be provided with information on what they can do when a problem emerges.

5. Team communication is supported

The system must support the operational team's communication. For instance the operators need to be aware of other team member's tasks and workload.

6 High and low attention monitoring is supported

The system must support the operator switching between high and low attention monitoring tasks. This means including the possibility to pass monitoring of certain assets to other operators in the design.

3.4.3 Usability Requirements

7. Compact visual layout

The system must present all the relevant information on overall operational statuses in a single screen.

8. Clarity of information presentation

The system must present information in such a manner that it is easy for the operator to understand. For instance alert messages should not contain system codes. Understandable expressions about the alert cause should be used instead.

9. Supporting workstation customization

The system must support the remote officer's common preference to customize their workstation screen layout.

3.4.4 Organizational Requirements

10. Integration with existing systems

The system must be integratable to the other systems used in a KM remote operation system, such as Kongsberg K-Chief.

11. Conforming with industry standards

The system must conform with the same maritime industry standards that are applied in the design of other Kongsberg software. This means for instance applying the OpenBridge design system that includes uniform user interface designs for maritime systems (Nordby et al. 2019).

12. Conforming with maritime regulations

In the design of the system, the maritime regulations concerning alert systems should be taken into account as is seen purposeful.

3.5 Producing Design Solutions

Based on findings from the participatory activities with users and other field experts, design solutions were iterated. It was considered best to produce a realistic user interface concept that could be used for validating and adjusting the user requirements found so far.

3.5.1 Existing Designs and Initial Design Ideas

During the course of the process, no existing interface designs that would fulfil the requirements described above were found. One prototypical alert system interface for a MASS ROC has been developed in the MUNIN project (Porathe, 2014).

Two concrete design ideas had already emerged within KM. Same types of

Table 2. Expert insights that were used for deriving the user needs and requirements (RQ).

		Expert insights
User needs	a) Minimise workload b) Provide SA	• (a) Minimise everyday workload of the engineer ... he will be the expert of system failures EXP04 INT04 • (b) I believe if you have maybe some sort of system or procedure in some kind of way that prevents you from losing focus on the navigation part, then maybe you will be able to do some small work on the vessel in port. But to mix them, I think it will be a big mess, really. You will miss parts of the checklist. I think it will be messy. WS02 NAV01 • (1) I want that alarm coming up when the system is showing me a real fault. Not just a ping and it doesn't get these answers, but it will come up with an error because the system did not give you a response in a quick enough time or situations like this. WS02 ENG02 • (2) Pump is burning but can we still take the ship to harbour instead of paying 100K for towing? DES01 INT02 • (1, 2) The kinds of events that the system thinks are escalating quickly should rise much more quickly. NAV04 INT05 • (2) Operator needs to be aware of the ship's mission ENG01 INT01 • (2, 12) ROC issues might endanger all operations DES02 WS01 • (1, 2, 5) When something beeps, the engineer needs to know what the ship's capabilities are EXP04 INT04 • (1, 2) Remote operation's alerts should be classified in a sensible way NAV04 INT05 • (2) Something that causes a caution in open waters causes an alarm in congested waters NAV04 INT05 • (1, 2, 4) Alarms should give context about what's wrong and how to fix ENG01 INT01 • (1) In different modes of operation: unnecessary alarms can easily be masked to avoid "ghost" alarms ENG01 INT01 • (3) Escalating alarm scenarios: Escalation can happen really fast ENG01 WS01 • (4) Operator himself needs to have the final call of what is the highest priority ENG01 WS01 • (2, 4, 12) Scenarios that involve human or environmental danger are of highest priority EXP04 INT04 • (5) I think if the technician is very busy, I think it will be some kind of extra workload for him to speak with me. So I should also have the opportunity to see the full picture, I think. I think if... If I want to, I can see the full picture. WS02 NAV01 • (2, 5) Operator needs to understand who is navigating a specific ship. DES01 INT02 • (3, 4, 5) Handovers: Easy to forget what you've been doing. Good to have ability to see the actions taken by you & by colleague MEET01 ENG02 • (1, 2, 3, 4, 7, 12) This is one of the main concerns from DNV. That you want to have this overall master screen. That you can easily see if there is something you need to investigate. In another screen to just dive down to that vessel. WS02 ENG02 • (a, 1) It's the finding of alarms that is important. Alarm can be an alarm, but it doesn't give you anything at all. There is a lot of work to just pull out the important ones WS02 ENG02 • (7) I don't see following many automation screens as a problem. But I would narrow everything down as much as possible because it's not... For me, I could have all the automation windows up and running on the IMS picture. That will give me enough information to know how the system is in real time when you have the alarm bar in top of everything. WS02 ENG02 • (3, 4) The first thing I do when I come on the bridge every morning is just jumping into the alarm history to see what's been going on. So that is the way to go forward. WS02 ENG02 • (8) No code language from an alarm but an understandable way of presenting info EXP04 INT04 • (1, 8) When it comes to alarm handling, a short description of the alarms. We must have a better explanation from a library. So it's much more easy to just jump into without sorting out what the codes mean WS02 ENG02 • (8) On alarm list you could highlight everything with a different color on each ship. So you can easily just sort out the ships by color. WS02 ENG02 • (9) I used to arrange the automation pages up to my liking: Going around the system, checking the system status and keeping alarm lists clear. Then when an alarm comes it's very clear to see. ENG01 INT01 • (9) Engineers like to customise their workstation ENG01 INT0 • (1, 8) More the same that we discussed on the navigation side. To have one screen showing the overview of all the vessels. Green light. Probably the same on the engineering side. WS02 NAV02 • (1) I think it's difficult when you get 20 alarms and what is the important one. You get 20 alarms and 19 of them go back to normal state after 2 seconds. You get the alarm that is really important, showing the same color. Not an I-O, but all is red. One of them is crucial. WS02 NAV02 • (4, 12) It's really hard for us to prioritise the alerts absolutely. It's the operator's and eventually shipping company's decision. EXP02 WS01 • (10, 11, 12) Let's follow the K-Chief alarm structure. So you go into the K-Chief and you see the same. WS02 NAV02
User RQ	1. Salient information	
	2. Contextual information	
	3. Transparent information	
	4. Support RO active involvement	
	5. Support team communication	
	6. Support high / low attention monitoring	
Usability RQ	7. Compact layout	
	8. Clarity of information presentation	
	9. Support workstation customization	
Organi-zational RQ	10. Integration with existing systems	
	11. Conforming with industry standards	
	12. Conforming with maritime regulations	

solutions were also included in the MUNIN interface (Man et al. 2015) .

First of them is presenting the overall status of different assets as simple “traffic lights”, where green color means that the system is ok, yellow that there is an underlying problem worth investigating and red color a state that compromises the safety of the operation.

Second of them is applying alarm aggregation. These will be discussed more in depth below.

3.5.2 Alarm Aggregation

How to prioritize the remote engineering officer’s alerts was considered the most challenging aspect in the project and it certainly will remain as a challenge in developing MASS systems.

In the expert interviews it was clarified that a *vessel’s capabilities in the context of the operation phase* are of primary concern for the operating team. For a vessel in traffic, among primary concerns is the status of the connectivity link between the vessel and the ROC. If connectivity is lost, the operation will automatically stop and the vessel will initiate a fallback state.

As high level vessel capabilities, *transit capability*, *berthing capability* and *alongside capability* can be identified.

For instance the transit capability is a product of functions such as navigation, maneuvering and machinery automation. Moreover, for instance the manouvering function depends on operation of thrusters and power management systems that on an electric ship include, for instance, batteries.

Central for MASS is to include enough redundancy in all critical systems so that a fault in one component or subsystem does not directly endanger the operation. For instance, a ship may have four thrusters, but still be “limped” back to harbour with only one functioning thruster.

As a viable solution for reducing the alarms that the operator gets, and helping them to direct attention, it was considered that the system should give alert messages *only when the underlying systems conditions directly affect the high level capabilities*.

The same principle of alarm aggregation can be applied both for vessels and ROC systems.

3.5.2 Design Features

Physically the system to be designed should be usable in a space of one screen of the operator's workstation. The system will be used in conjunction with conventional IAS system views and remote navigation system views such as route view, as well as live camera and radar views. The screen layout can be decided upon by each operator. The following is a summary of the aspects and features that were considered essential for the first prototype.

a) Assets in the Operation

The assets to be presented in the interface are: a) vessels, b) ROC, c) operator workstations (ROWS). The high level status of all the assets should be comprehensible from the system at any time. Design solution was to present all assets and their overall statuses in every view of the system.

b) Switching Between Low Attention and High Attention

Low attention mode refers to a state where nothing is demanding the operator's direct attention. In high attention mode, the operator is investigating some part of the system closely. For the design, the above mentioned principle of showing all assets in the view even for high attention mode was considered a good solution.

c) Minimalistic Presentation of High Level Status of Assets

Providing a minimalistic overall view to the status of all assets in the operation was considered an elementary feature. This is done in the design by applying the "traffic lights" idea so that in the low attention view, as well as in the high attention view each asset has a single indicator representing the overall status of the asset.

d) Distinction of the Assets

It is elementary that the status information from different assets is distinguishable to mitigate the so-called "carry over" effects of mixing information concerning different assets. In the first design, the assets are distinguishable by grouping the vessels and the ROC systems separately and each asset is placed in its own cell in the layout.

e) Visualization of the Status Aggregation

It was generally considered a good approach to visually represent the vessel's system based on the aggregation principle described above. This approach was endorsed by the experts early on during the participatory activities, and some early iterations of the visualisation principle were presented too. Aggregation visualisations for ship systems were produced for the first prototype, but these were not intended to be extremely realistic on the lower system level.

Visualizing the ROC systems in the same manner on sufficiently true-to-life level was found to be such a complex task, also leading to complex questions on the engineering officer's role and competencies, that it was not realised in the first design.

f) Status Aggregation Indicator

The status aggregation approach does not in itself yet solve the underlying issue of possibly having an overwhelming amount of system alert messages. The aggregation approach brings in another issue concerning the transparency of the interface. To mitigate this conundrum, a concept for an indicator that displays the amount of alerts concerning low level components, systems and functions was developed (Figure 7.).

g) Alert Categorization

IMO Bridge Alert Management (BAM) guideline for alert categorisation was applied in the design for the high level alert messages. The guideline proposes a four-level priorization. In BAM, emergency alarms are those that indicate immediate danger to human life or to the ship or its machinery. Alarms are conditions that require immediate attention and action to avoid any hazardous situation and to maintain safe operation. Warnings do not call for immediate attention of the operator but still need to be acknowledged in the interface by the operator, and cautions are alerts that do not call for explicit acknowledgement (IMO 2010).

h) Ship's Mission

In many discussions it was brought up that the operator must be aware of the ship's mission. In the first design, the operator is provided with a timeline view that indicates each ship's planned and current mission state.

i) Task Allocation in the Team

The tasks of the other operators in the team and which workstation they are using was also considered central information. In the first design, this information is provided next to each asset.

3.5.3 Prototyping

The first prototype for a Status Monitoring Interface based on the above mentioned features was produced in collaboration with UX-designers at KM and me. The OpenBridge design system was applied in the design.

An interactive evaluation version of the interface was produced using the ProtoPie software. The evaluation version included multiple scenarios involving different levels of system failures on three vessels.

The interactive version was intended to work as a probe and discussion aid for validating and refining the user requirements. It was considered that as it was not possible to evaluate it in a simulator setting in a realistic operation workstation, actual usability testing with determined tasks would not be carried out, even though the level of detail of the prototype would have made that possible.

Figure 6. shows a possible workstation layout with the timeline view of the status monitoring prototype on the bottom left screen.

3.5.4 Interface Designs

The interface prototype has two primary views – a *main view,* which features a mission timeline for each vessel, and a *system view,* featuring a system tree which is laid out following the alarm aggregation principle. These can also be referred as *low attention* and *high attention* views.

The "main view" is intended to give a good overall view of statuses of all technical systems in the operation, and the "system view" is for investigating a certain asset's systems' statuses more closely.

Figures **8.–12.** present the design. In the following is a brief description of the main functionalities of the interface.

Timeline

The vessel's timeline shows the vessel's planned mission with sailing and harbour times, times in congested pathways, the vessel's connectivity status and vessel health trend curve. The timeline is scrollable. Past issues are shown on the trend curve with a mouseover function. Known future issues such as possibly low connectivity are also shown.

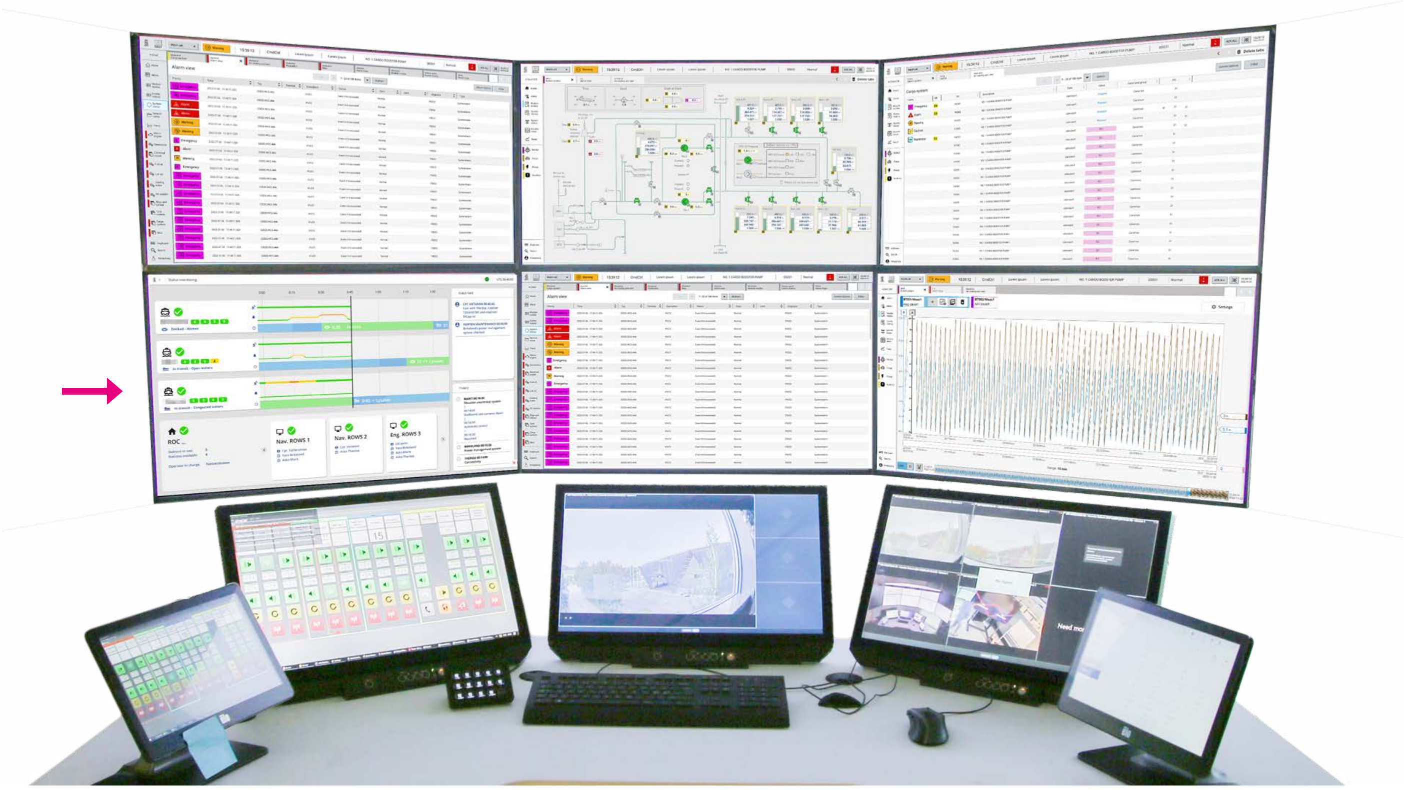
Aggregation Indicator

The aggregation indicator (**Figure 7.**) is placed next to the vessel's name and indicates the amout and severity of lower level alerts.

System Tree

The system tree is the primary component of the system view. It represents

Figure 6.
Example of a workstation layout. Proposed status monitoring interface is indicated with the red arrow.



the alarm aggregation model, consisting of components, functions and the asset's capabilities. The branches of the tree can be expanded and collapsed.

Use case example

The following example illustrates how an engineering officer would use the system.

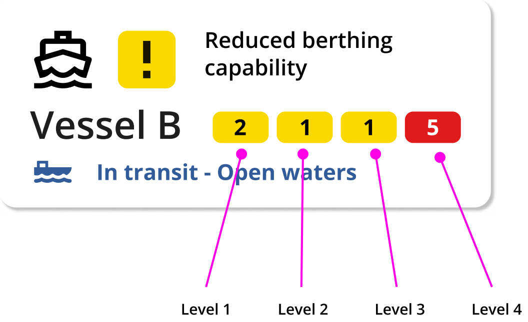
Remote Engineering Officer N.N. starts her shift. She refers first to the ***Main View*** *(Figure 8.) and sees that Ship A departs in 30 minutes, Ship B is just about to enter a congested fairway area, whereas Ship C has left the harbour 15 minutes ago and is soon in open waters.*

As all assets in the operation, including the ROWS station, are showing a green light, N.N. checks the timeline back and sees, what have been the past alerts for each vessel and workstation.

A ***high level alert*** *of lowest priority level comes from Ship B, (Figure 7.), showing that the ship has reduced berthing capability. The alert is low priority, because the ship is not in transit. N.N. refers to the* ***system view*** *(Figure 12.) of Ship B and sees instantly the issue being that the port side situation awareness cameras are not functioning.*

From the system view N.N. navigates to the camera system's pages and sees that there is an automated software update going on: No actions are needed. N.N. follows through that the cameras start to operate before the ship is due to sail. The Master of the operation who works in the next ROWS has seen the

Figure 7.
The aggregation indicator shows the amounts of alerts at different levels of the vessel's systems.



same alert message and asks over his shoulder what is the state of the port side cameras and whether the issue will delay the operation. N.N. confirms that the ship is most probably ready to sail in schedule.

Now Ship B is entering a congested fairway. N.N. sees from the main window that all systems are working properly, but as after a quick assessment of the timeline information, Ship B obviously is the vessel under biggest risk in the fleet at the moment. N.N. checks the past condition of the most critical systems, such as power management, propulsion and connectivity. She sees nothing alarming in the near history that would point to underlying problems.

Ship A's cameras come back to their normal state, but soon another alert comes from the same ship. There is a problem in the charging system. Right after this, the port crew messages in the ***status feed*** *that they have already fixed the issue. Now that all Ship A systems give a green light, the ship is ready to sail.*

3.6 Evaluating the Designs

Three field experts, of whom two are chief engineers and one is a captain, took part in the evaluation of the prototype. All participants are familiar with the concept of MASS and are involved in developing the adjacent technologies. All the evaluators were personally knowledgeable of KM's proceedings in the field of MASS control systems, and have a role in their development.

3.6.1 Technical Details and Manuscript of the Prototype

The prototype that was running on ProtoPie software, was based on the interface designs and the specific asset combination (vessels, ROC and ROWS) presented in previous pages. The prototype illustrated a timeframe of 4 hours of operation time and included 22 points of time where the user could freely navigate between the main view and system views of three ships. It was also possible to focus the system view to show only the part of the system that was showing an issue.

The prototype was self-advancing without stopping or going back options. Each point of time took between 60-15 seconds to load.

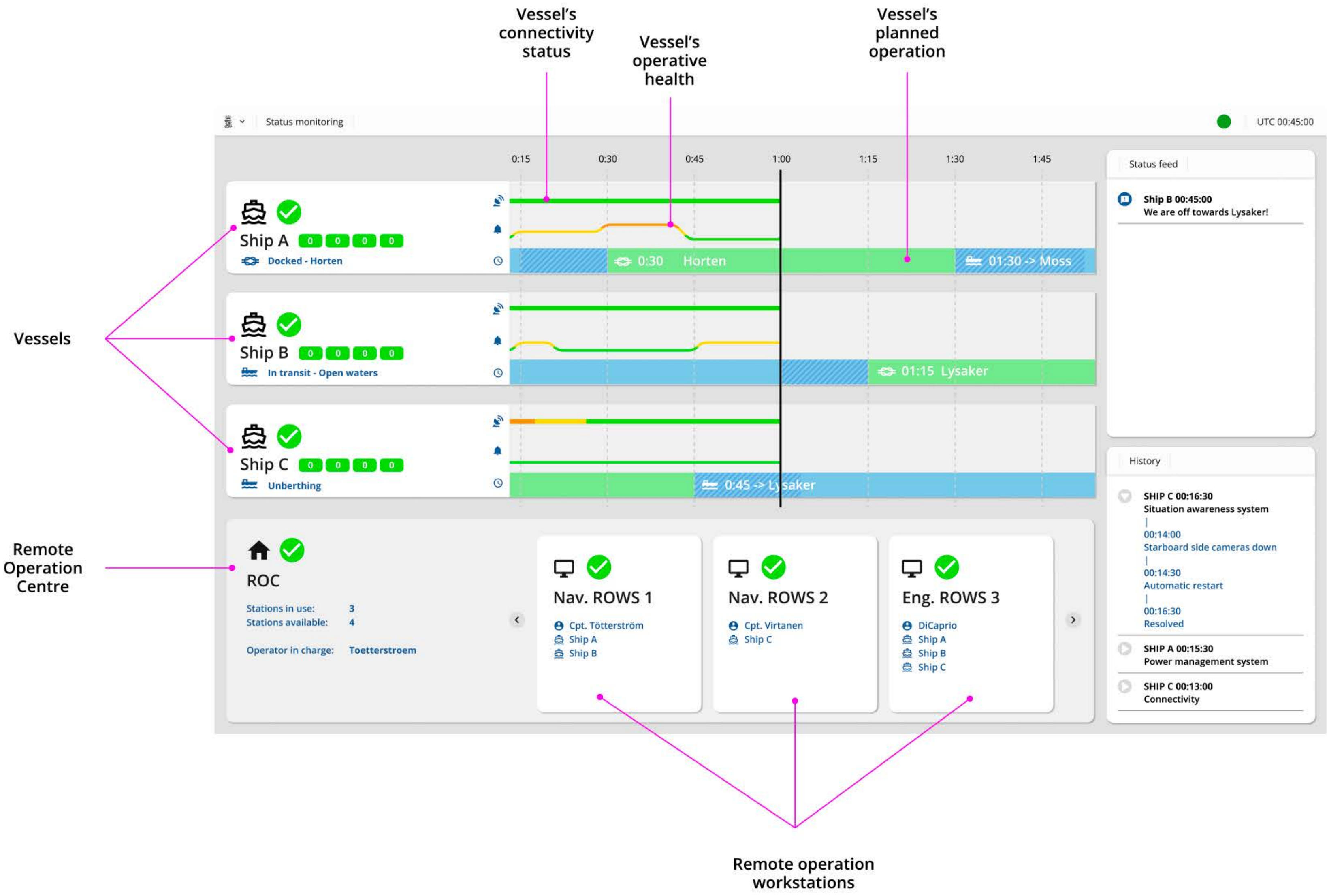
A manuscript with on average one problem emerging at each point of time was done as keyframes Figma software. The problems aimed to be realistic scenarios, based on interviewed expert's prospects. The frames were transferred to an interactive ProtoPie timeline. In the manuscript, the system problems of different severity levels emerged from the three different ships. Also detailed system messages and imaginative crew chat messages were shown adjacent to the alert.

3.6.2 Evaluation Setting

Evaluation took place in individual, 30-minute online meetings with the participants. In the evaluation, the participants interacted with the prototype that was made available through ProtoPie's cloud service. Participants shared their screen in the meeting, and the meeting audio and video was recorded and transcribed and qualitative data was extracted from the transcriptions.

Participants were given a brief description of the motivation of the study and necessary information about the functionalities found in the prototype. Participants were encouraged to talk aloud while interacting with the prototype.

Figure 8.
Main view with the timeline.



UTC 00:45:00

Ship B 00:45:00
We are off towards Lysaker!

Stations in use: 3
Stations available: 4

Operator in charge: Toetterstroem

Nav. ROWS 1
- Cpt. Tötterström
- Ship A
- Ship B

Nav. ROWS 2
- Cpt. Virtanen
- Ship C

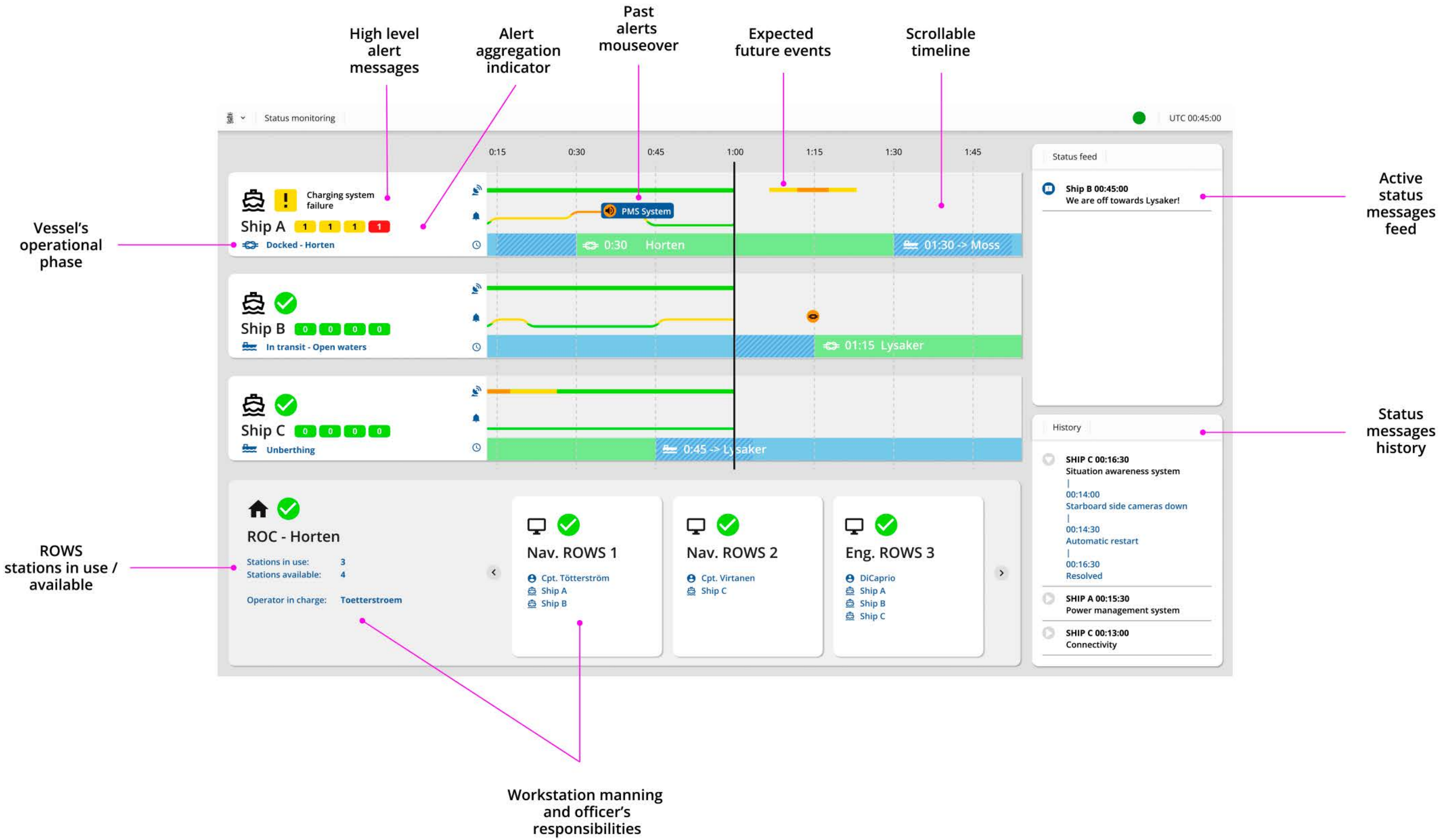
Eng. ROWS 3
- DiCaprio
- Ship A
- Ship B
- Ship C

SHIP C 00:16:30
Situation awareness system
|
00:14:00
Starboard side cameras down
|
00:14:30
Automatic restart
|
00:16:30
Resolved

SHIP A 00:15:30
Power management system

SHIP C 00:13:00
Connectivity

Figure 9.
Main view with the timeline.



Stations in use: 3
Stations available: 4
Operator in charge: Toetterstroem

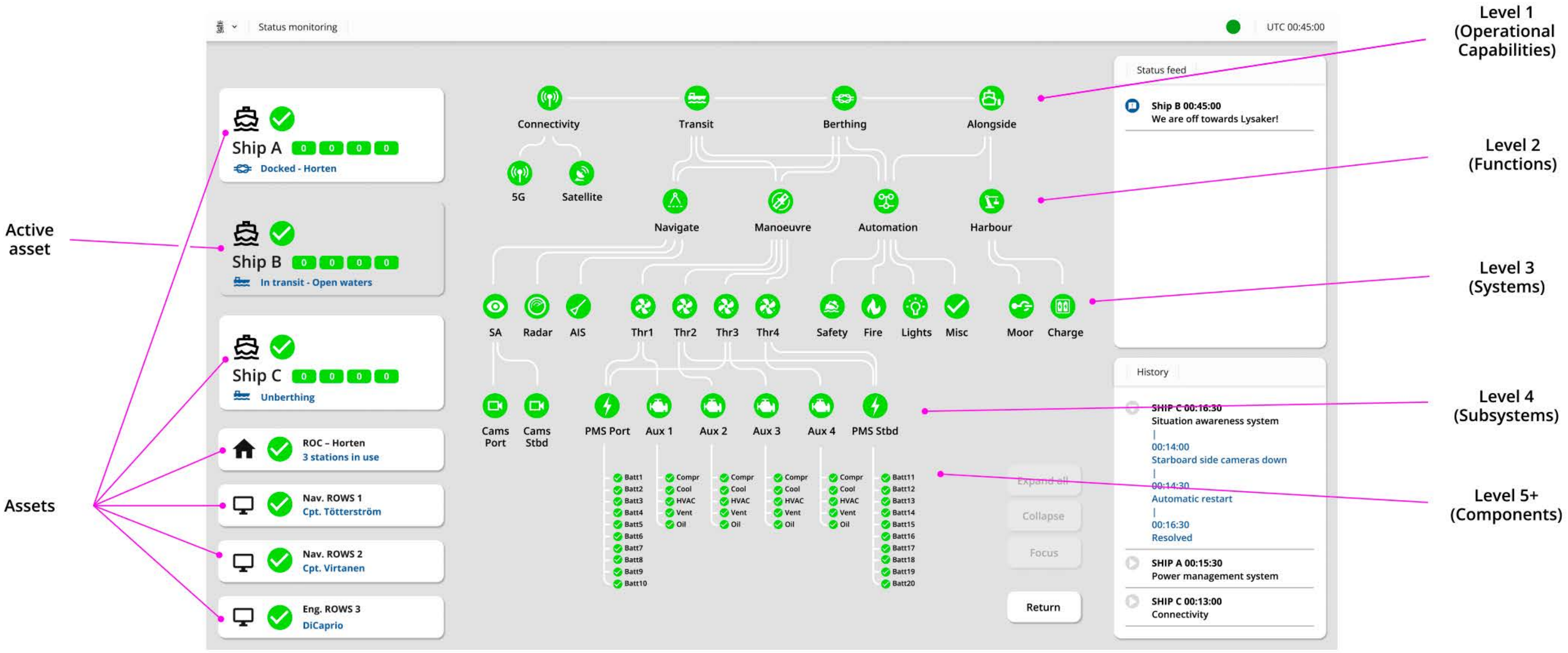
Ship B 00:45:00
We are off towards Lysaker!

SHIP C 00:16:30
Situation awareness system
|
00:14:00
Starboard side cameras down
|
00:14:30
Automatic restart
|
00:16:30
Resolved

SHIP A 00:15:30
Power management system

SHIP C 00:13:00
Connectivity

Figure 10.
System view with the system tree.



Ship B 00:45:00
We are off towards Lysaker!

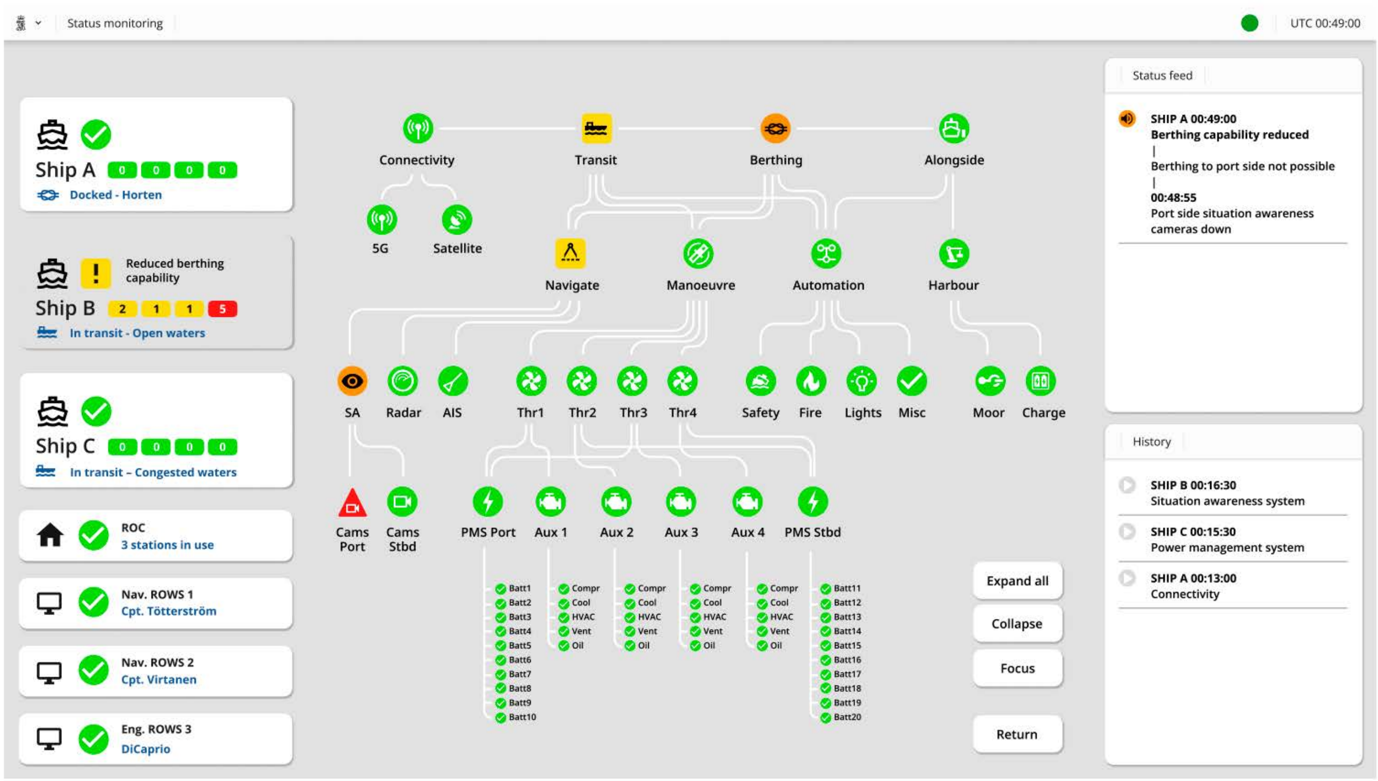
SHIP C 00:16:30
Situation awareness system
|
00:14:00
Starboard side cameras down
|
00:14:30
Automatic restart
|
00:16:30
Resolved

SHIP A 00:15:30
Power management system

SHIP C 00:13:00
Connectivity

Figure 11.
System view with an issue that causes a high level caution message.

- ✓ Status OK
- ! Caution
- 🔊 Warning
- ⚠ Alarm
- ✓ Status Unknown (Last known status shown)
- FBS Vessel in Fallback State



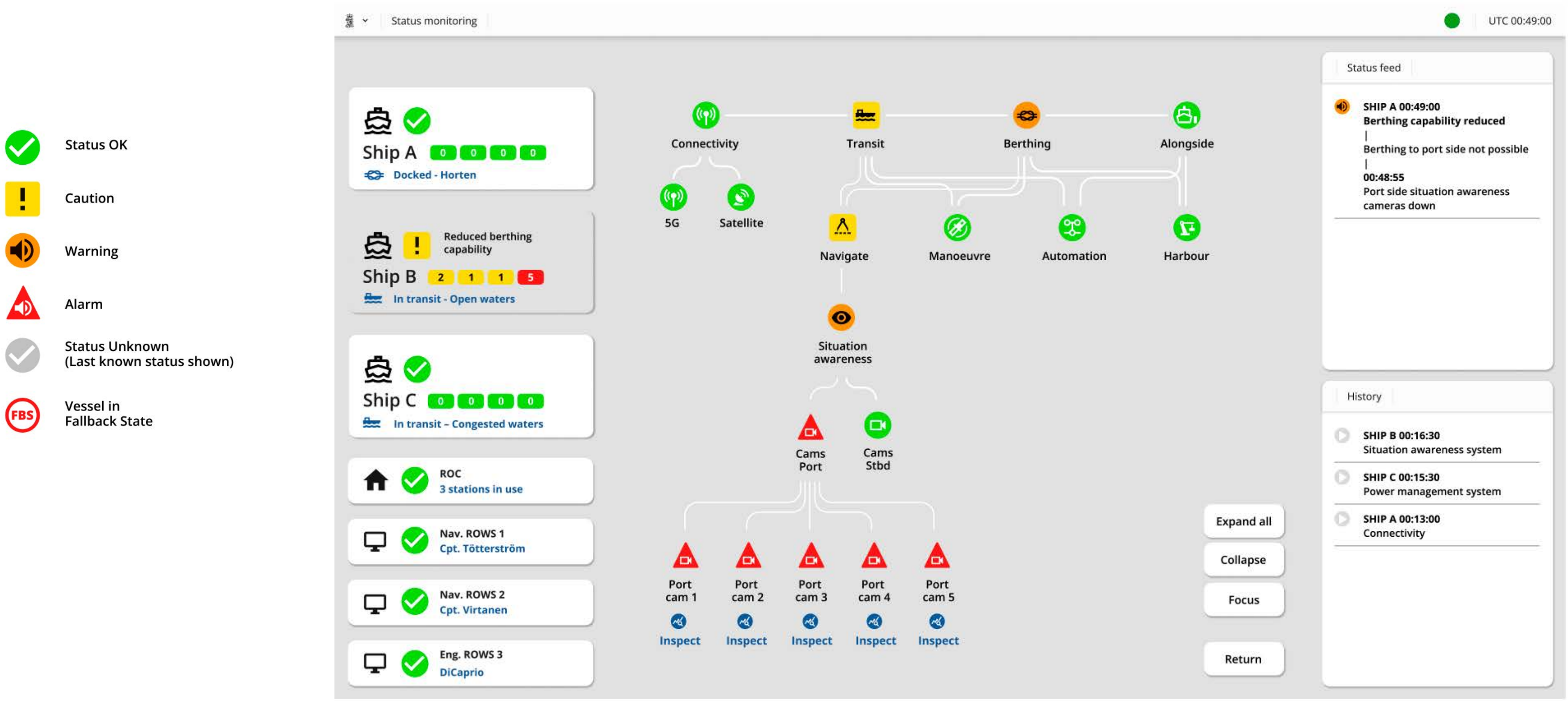
SHIP A 00:49:00
Berthing capability reduced
|
Berthing to port side not possible
|
00:48:55
Port side situation awareness cameras down

SHIP B 00:16:30
Situation awareness system

SHIP C 00:15:30
Power management system

SHIP A 00:13:00
Connectivity

Figure 12.
System view with an alert source in focus.



Status monitoring

UTC 00:49:00

Ship A 0 0 0 0
Docked - Horten

Reduced berthing capability
Ship B 2 1 1 5
In transit - Open waters

Ship C 0 0 0 0
In transit – Congested waters

ROC
3 stations in use

Nav. ROWS 1
Cpt. Tötterström

Nav. ROWS 2
Cpt. Virtanen

Eng. ROWS 3
DiCaprio

Status feed

SHIP A 00:49:00
Berthing capability reduced
|
Berthing to port side not possible
|
00:48:55
Port side situation awareness cameras down

History

SHIP B 00:16:30
Situation awareness system

SHIP C 00:15:30
Power management system

SHIP A 00:13:00
Connectivity

4. Results

In the following, the findings from the evaluation of the early stage design are presented. Some clear validation for the identified user requirements and design solutions was gained, as well as critical comments and proposals that can help to adjust the user requirements and the next iteration of the design. The evaluator's positive comments are mapped to user requirements in **Table 3.** (p. 48) and critical comments and proposals in **Table 4.** (p. 49)

4.1 A Collected Status Monitoring Interface is Needed in Multivessel MASS Operations

The participatory evaluation provided evidence for the general assumption that an interface that shows the status of all assets (vessels, ROC systems and ROWS) and other critical information, such as times of entering high risk areas, in the operation is needed for remote operation of a fleet of ships. Evidence was found that a) collecting the critical information in one window and b) structuring it in a way that affords both getting a quick overall understanding of the status of all the assets in the operation and distinction of information relating to each individual asset is a good general approach.

It was for instance considered very useful for the operator to see which remote navigator is responsible for which vessel.

4.2 Status Aggregation Approach Has Multiple Benefits

Evidence was found that the status aggregation approach is in many ways sensible in a multivessel, remote MASS operation. The evaluators pointed out the value of the approach in ways that support the identified user requirements (RQ) as follows:

1. Status Information is Salient

The evaluators pointed out that through the aggregation approach, it is possible to filter out lower-level system alerts that are not calling for the operator's immediate attention.

Table 3. Positive feedback from the evaluators mapped to user needs

		Expert insights
User needs	a) Minimise workload b) Provide SA	• **(a, b)** “For an overall screen [timeline view] this could be quite a relaxing view to look at.” ENG02 • **(b, 1, 2, 8)** “Provides faster understanding of the situational awareness that’s going on.” NAV03 • **(1)** “When ship’s capability indicators are showing green you are basically ok.” ENG01 • **(1, 2)** “This is a very very good start for our overall healthy view.” ENG02 • **(1, 2, 4)** “This is not ‘alarm handling’, which I think is ok to do in the IAS, but this system is an allover view.” NAV03 • **(2)** [Aggregation view]: “Of course, when you have a layout like this, you will have a a better scope that what’s going on.” ENG02 • **(5)** “Imagine that you have not only three vessel, but you have five or six, and then you also see that who is responsible operator for the different stations which is good.” NAV03 • **(5)** The [aggregation view] can be also the overview for the inspector or boss not sitting in the same building if it can be delivered ENG02 • **(5)** “It is useful to show which ROWS are manned and which are in standby mode.” ENG01 • **(5)** [Aggregation view]: “If the captain and the engineer is not present in the same room, this will actually be the best presentation of the health and the safe routing of the vessels.” ENG02 • **(5)** “Good that you see the same view as engineer or navigator.” NAV03 • **(5)** “It would definitely enhance communication within the team.” NAV03 • **(5) “**It’s not only for the engineer, but the other operators who should know all of these things but don’t need to deep dive to the IAS.” NAV03 • **(8) “**Important that the tree view is easily understandable” NAV03
User RQ	1. Salient information	
	2. Contextual information	
	3. Transparent information	
	4. Support RO active involvement	
	5. Support team communication	
	6. Support high / low attention monitoring	
Usability RQ	7. Compact layout	
	8. Clarity of information presentation	
	9. Support workstation customization	
Organi-zational RQ	10. Integration with existing systems	
	11. Conforming with industry standards	
	12. Conforming with maritime regulations	

Table 4. Insights, proposals and critical comments from the evaluators mapped to user needs.

		Expert insights
User needs	a) Minimise workload b) Provide SA	• **(a, b, 1)** “Little bit of alarms is healthy but take away the non essential ones” ENG02 • **(1, 2, 7, 8)** “With one glance to the collected status window the operator should get a really good overview of the systems status.” ENG01 • **(2)** “Use modes for different operational phases could be useful. Modal masking of status information woud be good. Information that is irrelevant for the operations phase could be left out of view.” ENG01 • **(3, 4)** “Provide the operator aids to remember what the past alerts were.” ENG01 • **(8)** The tree view to the system should be simple enough to keep it comprehensible.” ENG01 • **(1, 4, 8)** [Timeline view] “How the lower level alerts are presented in the “status aggregation indicator” is not logical and is confusing” ENG01 • **(2, 5)** “I guess engineering alarms should be called somehow separated from navigation alarms. You could see a light or something that there is alarm in the machine, but you don’t want that alarm for the navigation part.” ENG02 • **(4)** “It is not necessary to provide links to IAS, this is just for overall picture” NAV03 • **(8)** “Do not take away all the acoustic signals.” ENG02 • **(9)** “I like the tool. But for me as an engineer I prefer to see the top line of each ship’s IMS and keep the alarm bar gray which means that there are no alarmxs” ENG02 • **(N/A)** “Mission planning could be integrated to the same system: You need a checklist where you see that all the equipment is running before departure. Not only for engineering but you could use it as a planning software NAV03
User RQ	1. Salient information	
	2. Contextual information	
	3. Transparent information	
	4. Support RO active involvement	
	5. Support team communication	
	6. Support high / low attention monitoring	
Usability RQ	7. Compact layout	
	8. Clarity of information presentation	
	9. Support workstation customization	
Organi-zational RQ	10. Integration with existing systems	
	11. Conforming with industry standards	
	12. Conforming with maritime regulations	

2. Status Information is Contextual

Providing status information aggregated as the ship's primary capabilities and most crucial system's statuses were considered to help the operator in understanding the contextual meaning of the information.

3. Status Information is Transparent /

4. Operator's Active Involvement Is Supported

The evaluators saw that a simplified overall visualization of the vessel's system, which indicates possible failures in sub-systems, provides an efficient way to inspect the health of the vessel.

5. Team Communication is Supported

The simplified system tree visualization of a vessel's systems was seen as a promising tool for communicating the system status information within the operation team. It was especially stated that for those team members who are not engineering experts, the visualization can provide sufficient level information on the critical systems.

Generally, the evaluators pointed out a need for tools that would provide means to efficiently communicate system status information to the operation team. The approach of the prototype was greeted as a good start towards this goal.

4.3 Proposals Elicited by the Prototype

The simplified system visualization was seen as a potentially useful tool also for mission planning and departure procedures involving thorough system checks.

Providing means to check the system's status history was considered an essential feature that was not included in the prototype.

Showing the vessel's primary capabilities and status of most crucial systems was proposed to be possibly shown in the overall view, but it was also acknowledged that this might compromise the clarity of information.

It was also proposed that the system could include use modes for different operational phases and status information that is irrelevant for the current operation phase could be left out of view.

4.4 Criticism

It was pointed out that the status aggregation indicator (fig. 7. p.46) that shows the amount of underlying system alerts was not providing salient information about the system's status. It was seen that it essentially bears the same problems as having a system which produces a significant amount of disturbing and unnecessary alarms.

One evaluator noted that as an engineering officer, he still prefers the conventional IAS tools as a primary means of monitoring the systems statuses and saw that the simplified view might not give information that is sufficiently precise.

Another evaluator noted that introduction of new systems inherently causes additional latency, which can have severe consequences.

5. Discussion

An early-phase design for a remote engineering officer's status monitoring system in a multivessel, remote MASS operation was developed and evaluated in a human-centred design process. The process involved multiple field experts with knowledge of MASS systems. Findings from the evaluation were presented in the previous chapter.

The prototype design proved to be an effective tool for eliciting expert insights, and validating and further refining the user requirements for the design of this type of system.

5.1 Responding to the Research Question

My research question was: **What types of new requirements the change in the working context of maritime engineering officers will brings**

The research pointed out and shed light on some elementary changes that the introduction of multivessel MASS operations brings to mariners.

Change in System Complexity

A MASS operation will inherently be much more complex than a conventional manned shipping operation because of the multiple new systems that are also critical for the operation, such as the ROC itself, the connectivity systems and the digital orchestrators. It is elementary that the operator *understands how the system is operating* at any given time and is *able to judge whether the operation is safe*. As this research focuses on the status monitoring system, the new requirements presented here deal with *clear and comprehensible presentation of systems' statuses* and *supporting the operator in effectively focusing their attention.*

Change in Working Role and Style

Moving the work from ship to shore changes the work not only physically, but also the engineering officer's working role and responsibilities change. We do not know yet the ratio of so-called high and low attention monitoring times, but it is fair to expect that most of the operation time in a tested and tried MASS system will be low attention monitoring. Thus it is elementary that the *operator's tasks are supported by the systems and interfaces* provided when rapid response is needed. System's *predictive capabilities* and *capabilities to support troubleshooting* are in demand.

Change in Teamwork

Moreover it is expected, that in a MASS operation the operators will at times need to swap the monitoring tasks, especially when high attention is needed for some of the assets. Thus it is needed that the *system supports fluid changes of monitoring responsibilities*. This poses new demands for information presentation and means of communication.

Ever Present Problem of Too Much Information and Alerts

The field experts interviewed for this study brought up how it is extremely common that maritime automation systems produce too many alerts, and how finding the salient ones is a key challenge. According to Endsley and Garland, getting the right information at the right time is essential for situational awareness (Endsley and Garland, 2000). Most in demand for the future remote engineering officer and the whole operation team is Level 3 SA – ability to forecast future situations (Endsley, 1995).

Requirements from Evaluation

In practical terms, the response to the proposed design from the evaluators was explicitly that a status monitoring system that, *a) displays the vessel's system statuses in a single view* and *indicates possible underlying failures, b) aggregates the statuses as meaningful higher level status indicators that make sense in relation to the mission* and *c) is accessible for all members of the operation team,* both enhances situational awareness and team communication.

The experts pointing out the feasibility of shared tools that have clear and mutually understandable form, bears strong connection to Edwin Hutchin's findings on situated cognition, namely that workers in a team may distribute their awareness via the tools they use (Hutchins, 1995).

The findings in this study point to that to design for shared situational awareness one should come up with accessible tools that can be shared in the team and that are able to give salient information at the right time.

5.2 Situation Awareness Research in MASS context

The status monitoring system that was developed and described in this study, proved to be usable and worth developing further especially because it was shown to be able to enhance team communication. The operational concepts described in Chapter 3. can be applied in future studies in the field.

Earlier research, such as was done in Man et. al. (Man et al., 2015), has both identified the need for research concerning teamwork in remote MASS operations, and also brought up the challenges of carrying out studies on remote operator's work in such a way that they would produce results that would be highly informative for designing new tools in the field.

An obvious challenge for research exists, which is that the development of MASS is in such an early phase that many aspects are left under high speculation. Particularly the fact that such intelligent systems that would be able to carry out shipping operations autonomously and on a regular basis do not yet exist, leaves many central aspects of the remote operator's work unknown. Before the capabilities of the overall, intelligent operation systems are known, it is very hard to estimate how often and in which ways will the operators need to intervene. Thus it is also difficult to arrange realistic research settings, especially for studying teamwork.

5.3 Ecological Interface Design

It is exciting to look at the MASS control systems through the Ecological Interface Design (EID) framework, in which the basic philosophy is to provide resilience in the face of unforeseen events (Borst et al., 2015). The reasoning behind the aggregation model seems to bear strong connections to many details found in EID and also Jens Rasmussen's abstraction-decomposition model of cognitive task analysis (Naikar, 2017).

A philosophy called single-sensor-single-indicator was common in early nuclear power plants (Borst et al., 2015) and actually to some extent the same philosophy seems to be applied when a maritime machinery automation system is giving “so many disturbing highlighted alarms” as one chief engineer in my study said.

Borst et. al summarise the goal of ecological representation as ‘organizing the information in ways that leverage the deep structure of the work domain so that meaningful associations among the variables are more salient’. There seem to have been many misconceptions about the purpose and usefulness of EID since its introduction. Vicente and Rasmussen intended the framework to be used in expert systems, not for designing interfaces that anyone could use with no experience.

It is maybe appropriate to expect with the high level of vessel autonomy that the developers of MASS systems are aiming at, that many of the control tasks the operators will face will demand high levels of analysis and problem solving. Thus, following Rasmussen, the interface should help the operator by offering a ‘faithful, externalised symbolic model to support mental experiments’ (Rasmussen, 1999).

Possibly the simplified vessel system model that was a feature of the first prototype in this study is not ‘faithful’ enough to truly help in solving complicated vessel side system problems, but at least it is a step in that direction.

5.4 MASS operation as a Joint Cognitive System

As Kari and Steinert pointed out (Kari and Steinert, 2021), the MASS operator’s situational awareness is most often discussed based on human-machine interactions. This is an understandable feature of a field that is driven by technological advancements.

The paradigm of Cognitive System Engineering (CSE) points out the benefits of emphasising human-technology co-agency instead of funcional separatedness. Understanding how humans cooperate and act proactively in the work context, and how human actions should not be considered one by one but as a continued flow, is central in CSE. In the approach of CSE the functioning of the Joint Cognitive System formed by humans and technology is studied (Hollnagel and Woods, 2005).

In this study it was not possible to study the Joint Cognitive System that a future MASS system will be on a true to life level. When the related technologies mature more, it is worth considering the system, with its users and intelligent agents on the level of a JCS.

5.5 Limitations

Elementary aspects of the future remote operator's work could not be included in the research.

Firstly, the prototype design was evaluated as a single screen isolated presentation, as it was not possible with the resources available to produce a more realistic simulator test setting in an actual ROC.

Secondly, it would be beneficial for studying the designs in realistic teamwork scenarios involving at least workers in the roles of an engineer and a navigator.

Thirdly, the performance of the autonomous technologies will greatly affect the operator's work, as was described above in 5.1.

5.6 Conclusion

This thesis identified central user requirements for a remote engineer's status monitoring tool through a human-centred design process. A wide and multidisciplinary stakeholder base participated in the interviews, workshops and evaluation of the proposal for an early phase design.

Evaluation of the early phase design provided evidence for that:

1. A collected monitoring window including information on top-level status of the systems to be monitored, different vessel's operation phase and responsibilities of operators in the remote operation team is needed for a multivessel remote operation

2. An interactive visualization of a vessel's capabilities and critical systems statuses helps a remote operation team to maintain sit-

uational awareness and to communicate efficiently when problems emerge from a vessel’s systems

This study contributes to the knowledge about future MASS operator’s needs concerning system status monitoring and team communication. It builds on the previous research on MASS and proposes concrete design solutions for system status monitoring in a multivessel operation. Solutions of this type should be further developed and validated in future research.

6. Personal Reflection

As it is both recommended by my Department and also because I find it a great opportunity, I will as the last words reflect on how the thesis process was for me and what I might have learned from it.

First of all, working with the subject from start to finish has been extremely inspiring and interesting. I did not choose the topic, but the topic chose me when I applied to work on the project. As of this writing, I am still inspired, which surprises me, as the process of how this thesis took its final shape was far from smooth sailing. Namely, I found it very challenging to academically frame the topic so that it makes a thesis that I am capable of writing. Without the patient support from my thesis supervisor Virpi Roto and thesis advisor Antony William Joseph, I would not have made it to this point.

The design case that was carried out was the first of its kind for me. I have not done user experience or user interface design in this depth before. The human factors/ergonomics concepts, frameworks, and everything relating was basically all new ground for me.

It was a formidable opportunity to work with Kongsberg and see how these new technologies around MASS are taking shape in quick, iterative processes. This cleared me how differently the design processes are seen from academic and industry perspectives. This must be obvious to anyone who has experience from both worlds.

Two things may emerge as takeaways of most personal significance.

First is the experience of producing knowledge that – at least I believe this is the case but ask for objections as we are in the academic domain – is grounded. How the knowledge takes time to emerge through analysis and reframing in time. At the final stage of the process, I felt deeply engaged in conversation with the study data.

The second relates to the academic practices and routines of searching, reading, organizing, and writing. I have always felt a bit intimidated by the "academic pirouettes" as Margareta Lützhöft (Lützhöft, 2004) in her extremely entertaining dissertation describes the things that just need to be in a thesis for it to be a thesis. During this study process, I learned a lot from the practical side of academic practices, but maybe even more importantly, was so fascinated by the topics I was working with, that I now feel I want to dive deeper.

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