Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

Jooyoung Park

Graphical User Interface Design for a Remote Operator to Monitor and Control Multiple Autonomous Ferries

Master's thesis in Industrial Design Engineering
Supervisor: Ole Andreas Alsos
Co-supervisor: Øyvind Smogeli
January 2022

NTNU
Norwegian University of
Science and Technology

Jooyoung Park

Graphical User Interface Design for a Remote Operator to Monitor and Control Multiple Autonomous Ferries

Master's thesis in Industrial Design Engineering
Supervisor: Ole Andreas Alsos
Co-supervisor: Øyvind Smogeli
January 2022

Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

NTNU
Norwegian University of Science and Technology

02
03
01
05
08
06

Abstract

This master's project aims to design and test a prototype of a graphical user interface for a fleet of autonomous ferries for remote operators.

The unmanned autonomous ferry is based on the Shore Control Lab's milliAmpere2 project; the design premises and design principles covered by the subject matter were defined by the author while carrying out the project.

The literature study defines the conceptual and technical aspects of autonomous vessels, and recognizes the challenges that need to be addressed in order to safely and efficiently perform remote monitoring.

Through design research, the project explores how the graphical user interface facilitates the operators to enhance situation awareness and expand human performance.

The functional prototype as an outcome of this project can be reached online: https://2o6ovt.axshare.com/

Acknowledgements

I would like to thank Ole Andreas Alsos, my primary supervisor, for his guidance, feedback and participation in the project through the weekly supervisory meetings.

I would also like to thank my co-supervisor Øyvind Smogeli for providing guidance on the operation of the milliAmpere2, and Thomas Porathe for his pioneering and ongoing research on the maritime autonomous surface vessel upon which my project is based.

I would also like to thank Felix-Marcel Petermann, Erik Veitch and Andreas Madsen for providing useful input to the project; YoungRong Kim for his advice and feedback at every step, and all participants in the survey and interview.

Lastly, I would like to thank my beloved family Theo, Genie and Sungsoo for their encouragement, support, and perseverance.

Preface

The main purpose of this master's thesis is to propose the best possible GUI concept for a remote operations team monitoring a fleet of milliAmpere2, an autonomous passenger ferry that will operate in Trondheim.

The requirements for the GUI were ambiguous, so literature studies and design research were conducted to establish the design premise. In addition, design principles were derived through research.

The project has built a clickable prototype that shows an alarm system and visualized information to monitor autonomous maneuvering. This report contains descriptions of all processes and the final prototype of the project.

Contents

Abstract	5
Acknowledgements	6
Preface	7
Glossary	11
1. Introduction	
Motivation	14
Scope	17
Project Outline	18
Project Description	19
Timeline	20
2. Research	
MASS	24
Shore Control Center (SCC)	26
MUNIN Project	28
milliAmpere2	30
Comparison of MUNIN and milliAmpere2	32
User Interface Design Guidelines	33
Situation Awareness (SA)	34
Levels of Human Interaction with Automation	36
User-Centered Design Guidelines	38
3. Approach and Method	
Approach	43
Methodology	44
4. Discover	
The Starting Point	48
Interview #1	52
Survey #1	56
Sketch #1	58
Interview #2	59
Sketch #2	64
Workshop	66
Sketch #3	71
5. Define	
Problem Statement	77
User Scenario and System Architecture	78
6. Develop	
Sketch #4 (Iteration 1)	82
Prototype #1 (Iteration 2)	89
Survey #2	94
Prototype #2 (Iteration 3)	98
Usability Test	103
7. Deliver	
Design Premises	106
Design Principles	108
Design Outcome	109
Prototype Implementation	123
8. Reflections	
Reflections	126
References	128
Appendix 1.	133
Appendix 2.	144
Appendix 3.	146

Glossary

AI	Artificial Intelligence
CCTV	Closed-circuit television
COG	Course Over Ground
CPA	Closest Point of Approach
DP	Dynamic Positioning
ECDIS	Electronic Chart Display and Information System
ETA	Estimated Time to Arrival
GSM	Global system for Mobile Communications
GUI	Graphical User Interface
HDG	Heading
IMO	International Maritime Organization
mA	milliAmpere project
mA2	milliAmpere2 Project
MASS	Maritime Autonomous Surface Ship
MB	Maritime Broadband), and VHF(
MUNIN	Maritime Unmanned Navigation through Intelligence in Network
ROC	Remote Operation Center
RPM	Revolutions Per Minute
RSE	Regulatory Scoping Exercise
SA	Situation Awareness
SCC	Shore Control Center
SCL	Shore Control Lab
SOG	Speed Over Ground
STW	Speed Through Water
TCPA	Time to Closest Point of Approach
UCD	User-Centered Design
UI	User Interface
VHF	Very High Frequency

1 INTRODUCTION

Motivation

With the development of technology, there have been rapid changes in various fields. In particular, the spread of smartphones has brought about great changes, and people's dependence on digital technology has increased as well as changes in human daily life and work environment. As the system accumulates a lot of information, technologies that utilize it have also been developed. As the amount of information that AI can quickly process based on big data has increased, this has led to the fourth industrial revolution. It is said that unmanned autonomous systems and robots will emerge, which will replace human labor.

The maritime industry, for that matter, cannot avoid these changes. Ships have long been an important means of transportation and transport. Consequently, international shipping by sea accounts for approximately 90% of all shipments around the world, and the demands for global freight are continuously increasing. If such vessels become unmanned, it is expected to reduce operating costs by replacing human labor, increase stability by eliminating human errors, and reduce emissions and fuel costs by operating with electric batteries (Yara, 2021). Numerous studies and experiments are being conducted in companies and academies for the development of unmanned autonomous surface vessels to ensure their safe operation and maximize the benefits.

Especially in Norway, several commercial projects have been launched in recent years with advanced autonomous technology. Yara Birkeland, the world's first fully electric and autonomous container ship with zero emissions, has finished construction. Commercial operation is expected to begin in 2022 in Eastern Norway (Yara, 2021). Additionally, Zeabuz, a start-up from the Norwegian University of Science and Technology (NTNU) research community, is under development of autonomous passenger ferries for urban waterways. It aims to make emission-free autonomous passenger ferries, and launch them in 2022 (Zeabuz).

As such efforts are being made to disseminate unmanned vessels to the deep sea and canals; hence, autonomous vessels will ultimately aim for unmanned operation.

The changes towards unmanned autonomous paradigm with increased influence of systems emerses safety issues as well. Even if the technology is mature enough to bring the autonomous systems to reality, there can be an accident due to system error or an unexpected circumstance. Therefore, to avoid or cope with the situation, human monitoring is essential even remotely. The GUI will take the indispensable role.

- *How to design a GUI understandable for remote monitoring?*
- *How can humans understand the situation of unmanned vessels onshore properly?*
- *What if an operator monitors more than one vessel?*

NTNU
Fakultet for arkitektur og design
Institutt for design

Masteroppgave for student Jooyoung Park

Interface design for a remote operator to monitor and control multiple autonomous ferries

In Trondheim, an autonomous, electrical passenger ferry crossing Nidelven between Ravnkloa and Fosenkaia, carrying up to 12 passengers, launched in 2021. The vessel is regarded as alternative urban transportation because of its advantages on time-saving - takes 1 minute meanwhile 15 minutes on foot, and eco-friendly vessel as no carbon emitted.

The master project pursues designing an overview interface for the operator(s) at a shore support center to monitor or control when necessary a fleet of autonomous unmanned passenger ferries (at least four). It will be displayed in the control room's status monitor independently of the interface for monitoring individual ferries to provide different perspectives. However, in terms of content, they are based on the same real-time information and are linked to each other. Ferries are scalable and adaptable to different routes, cities, and countries as the technology matures. It focuses on what information should contain, how it should be present, and how to keep remote operators situational to monitor at one place.

This project will include the following activities:

- Gathering and analysis of information
- User studies and scenarios
- Ideation and concept development
- Iterative prototyping
- Presentation of interface design concept

Oppgaven utføres etter "Retningslinjer for masteroppgaver i Industriell design".

Ansvarlig faglærer (hovedveileder ID): Ole Andreas Alsos
Eventuelt biveileder: Øyvind Smogeli
Bedriftskontakt: Zeabuz
Utleveringsdato: 06. 09. 2021
Innleveringsfrist: 31. 01. 2022

Ole Andreas Alsos Trondheim, NTNU, 06. 09. 2021 Sara Brinch

Ole Andreas Alsos
Ansvarlig faglærer

Sara Brinch
Instituttleder

Scope

The scope of the thesis:

- Literature review on autonomous vessels and operation, and the role of human operator in monitoring autonomous vessels
- Study of remote operator as a user of this interface
- Research on the components that the interface should contain
- Designing graphical user interface and building a prototype
- Usability test

Project Outline

To address the direction and scope of the project, the kickoff meeting with supervisors and a Ph.d student was held via Teams.

Kickoff meeting (8. Sep. 2021)

Participants: Supervisor, Co-supervisor, Ph.d student

- The project deals with milliAmpere2 which is an ongoing research project at NTNU
- It will operate in Trondheim area
- The question ‘How many operators will monitor how many ferries?’ is not yet defined; the project should include this manning issue
- The ‘remote operator’ is not yet defined as well
- If a team is to monitor a fleet, indicators would be needed
- The stakeholders are Trondheim municipality, AtB, Trondheim harbor, etc.

Findings as a study field
- Who will be the remote operator?
- How many vessels can a team of remote operators monitor at once?

Project Description

The project is to design a graphical user interface for remote operators at the shore control center to monitor a fleet of unmanned autonomous urban ferries operating in Trondheim canal. However, the GUI does not include all the technical and engineering components such as remote navigational control or vessel’s system configuration.

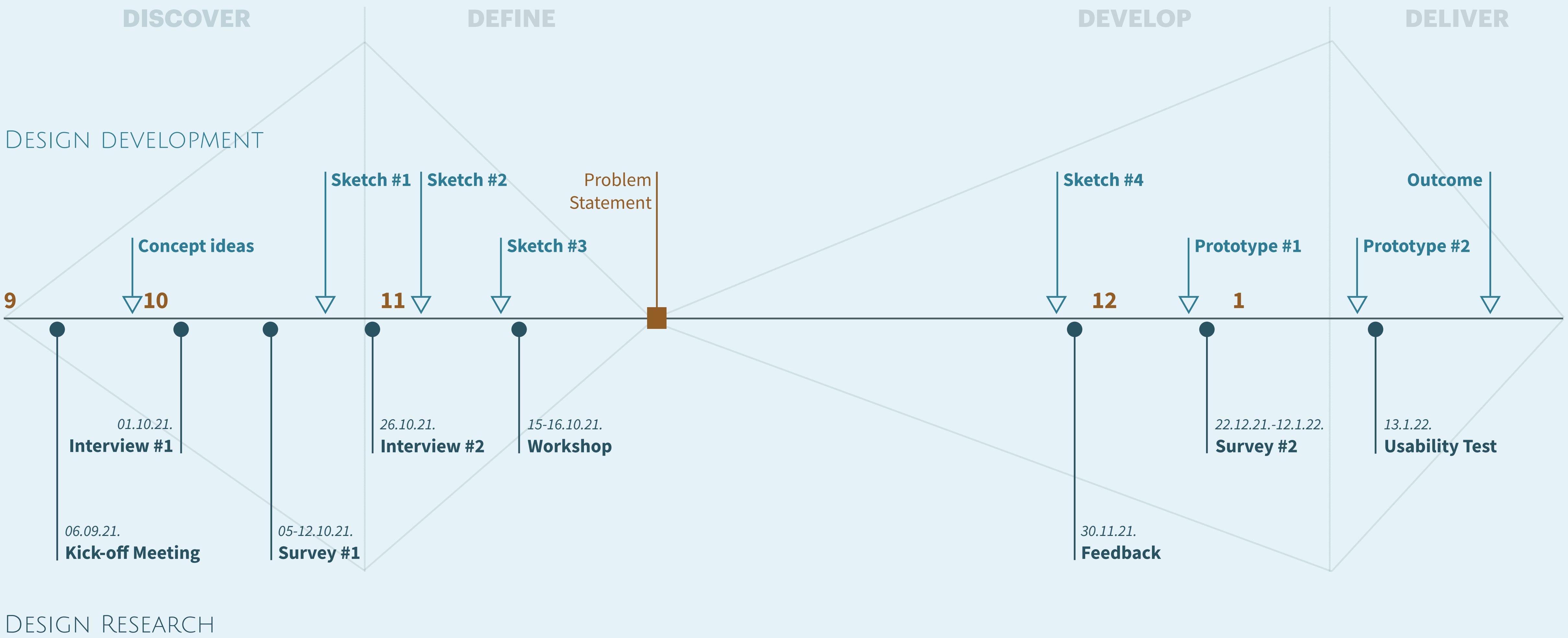
In order for the interface to be more practical and user-friendly, the focus will be on:

- A quick and smooth situation awareness both in normal and abnormal situations
- Intuitive display to provide information on the status of vessels
- Indicators to mark each operator’s work applicable in a team

In order to achieve this goal, various design research shall be conducted on the following detailed topics:

- Inferring the manning in the SCC
- Sorting the components to be displayed on the interface
- The role of GUI in the SCC
- Addressing the duty of remote operators

Timeline



DISCOVER
DEFINE
DEVELOP
DELIVER
Design development
Sketch #1
Sketch #2
Problem Statement
Sketch #4
Outcome
Concept ideas
Sketch #3
Prototype #1
Prototype #2
9
10
11
12
1
01.10.21.
Interview #1
26.10.21.
Interview #2
15-16.10.21.
Workshop
22.12.21.-12.1.22.
Survey #2
13.1.22.
Usability Test
06.09.21.
Kick-off Meeting
05-12.10.21.
Survey #1
30.11.21.
Feedback
Design Research

2 RESEARCH

MASS

MASS (Maritime Autonomous Surface Ship) is a generic term for unmanned autonomous ships defined by the International Maritime Organization (IMO). “MASS” was defined as a vessel capable of operating independently without human interaction to a varying degree for the purpose of the RSE (Regulatory Scoping Exercise).

Various research and development are being carried out in academia and industries, but in terms of enactment of laws, it is still insufficient. With the aim to assess the regulation of MASS, an RSE has been accomplished by IMO to analyze relevant ship safety treaties (IMO, 2021A). Therefore, it is expected that specific regulations will be enacted in various areas such as the design, construction, and operation of autonomous ships in the not too distant future.

Meanwhile, autonomous navigation can be divided into several stages (Table 2.1). It also indicates how much effort people are putting in at each step. MASS is often mistaken for a synonym to unmanned ships. A MASS may be unmanned, even though the autonomous navigation system may be responsible for most of the monotonous monitoring, it may still be manned with maintenance crew or navigators. However, whether the bridge is manned or unmanned, the shore control center will almost definitely be overseeing the MASS (Porathe et al., 2020).

The ultimate goal of MASS would be “fully autonomous”, i.e., that the ship manages and controls all plans and situations by itself, without human monitoring and intervention. However, with current technologies and developments, the final goal is unrealistic, and “constrained autonomous” is expected to come in the near future (Rødseth et al., 2017). This concept is based on unmanned ships maneuvering with fully autonomous ship systems, and operators at a shore control center who can monitor the ships’ activities and intervene when needed.

Table 2.1 *Level of autonomy and human involvement accordingly (Rødseth et al., 2017)*

Level	Description
Direct control	Direct control of ship, minimal automation and decision support.
Decision support	Decision support and advice to crew on bridge. Crew decides.
Automatic bridge	Automated operation, but under continuous supervision by crew.
Periodically unmanned	Supervised by shore. Muster crew if necessary.
Remote control	Unmanned, continuously monitored and direct control from shore.
Automatic	Unmanned under automatic control, monitored from shore.
Constrained autonomous	Unmanned, partly autonomous, supervised by shore.
Fully autonomous	Unmanned and without supervision.

Shore Control Center (SCC)

Shore Control Center (SCC) is a control room where operators are able to monitor, supervise, and intervene in the operation of the autonomous vessels remotely (IMO, 2021B). There are various expressions that have the same meaning as the SCC-remote control station, remote control center, remote control room, shore control station, etc. In this document, SCC will be used primarily.

In a SCC, MASS still needs human operators' involvement on shore, except for the fully autonomous mode. In the SCC, operators can monitor and control one or more unmanned ships remotely and intervene when needed. The SCC communicates with the ships at short time intervals through available communication technologies such as satellites, GSM (Global system for Mobile Communications), MB(Maritime Broadband), and VHF(Very High Frequency). In the event that the autonomous system fails, the SCC should have a smart warning system and take over manual control. The wireless communication systems between the ships and the SCC are vital for the secure and efficient operation of an autonomous ship. Figure 2.1 depicts the MASS and SCC structures, along with the required equipment and functions, as well as the relationship formed by satellite data and information.

The aim of SCC is to constantly monitor one or more MASS remotely and intervene when needed. Porathe and Man (2014) were the leading researchers to investigate the fundamental roles and potential issues of SCCs for unmanned ships. They described the roles of operators as follows:

1. Monitoring voyage and updating the ship route: in accordance with the weather conditions, monitoring nautical traffic, and navigational notices in relation to the ship's position, as well as modifying the ship's path when needed. The ships' maneuvering and voyage will be monitored using a variety of representations of information that was typically provided to mariners on manned ships (position, rudder angle, rate of turn, direction, and video feeds of the environment).
2. Monitoring the ship's status: this involves taking into account a variety of technological aspects of the state of the ship, such as engine health and satellite contact signal status.
3. Communication with other ships: the SCC will be responsible for listening to and responding to radio and distress channels.
4. Decision-making for all of the above: the SCC will have to make decisions in light of issues such as weather, ship condition and maintenance needs, vessel traffic, business goals, and cargo in unexpected situations arising from time to time.

If there is a problem, the operators in SCC will be alerted. The cases of intervention can be descriptive in three levels (Porathe et al., 2014):

- Indirect control: MASS keeps operating under autonomous control, but operators may update waypoints to avoid, e.g. bad weather or accident areas.
- Direct control: MASS keeps operating under autonomous control, but operators cancel track for specific maneuvering, e.g. heaving to to give lee for a search and rescue operation.
- Situation handling: The autonomous system is bypassed and the human operators at SCC take over manual controls just like a remote bridge.

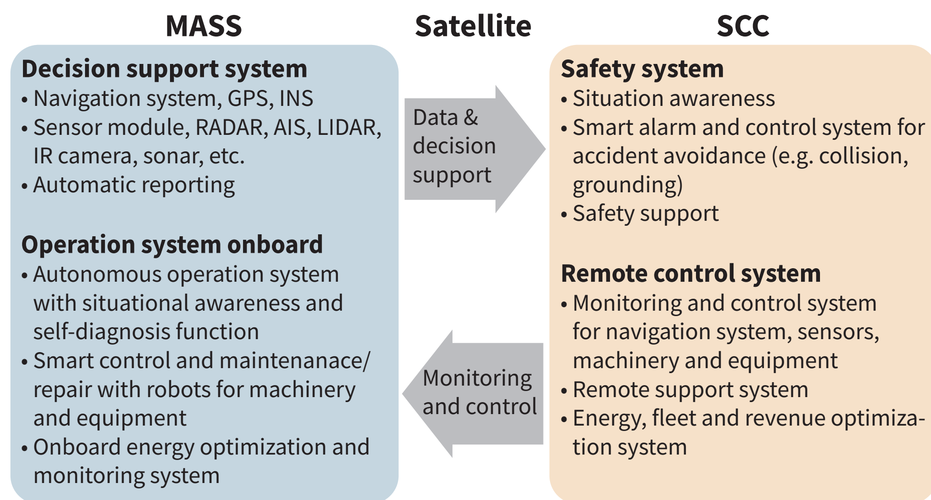


Figure 2.1 MASS and SCC systems and their relationship (Kim et al., 2020)

MUNIN Project

The MUNIN project laid the foundation for an unmanned ship by developing the concept of navigation, system, and operation. The Maritime Unmanned Navigation through Intelligence in Network (MUNIN), a joint research project involving collaborators from scientific and industrial backgrounds, proposed the concept of an unmanned merchant vessel. The main hypothesis of the MUNIN project was that "unmanned ship systems can autonomously sail on an intercontinental voyage at least as safely and efficiently as manned ships". Below are the main proposals proposed by MUNIN.

1. Shore control center where the operator is responsible for monitoring and control functions

A simple remote control solution using the existing communication method is difficult to continuously maintain the proper quality. Therefore, MUNIN proposed the concept that the vessel is operated autonomously by a new system onboard the vessel, but the monitoring and control functions are performed by the onshore operator from the shore control center (MUNIN, 2016).

2. Applying different operating modes for each operation phase

The MUNIN project presented the concept of applying different modes of operation to each phase of the voyage and changing the contribution of remote operators accordingly. Figure 2.2 shows the change in autonomous mode in typical navigation (Rødseth et al. 2017).

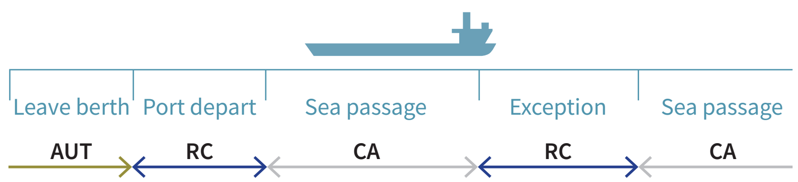


Figure 2.2 Autonomous modes in ship voyage proposed by Rødseth et al. (2017) (AUT: remotely monitored and fully automatic, RC: direct remote control, CA: constrained autonomy)

3. Simultaneous monitoring of multiple vessels

The MUNIN project envisioned a transatlantic voyage from Europe to South America, which was a conceptualized example of the project. They then made an outline of an operator spending ten minutes every hour monitoring six different vessels in the ocean and checking each vessel's key performance indicators in the open ocean (Porathe et al., 2020).

4. Interface design

The MUNIN project also included a dashboard design. Figure 2.3 is the operator's work station when controlling six ships simultaneously, and Figure 2.4 is the dashboard representing one vessel and home screen for the interface. Therefore, in order to monitor six vessels, six dashboards should be arranged as shown in Figure 2.3.

The main feature is that a circular table is placed on the left that separates nine operation modes and assigns a color to each mode so that the operator can immediately notice the current operating mode. In addition, a panel that can check 9 information selected as necessary for remote control and give an alarm in yellow and red background when a situation occurs is placed on the right side.

The MUNIN project dealt with the interface as a whole, not only in this homepage, but also all the parts necessary for operation, such as navigation, system management, and administrative management (Porathe et al., 2014; 2013).

Figure 2.3 Operator's workstation

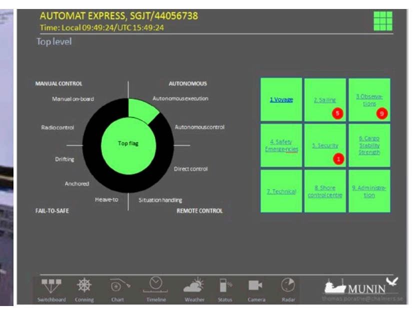


Figure 2.4 Dashboard detail

milliAmpere2

milliAmpere2 (mA2) is a small urban passenger ferry project that has been continuously researched and developed by NTNU for many years, and is the next step of the milliAmpere project.

milliAmpere (mA) is a prototype made at half of the full scale to test the basics of autonomous navigation, and create a basis for developing further technology.
mA2 is being developed with the goal of fully unmanned autonomous operation, and the applied area will operate Ravnkloa and Fosenkaia back and forth to replace the role of a bridge. The ship can carry 12 people and bicycles, and will be monitored from a SCC (Havdal et al., 2017).

The milliAmpere2 is a full-fledged prototype with maneuvering capabilities and it supports infrastructure to enable it to test its passenger carrier if it is ready for commercial use with passengers onboard. This allows for additional core autonomous research and development, as well as research on a variety of topics such as user interaction design, remote assistance center integration and ferry operations. Various departments in NTNU including Marine Technology and Cybernetics, are conducting research on this project on various topics. In the Industrial Design department, previous master's students designed the vessel and the dock (Figure 2.5, 2.6), and the participation continues in various topics such as building trust for autonomous systems, designing shore control center, and interface design.

In the future, mA2 is expected to play a role of Urban Public Transport in a scalable manner not only in Trondheim, but also in canals of other regions and other countries, such as moving in a fixed route like a water bus beyond crossing a canal.

Figure 2.5 Illustration of milleAmpere2 (Mustvedt, 2019)

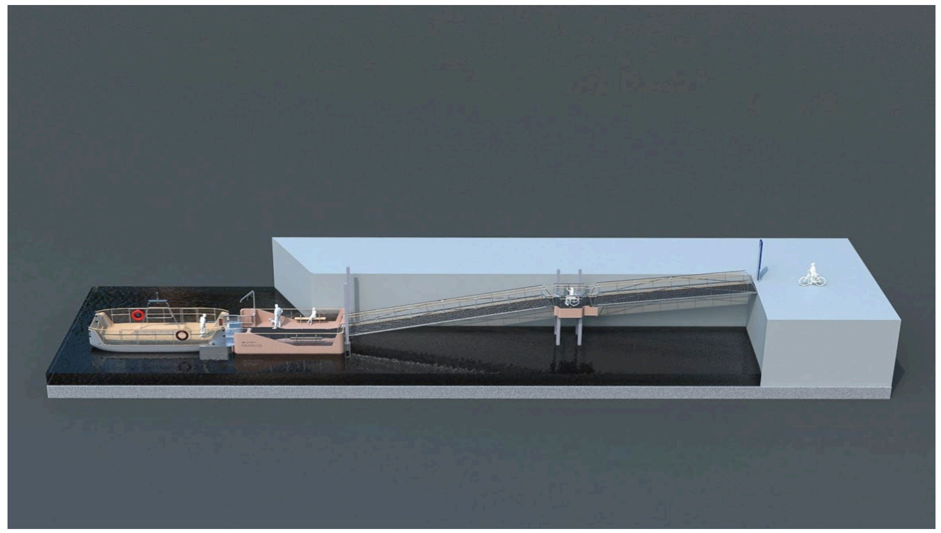


Figure 2.6 Illustration of Ravnkloa Dock (Ellingsen et al., 2020)

Comparison of MUNIN and milliAmpere2

Both the projects are in regard to autonomous vessels; however, there are many differences as described in Table 2.2. As the mA2 does not have a clear operation concept, the MUNIN project has to be a reference to build it.

Table 2.2 *Comparison of MUNIN and milliAmpere2*

	MUNIN	milliAmpere2
Vessel type	Dry bulk carrier	Urban ferry
Vessel size	200m	8.5 X 3.5 m
Purpose	Intercontinental trade	Passenger transport
Freight	Dry bulk	Up to 12 passengers
Level of autonomy	Varies depending on the operation phase	Constrained autonomous
Operation mode	Varies depending on the operation phase	TBD
Voyage route	Europe to South Africa	Crossing canal, back and forth
Voyage duration	Months	Minutes
Monitoring concep	Active monitoring (Porathe et al, 2020)	TBD

User Interface Design Guidelines

User interfaces allow humans to interact with systems or machines, and are responsible for visual information transfer and manipulation. A good user interface design is essential to ensure that systems and machines operate efficiently, safely and in a user-friendly manner, and to achieve the desired results (Poranen et al., 2018).

The goal of User Interface Design Guidelines is to enable faster and better UI design. Table 2.4 compares the two most well-known user-interface guideline lists to analyze the kind of rules they contain.

Both lists require consistency in design and include rules for error prevention, which also mentions usability. This is to mitigate the risk of system failure due to human error and to create a stable and effective system (Johnson 2010, p.13).

Table 2.4 *The two best-known lists of user interface design guidelines* (Johnson 2010, p.13)

Shneiderman and Plaisant	Nielsen and Molich
• Strive for consistency • Cater to universal usability • Offer informative feedback • Design task flows to yield closure • Prevent errors • Permit easy reversal of actions • Make users feel they are in contol • Minimize short-term memory load	• Consistency and standards • Visibility of system status • Match between system and real world • User control and freedom • Error prevention • Recognition rather than recall • Flexibility and efficiency of use • Aesthetic and minimalist design • Help users recognize, diagnose, and recover from errors • Provide online documentatiln and help

Situation Awareness (SA)

Many researchers say the importance of gaining enough situation awareness for shore human operators (Porathe et al., 2014) is to avoid human-out-of-the-loop syndrome. Mika Endsley coined the term SA which is described as “being aware of what is happening around you and understanding what that information means to you now and in the future” (Endsley et al., 2012, p.13).

This concept is especially required for operators who should make fast and safe decisions. Advanced automation can initiate actions without requiring immediate or direct operator input, and it can modulate or override user input. These characteristics of modern technology place high demands on operators’ attention and expertise, as they must maintain awareness of the automation’s status, actions, intentions, and shortcomings in order to moderate their activities with the system effectively (Sarter et al., 1997).

SA consists of three levels; 1) Perception, 2) Comprehension, and 3) Projection (Endsley et al., 2012).

In the manned ship, the ship handler achieves level 1 SA by directly perceiving useful information from the task environment and; understanding surroundings by integrating individual cues into a useful mental model (e.g., knowledge and experience) of the current situation(level 2 SA); and predicting how things work based on their comprehension of the scenario(level 3 SA).

Figure 2.7 uses the operation of a vessel to explain the types of information associated with each stage.

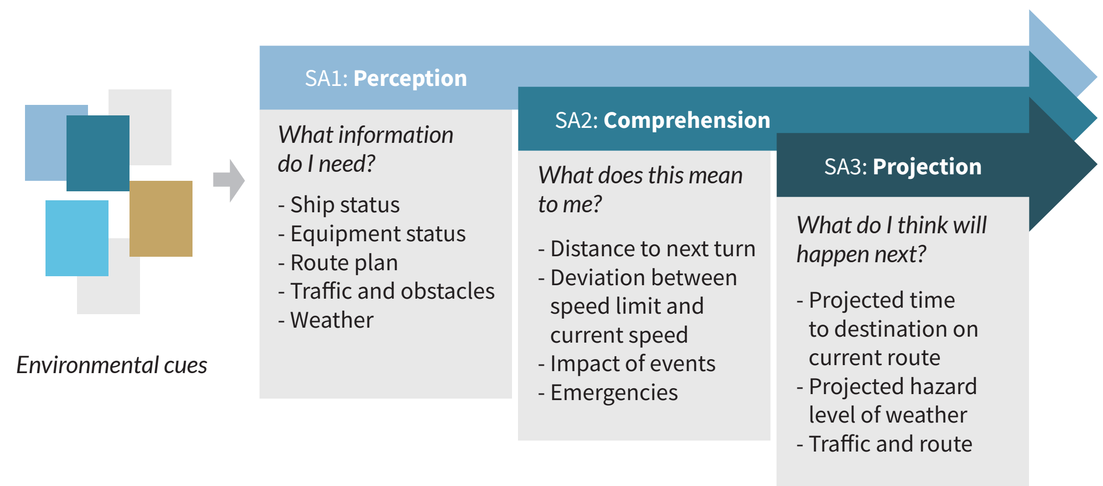


Figure 2.7 The three stages of SA applied to task of navigators (Oury et al., 2021)

Levels of Human Interaction with Automation

The definition of automation in the Oxford English Dictionary(1989) is the use of electronic or mechanical devices to replace human labor. Automation may not only be able to replace but also transmute human behavior, and it may request new coordination demands on the human operator. Thus, appropriate selection of the level of automation is essential.

The Table 2.3 shows a 10-point scale for the level of autonomy. As autonomy goes from a low level to a high level, it shows changes in behaviors performed by computer autonomy and changes in attitudes towards humans.

Table 2.3 *Levels of automation of decision and action selection (Parasuraman et al. 2000)*

	Levels of Automation of Decision and Actiton Selection
High	10. The computer decides everything, act autonomously, ignoring the human.
	9. informs the human only if it, the computer, decides to
	8. informs the human only if asked, or
	7. executes automatically, then necessarily informs the human, and
	6. allows the human a restricted time to veto before automatic execution, or
	5. executes that suggestion if the human approves, or
	4. suggests one alternative
	3. narrow th selection down to a few, or
	2. The computer offers a complete set of decision/ action alternatives, or
Low	1. The computer offers no assistance: human must take all decisions and actions.

At a lower level 2, for example, automation gives humans a variety of options and humans can choose from the options. This option gradually decreases as the level of automation increases so that humans have the right to only approve or veto before execution within a time limit, and ultimately are excluded from decision-making and autonomy progress (Parasuraman et al. 2000).

This human-automation relationship is a fundamental factor in setting the scope of interface design. In accordance with the degree of human intervention, the utilization of necessary interface equipment should be changed as shown in Figure 2.8.

If humans perform all processes of 1) information acquisition, 2) information analysis, 3) decision-making, and 4) execution, research on how to transmit input to automation will be actively conducted. Conversely, if humans are only involved in decision-making or execution, the focus should be on how to effectively communicate information in automation rather than equipment.

Monitoring	Supervision	Assisted Control	Direct Control
Offline monitoring of assets	"Expert in the loop" type of support for the onboard crew	Remote operator controlling the operation or assisting onboard crew with higher level controls	Remote operator controlling the vessel with direct controls and having full operational responsibility

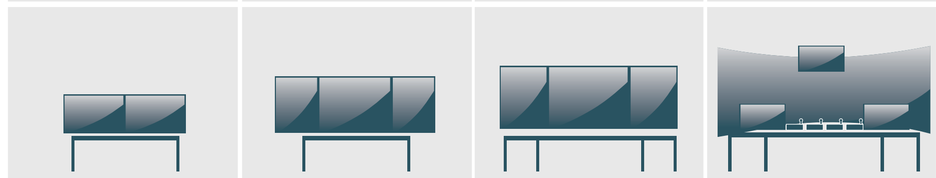


Figure 2.8 Changes in the interface equipment according to the degree of human intervention (Kongberg, 2020)

User-Centered Design Guidelines

In order to design a high-performance system, the functions of the operator must be integrated. This is because the operator is a component of the system, just like sensors or underlying codes (Oury et al., 2021).

Endsley et al. (2003, p. 5) explained the UCD as follows:
"*User-centered design challenges designers to mold the interface around the capabilities and needs of the operators. Rather than displaying information that is centered around the sensors and technologies that produce it, a user-centered design integrates this information in ways that fit the goals, tasks, and needs of the users. This philosophy is not borne primarily from a humanistic or altruistic desire, but rather from a desire to obtain optimal functioning of the overall human-machine system.*"

By designing for situation awareness in operators, designers can accomplish UCD. Endsley et al. (2003, pp. 8–9) outlined the main principles of user-centered design as follows:
1. Organize design around the user's goals, tasks, and abilities.
2. Technology should be organized around the way users process information and make decisions.
3. Technology must keep the user in control and aware of the state of the system.

This can be summarized in the Table 2.5 with more detailed design principles for each stage of SA (Endsley et al. 2003).

Table 2.5 *Design principles for each level of SA*

SA level 1	SA level 2	SA level 3
1. Make the information available 2. Make the information interpretable 3. Ensure the value and salience of each piece of information; eliminate or suppress unnecessary signals	1. Actively design the system to prevent misinterpretation of signals. Signals should be unambiguous, consistent, and instantly recognizable 2. Consider how the actual tasks will be done by the operators.	The third stage of SA is achieved through projecting the model of the situation into possible future outcomes.

Design Principles

Through the background research, the following design principles were established. The principles will play a role as the basis for framing the GUI design; the list will be added when the new design principles are derived from each stage of the design study.

1. Keep the consistency in design for error prevention and expanding users recognition.

2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)

3. Eliminate or suppress unnecessary information.

3

APPROACH AND **METHOD**

Approach

This interface shall be designed based on assumptions and hypotheses due to the uncertainties on the practical application of the interface.
The graphical user interface is designed to be adapted to milliAmpere2 in (nearly at the final stage of) development. It will be installed at the SCC, which is under investigation and development, and will be used by the remote operator which is not defined by IMO as to what kind of person they will be.

Assumptions and hypotheses were established by qualitative research with
- researchers in the relevant field,
- navigators with at least 5 year navigational experience because they currently perform a task most similar to that of remote operators,
- references,
- and advice from supervisors.

Therefore, every time a qualitative survey was conducted, insights could be obtained, and assumptions and hypotheses were slightly revised. The process of establishment of design premise and principles is written in this thesis.

Methodology

Literature review has been conducted to get the knowledge of autonomous vessels and GUI. Interviews, surveys, and workshops have been carried out to gather the participants' insight both online and offline. Due to the Covid-19 pandemic, there was a limitation in meeting people in person or having a field trip. With the final prototype, usability has been tested at the Shore Control Lab.

Literature reviews
A literature review is the process of finding, reading, summarizing, and evaluating previously published articles, books, reports, or web entries on a certain topic (Barzun & Graff, 1977). Background knowledge and information were obtained through various materials such as the study of milliAmpere2, autonomous navigation, GUI, etc., closely related to this project, and theories such as situation awareness, UI design guidelines and UCD guidelines.

Double diamonds
The design process model, called Double Diamond, is the most common design process visualization and is divided into four phases: Discover, Define, Develop, and Deliver (Design council, 2015). Two of the diverging and converging processes define the problem and create a solution. This project also followed a similar pattern, which is shown in the Figure 3.1.

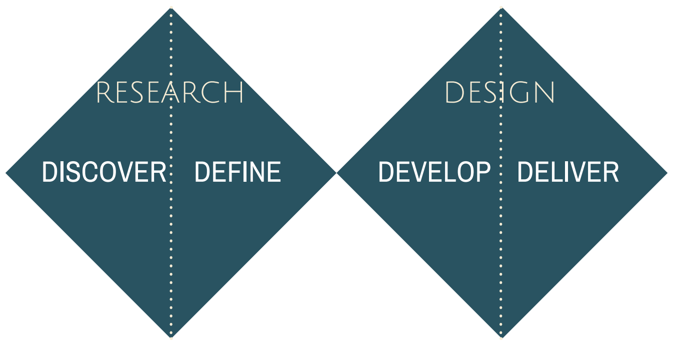


Figure 3.1 Double diamond (Design process model)

Prototyping
Prototyping is an early product development method that goes through several iterative processes of creating, testing, and modifying a prototype with users until satisfactory results are obtained as depicted in Figure 3.2. This model is most useful when design conditions or project requirements are not predetermined. In this project, four sketches were done and evaluated before clickable prototypes were created.

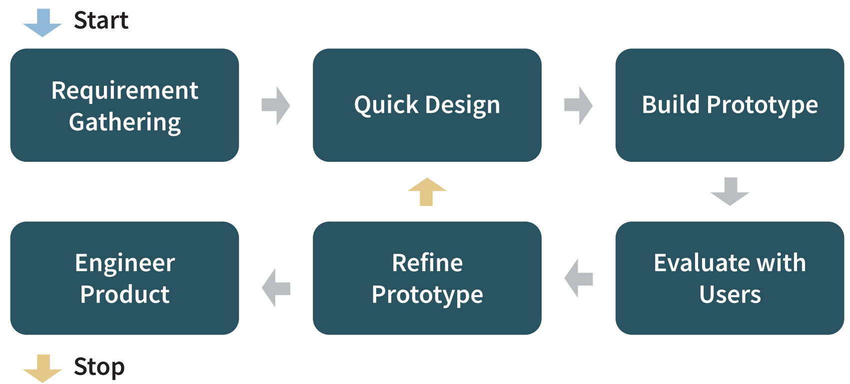
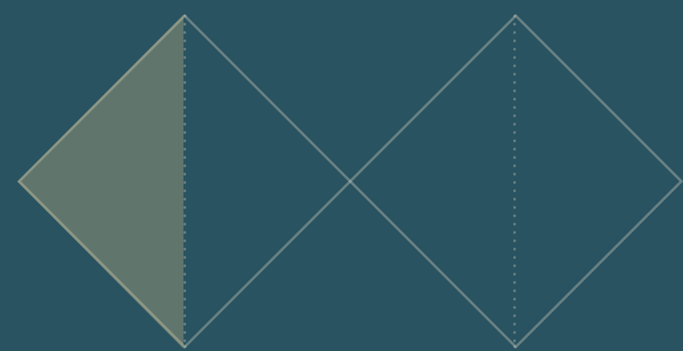


Figure 3.2 Prototyping process

Usability testing
Usability testing is a method of evaluating a product or service by testing it with potential users. Typically, during testing, participants attempt to perform tasks while the observer observes and takes notes. Usability testing gives design and development an opportunity to identify problems and fix them before moving on to the next step. In this project, feedback and advice from potential users were obtained through interviews or questionnaires at every stage, and a full-scale usability test was conducted at the end.

4 DISCOVER



The Starting Point

The project began with a simple aim of designing a graphical user interface for remote operators to monitor several vessels simultaneously without background or specific requirements; therefore, framing an operation concept for the ferries was the priority.
There was an operation concept established to perform the milliAmpere2 project.

milliAmpere2

- The vessel is designed to carry up to twelve passengers and bicycles
- The vessel has bow and stern ramps to let the passengers board and alight
- It is equipped with a sensor package consisting of forward, aft, and top cameras, radar, lidar, etc.
- Besides that, it is battery powered with induction charging, 4 azimuth thrusters, dynamic positioning system, etc. (Zeabuz).
- In October 2021, the autonomous operation test of mA2 was carried out with passengers on board (Figure 4.1).

Figure 4.1 milliAmpere2 in the Trondheim canal (photo: Erik Veitch)

The route

The operation plan for milliAmpere2 is to cross the canal between Ravnkloa and Fosenkaia ports (Figure 4.2).

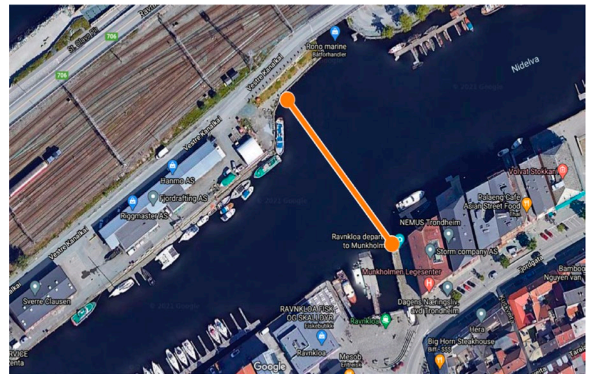


Figure 4.2 Canal-crossing plan of milliAmpere2

SCC

The current SCC in the Shore Control Lab in Nyhavna has two screens on the front wall and a wide curved screen on each of the two desks (Figure 4.3)(Veitch, 2021). The GUI will be displayed and used in this room.

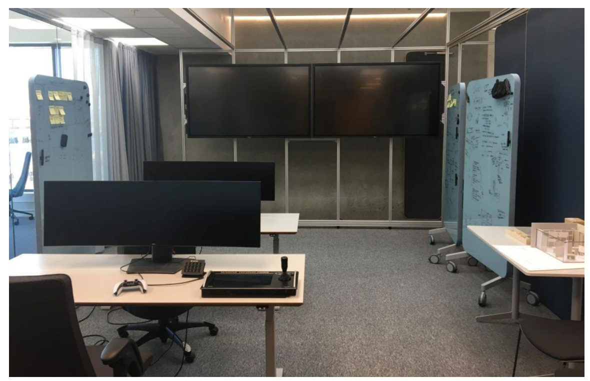


Figure 4.3 Control room at Shore Control Lab (photo: Shore Control Lab)

Revised operation concept for this project

However, just operating the ferry back and forth for a one minute distance does not require a fleet of ferries. Therefore, an expanded route with several docks should be redefined. To pursue it, a conceptual route plan (Figure 4.4) was provided by Øyvind Smogeli, the CTO of Zeabuz, which shows the potential scalability. There were many docks around the central Trondheim area and harbor, not only for crossing the harbor between Ravnkloa and Fosenkaia.
A new route has been defined having 8 docks around the Trondheim central area as illustrated in Figure 4.5, lessened from the concept of Zeabuz. The total length of the route (oneway) is approximately 4km according to the measurement of google maps.
The current vessel design is appropriate for the current route plan. To maneuver the redefined course, having side ramps would be more efficient. However, the influence of the vessel design on designing GUI is negligible, it will not be changed.

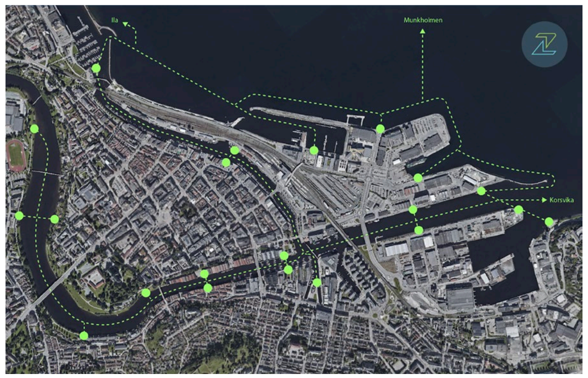


Figure 4.4 A conceptual plan of scalable operation

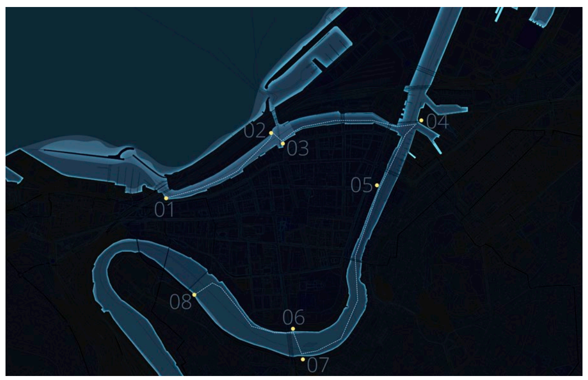


Figure 4.5 Planned operation route for this project

Design Premises

Since there are no precise requirements for designing GUI, the necessary design premises for GUI development is established through each step of design research.

1. A fleet of milliAmpere2 ferries is operating around the central Trondheim area stopping at eight ports.
2. The vessel is operated in constrained autonomous mode.
3. The operation is monitored at the SCC in Nyhavna so that the operators can intervene when needed.

Interview #1

Participant : First Officer of LNGC with 7 years experience

Date and duration : 1. 10. 2021, 120 minutes, in person

Goal :
To get an insight into the navigation job
To determine to the participant's thoughts about remote operation
To identify components to be included on the interface display for the remote operator

Prior to the interview, it is crucial for the interviewer to comprehend that designing an interface for a remote operator at the SCC, understanding how the remote operator works and recognizing his behavior in the control room are essential.

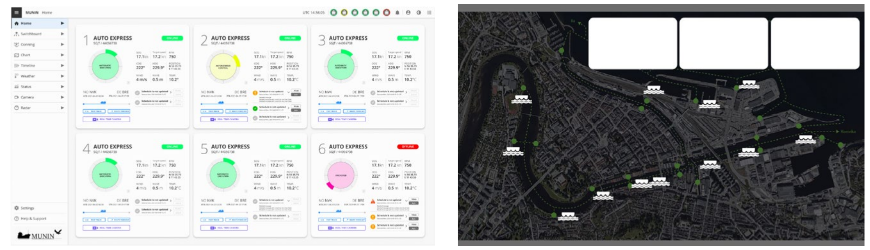
The main questions asked were:
• The participant's experience and background
• Team coordination and work routine onboard
• Who will be the remote operator?
• How many and what types of console displays did you control at the bridge?
• During the voyage, which information is necessary? How do we prioritize it?

In order for him to understand the concept well, three sketches (Figure 4.6) were presented:
• Multiple status panels (revised form of MUNIN project)
• Site map with information board
• Station routes (similar to a subway map)

From the three sketches presented, the participant said the first two seem to work but the third does not give any information to the operator.

A small task was also conducted to sort out the information which should be displayed on the printed paper, the multiple status panels.

30 pieces of information were selected from (Sharma et al. 2019) categorized into three parts- ship equipment, operation, and weather (Figure 4.7-A).



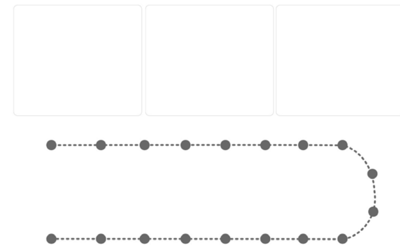
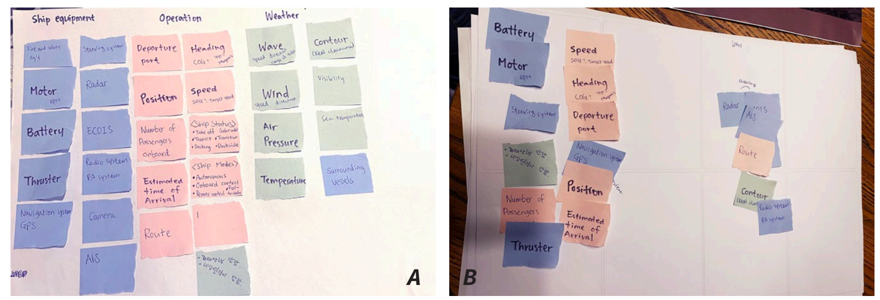


Figure 4.6 Three sketches presented to a participant

Firstly, he selected 12 pieces of information which he regarded as necessary information for navigation (Figure 4.7-B). Then, he had to choose again from the first selection to minimize the information.

He explained that aside from the minimized information in navigation for passenger safety related items being put as a priority, the detailed information should also be available in the other layers.

On the paper map, he chose and recommended putting the common and local information which is applied to all the vessels in operation (Figure 4.7-C).



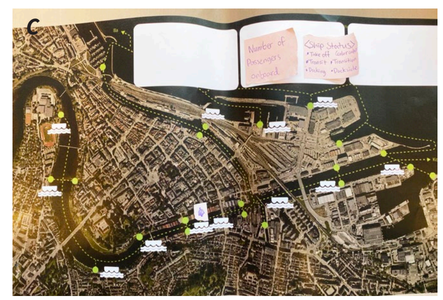


Figure 4.7 Small tasks for sorting out necessary information for each panel

Findings

Work experience
- Mostly one officer and one quartermaster worked together in one shift (one commands and the other operates)
- Travel in an average of 3 - 5 months per voyage
- During the navigation, the operators concentrate the most at the port and in congested water (approaching and leaving the port)

How to be a seafarer
- To become a seafarer, he must fulfill the requirements (certification including training on a training vessel, mandatory courses, rules and regulations, etc.)
- Experience is the most important

Autonomous vessel
To support the visibility and ship sense (Man et al., 2014), the autonomous vessel must be equipped with a variety of sensors
He voiced his opinion that if all the vessels are operated autonomously, with a highly-advanced technology, then the operators would not need to put their effort, knowledge, and navigational skills to good use.
At the beginning of operating an autonomous vessel, there would be a mixture of conventional and autonomous vessels, which means that the operators should follow the same rules and regulations to navigate, and solve problems especially to avoid collision. Hence, it is important for a remote operator to be a seafarer.
he chose the information of "safety" related to passengers and the vessel as a top priority
- Alarm
- System error (low battery, network error, etc.)
- Passenger safety issues
- Navigational abnormal situation (detailed information should be on the other layer to look at the situation in detail)
- Information of weather conditions is not so important during a voyage; it is needed in a plan phase, which is relevant for a long-distance voyage
- More navigational information (radar overlay) shall be on the desk screen

In urban navigation, it is a combination of short routes. There could be passengers waiting to board the vessel and variable conditions at each port; therefore, the task would be complicated depending on how autonomized the vessel and the docking system are, and how controllable the passengers are at the dock for safety.

Design Premises

1. A fleet of milliAmpere2 ferries is operating around the central Trondheim area stopping at eight ports.

2. The vessel is operated in constrained autonomous mode.

3. The operation is monitored at the SCC in Nyhavna so that the operators can intervene the control when needed.

4. The remote operator should have professional navigation knowledge, trained at the operational site with the GUI.

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.

2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)

3. Eliminate or suppress unnecessary information.

4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs

5. Detailed navigational information should be shown on the desk when needed

6. A means to help operators' understanding is needed when the vessel is at the dock

Survey #1

The insights from interview #1 were refined to a survey to get numerous opinions from seafarers. The main questionnaires and response are attached in Appendix 1.

Duration : 5-12. 10. 2021, via Google survey

Participant

Table 4.1 *Participants of Survey #1*

Occupation	Experience	No.	Sum
Navigator	less than a year	3	
	1-3 years	4	
	3-5 years	8	
	5-7 years	7	
	7+ years	8	30

Purpose
To ascertain if a remote operator necessarily has to be a seafarer
To determine which information is important and should be displayed
To recognise how the participants work and perceive information at the workstation

Method
An interview (2 hours) was held prior to the online survey with a former seafarer and this survey was structured based on it
The interviewee delivered this survey to his ex-coworkers and alumnae
The survey consisted of 3 parts (19 questions): participant demographics (2), navigation experience (12), and autonomous ferry and remote operation (7)
The components in the questionnaire 1.6 and 2.3 were adopted from a research (Sharma et al. 2019).

Findings
This survey showed that the respondents mainly care about their: 1. Own ship (maneuvering, system, etc.), 2. Target vessel, and 3. Passengers.
ECDIS is the most useful tool to attend to both their own ship and target ships' heading, route, speed, and to warn when there are possibilities of collision. In addition, it was pointed out that the lack of ship sense must be supplemented through the cameras.

In addition, when looking at the opinions regarding remote operators, the respondents answered that the remote operators need to understand navigating experience, nautical charts, and navigation rules and regulations at the same level as existing navigators. They also need to understand ports as much as pilots, and in addition, multitasking ability and concentration are required.
To the question of the number of ships that are likely to be monitored alone simultaneously, 2-5 ships accounted for the most at 46.4%, followed by 1 ship with 39.3%. Among them, there was a comment that it would be difficult to monitor multiple ships at the same time if several ships enter and depart ports simultaneously.

Also, at the dock, when the ship berths, approaches and leaves as well as the passengers board and alight, the navigators are needed to get enough situation awareness to secure the safety of the vessel and passengers, the participants said.

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.

2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)

3. Eliminate or suppress unnecessary information.

4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs

5. Detailed navigational information should be shown on the desk when needed

6. A means to help operators' understanding is needed when the vessel is at the dock

7. ECDIS or similar is needed to be displayed on the screen.

8. The number of vessels that one operator can monitor at the same time should be below five.

Sketch #1

The Design premises and the Design principles that have been derived from interview #1 and survey #1 resulted into Sketch #1 (Figure 4.8).

The sketch started with the status panel first, because it requires investigations to determine various components showing the vessel's status in an effective way.

This is the first sketch I drew while contemplating how to effectively show the status of the battery, the number of passengers on board, and proximity of target vessels. Icons showing the ship's operating status are included.

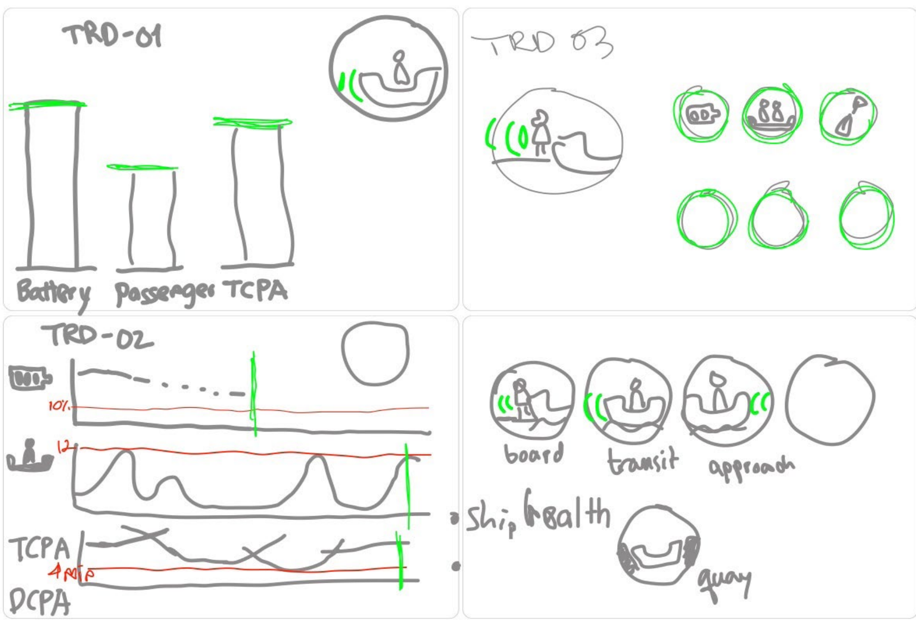


Figure 4.8 Sketch #1

Interview #2

Participant : Chief Officer of Coastal ferry and Offshore service vessels with 5 years of experience

Date and duration : 26. 10. 2021, 90 minutes

Goal :
To get an insight into the navigation job
To determine to the participant's thoughts about remote operation
To identify components to be included on the interface display for the remote operator by reviewing a concept sketch

The participant was one of the respondents of the survey #1. He had answered that the job of a remote operator is not similar to a navigator, and the reason was inquired.
Since he is a PhD student working on autonomous navigation at the department of Ocean Operations and Civil Engineering in NTNU, he was able to talk more in-depth about the MA2.

The main questions asked were:
The participant's experience and background
How is the remote operator different from the navigator?
How many and what types of console displays did you control at the bridge?
What was the impression when you saw the simulator?
Any advice on designing GUI?

Findings

Difference between navigator and remote operator

- The working place
- The number of vessels one is in charge of
- Consecutive working hours in navigation (he usually works for one hour in maneuvering, and then he may write a log note, go outside deck and check the

weather, communicate with other co-workers in the vessel, and do administrative jobs like painting the superstructure)
- Behavior and mindset of the navigator when he leaves land at the vessel's departure
- Rather, the DP operator seems to be similar
  DP operators' duty seems more similar to what remote operators at SCC are doing
  They usually sit in front of the designated desk and monitor if the autonomous system works correctly

Traffic at the canal
- With the current technology, the Marine Traffic website is the only way to check the marine traffic. However, it only shows the vessels equipped with AIS, so it would be hard to survey the traffic at the canal.
- There would be lots of non-conventional targets like swimmers and small ships, which will not be shown in the Marine Traffic.
- According to a colleague who works at a large cruise liner, when the cruise ship leaves the port, many small leisure crafts come along or follow to look at the cruise from a close distance. The small crafts are equipped with AIS class B, so the navigator at the cruise ship would suppress the class B AIS so as to be invisible on the radar screen because they cause many collision alarms which will affect the cruise's departure. However, the cruise liner has its own schedule and plan- it should depart on time and cannot change the route.
- So, the navigator has nothing else but just to believe that the small ships would not sail right in front of him.

Working at the bridge
- Basically there are lots of screens; in the middle console, there is a conning display showing the vessel movement, and the weather conditions like wind speed, direction, etc.
- It also has a power management system showing power consumption on each of the engines, the indication showing RPM, and the thruster showing the pitch of the propellers.
- There are normally dual sets, the two sets of radar and ECDIS. So, setting the radars in different ranges enables him to see or detect surroundings in different perspectives.

Range of radar
- Depending on the length of pulse, the scale on the radar screen varies.
- So, he usually used two different ranges of radar screens so as not to miss the targets by being aware of the surroundings on a smaller and wider range.
- In the same way, in case of milliAmpere2, it may need an emphasized bird's-eye view to support the operator's situational awareness.
- Also, if the camera automatically shows where the situation happens, it would be helpful.

The components of the status panel

At the final stage of the interview, the schematic diagram of Sketch #1 was reviewed. He helped to supplement the missing components, and remove unnecessary components. The result is illustrated in Figure 4.9.

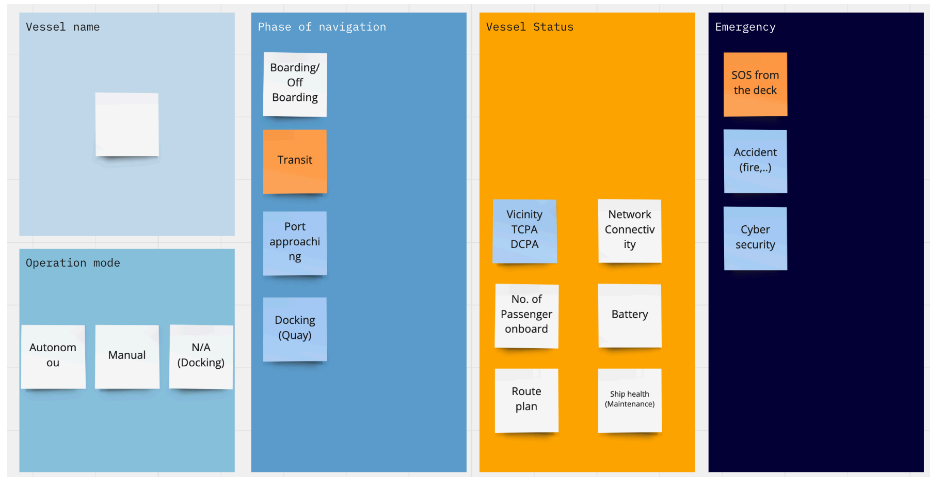


Figure 4.9 Components of the status panel

Design Premises

1. A fleet of milliAmpere2 ferries is operating around the central Trondheim area stopping at eight ports.
2. The vessel is operated in constrained autonomous mode.
3. The operation is monitored at the SCC in Nyhavna so that the operators can intervene the control when needed.
4. The remote operator should have professional navigation knowledge, trained at the operational site with the GUI.
5. The traffic at the Trondheim canal is not busy. (The span of the canal is not wide, so if there are people watching the ferry, they can do it from the shore.)

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.
2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)
3. Eliminate or suppress unnecessary information.
4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs
5. Detailed navigational information should be shown on the desk when needed
6. A means to help operators' understanding is needed when the vessel is at the dock
7. ECDIS or similar is needed to be displayed on the screen.
8. The number of vessels that one operator can monitor at the same time should be below five.
9. Screens with different perspective shall support the remote operators' situation awareness along with the cameras
10. The screen shall show the status of the system and machinery

Sketch #2

With the design principles gained so far, the second sketch (Figure 4.10) has been drawn.
The small panel represents the status of one vessel. So, when the operator monitors several vessels at the same time, then the same number of panels will be shown on a large screen.
This interface design intended to support the operator's understanding of the status of the vessel promptly, not only by seeing the current status but also referring to the previous status to be able to deduce the cause of the current situation. This will ultimately allow the operator to cope with the situation with an accurate and quick decision. The detail description is in Table 4.2.
Because this vessel runs with fully autonomous systems, and the operator does not need to take over the control so often, I focused on how to show her status quickly and intuitively rather than containing systems controllable in detail.
Thus, this panel shows her operation phase, operation mode, system status, surroundings and alarm when something happens.

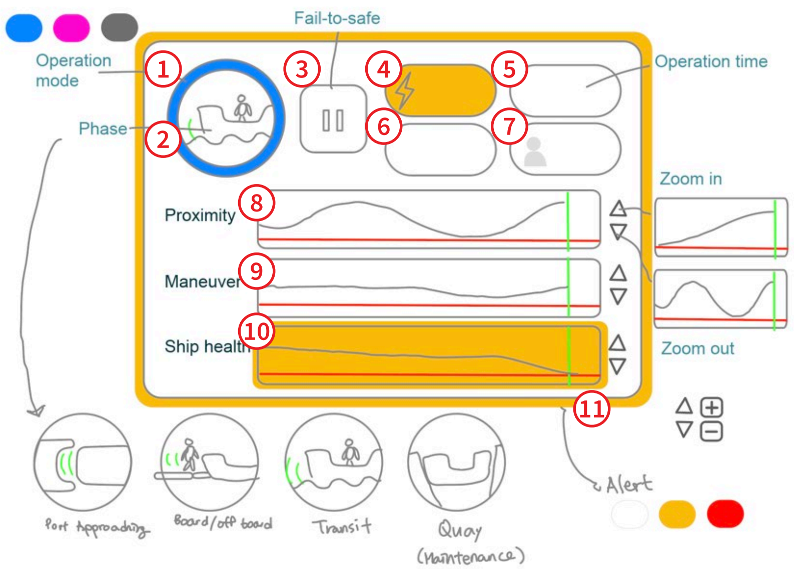


Figure 4.10 Components of the status panel

Table 4.2 *Description of Sketch #2*

	Component	Description	Feedback	To-do
1	Operation mode	Shows operation mode by the change in color	(Why does blue represent autonomous operation?)	Re-investigate the color code
2	Operation phase	Shows one of the 5 phases: port approaching, on board/ off board, transit, at a quay (under maintenance or standby), and in error. When the operation phase is changed, the icon will also change accordingly.	Icons should be more clearer	Revise the icon design
3	Fail-to-safety mode	Emergency stop when the autonomous system or the operator cannot control the situation, and is waiting for a solution		
4	Battery gauge	Shows battery percentage		
5	Cumulated operation time	To estimate when the vessel needs charging and is to be taken over by another vessel		
6	SOS call button	To communicate with the passengers onboard		
7	No. of passenger	To indicate how many passengers are onboard		
8	Proximity	Shows the flow of past and present condition of the ship's vicinity, obstacle with abnormal movement, detected from radar, lidar, cameras, etc., zoomable		Test if it works
9	Maneuver	Shows the flow of past and present condition of the ship's speed, heading, thruster movement, etc., zoomable		Test if it works
10	Ship health	To indicate the maintenance time frame - thruster handling, battery heat, run out of battery, systemic issues, etc., zoomable		Test if it works
11	Alarm	Shows alert/alarm by color code of yellow or red		

Workshop

This workshop was conducted after the preliminary prototype had been completed, and it was a great opportunity to get feedback from the participants. Also, by discovering the design opportunities through the workshop, reassessment of adding or deleting components or functionalities was possible.

The workshop was framed by referring to the process of Design thinking workshop (EdTech, 2019). It has the five stages of the design thinking workshop process: Empathize, Define, Ideate, Prototype, and Test. The first four were conducted during session 1- Activity, and the test was replaced with a review in session 2. Review of Sketch #3.

Participation : 6 Ph.D students' research on relevant fields of the whole autonomous urban ferry project (Table 4.3).
The process was the same, but the first workshop was in person with two participants, and the second one was conducted online with four participants from Ålesund, Oslo and Trondheim. They could have been combined, but two separated workshops was thought to be more efficient to facilitate within a limited time- 100 minutes, and be beneficial to get the outcomes from different points of view.

Table 4.3 *Participants of the workshops*

	Participant	Lab	Location	Workshop
1	NTNU Ph.d student	Shore control lab	Trondheim	In person
2	NTNU Ph.d student	Shore control lab	Trondheim	In person
3	NTNU Ph.d student	Shore control lab	Trondheim	Online
4	NTNU Ph.d student	Shore control lab	Oslo	Online
5	NTNU Ph.d student	Ship operation research lab	Ålesund	Online
6	NTNU Ph.d student	Ship operation research lab	Ålesund	Online

Place and duration: Shore Control Lab (physical) / Teams and Miro.com (online), 100 minutes, 15th and 16th November

Aim : 1) Addressing the challenges that the remote operators may encounter at the shore control center, turning them into design opportunities, and finding solutions together
2) Reviewing a prototype and finding rooms for improvement

Exercises:
Workshop outline is attached in Appendix 2.

- Brainstorming the operators' challenges on several operational phases and different situations
- Sorting and grouping the challenges into clusters
- Voting to rank the important and urgent clusters
- Deriving a problem statement
- Making "How Might We" questions to mitigate the problem
- Ideating and presenting a solution to the problem
- Presenting a prototype
- Getting feedback

Session 1. Activity

Brainstorming: What kind of challenges may the operator face at the SCC?
In each of the given conditions, the participants brainstormed the challenges that the operators may experience, and the results are shown in Figure 4.11.

Figure 4.11 The ideas from brainstorming through two workshops

Cluster : Sort and group the similar challenges and define each cluster (Figure 4.12)

9 clusters from Workshop 1:
Safety monitoring, Dynamic workload, Team coordination, Preventative plannings, Maneuvering, Communication, Procedural preventative maintenance,

Environmental factors, Time- and safety- critical decision-making

7 clusters from Workshop 2:
Operator's well-being and situation awareness, Priority/ decision-making, Passengers, Risk management, Technical issue, Monitoring routines, Operational issue

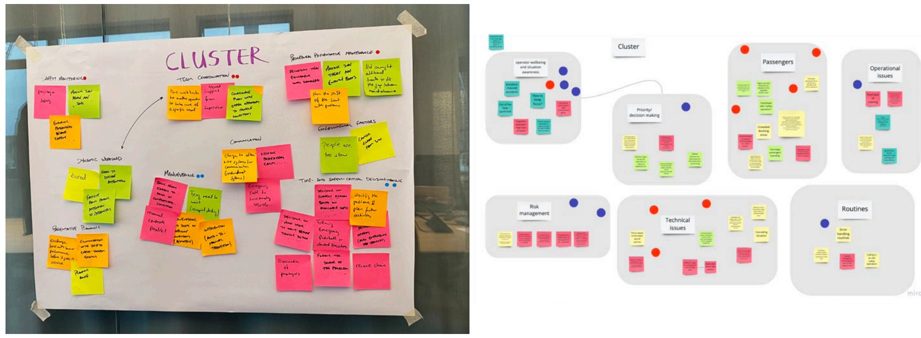


Figure 4. 12 Clusters of similar ideas

Vote for the two most urgent and important issues respectively.
"Urgent" refers to the passenger's safety concerns whereas "Important" refers to the issues when operating at the SCC. Through this activity, it was possible to narrow down and rank the problem area.

Selected clusters from Workshop 1
Team coordination, Maneuvering, Time- and safety- critical decision-making

Selected clusters from Workshop 2
Operator's well-being and situation awareness, Passengers

Problem statement/ 'How Might We…?' questions (IDEO design kit)

This statement addresses the most challenging area and helps to infer the priority of components when designing an interface for the operator. Figure 4.13 is showing the statements of both groups.

With the following task, the participants were able to reverse the problem into opportunity by rephrasing the statement to multiple 'How Might We…?' questions. This questioning format brought a chance to find solutions in various ways. Even though the 'How Might We'(HMW) does not offer a specific solution, it makes a frame for innovative thinking.

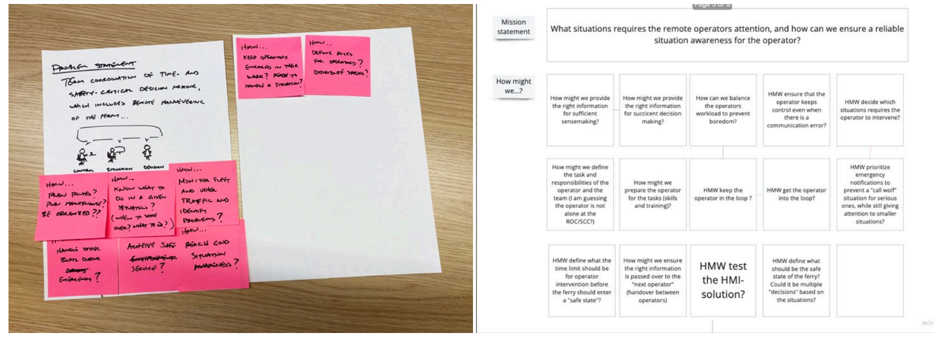


Figure 4. 13 Problem statements

The results from the 2 groups were as follows:

Workshop 1) Team coordination of time- and safety- critical decision making, which includes remote maneuvering of the ferry.

HMW plan routes, plan maintenance, and be organized?
HMW know what to do in a given situation? (when to take over? What to do?)
HMW monitor fleet and other traffic, and identify problems?
HMW handle other boats during emergency?
HMW achieve safe service?
HMW reach good situation awareness?
HMW keep operators engaged in their work and ready them to handle a situation?
HMW define roles for operators and distribute tasks?

Workshop 2) What situations require the remote operator's attention, and how can we ensure a reliable situation awareness for the operator?

HMW provide the right information for sufficient sense-making?
HMW provide the right information for succinct decision-making?
HMW define the task and responsibilities of the operator and the team?
HMW prepare the operator for the task?
HMW ensure that the operator keeps control even when there is a communication error?
HMW decide which situations require the operator to intervene?
HMW prioritize emergency notification to prevent a "call wolf" situation for serious ones, while still giving attention to smaller situations?
HMW keep the operator in the loop?
HMW balance the operator's workload to prevent boredom?
HMW ensure the right information is passed over to the "next operator"?

The two statements seemed different at the first glance- the first one focused on team coordination whereas the second one concentrated on the operator's

situation awareness.
However, interestingly, there were a lot of overlapping ‘How Might We’ questions regarding decision-making, defining tasks in a team, and achieving situation awareness.

Solution

At the final stage of the activity, each participant had to come up with a solution. It was planned to visualize the solution in as much detail as possible. This activity suggests one solid solution which can be tested, and analyzed later by making a prototype and giving feedback. However, it was going to be demanding and time consuming, so I had to stop at this stage. In the limited time of 15 minutes, the participants put in all their effort. The outcomes are shown in Figure 4.14.

Group 1 drew two solutions: one is to show on the display screen which operator is in charge of which ferry, and how the supervisor would monitor them; the other is claiming that the operator and supervisor need to communicate to solve a problem in certain situations.

For group 2, drawing their solution was not convenient online, so they had to describe it in text. There were 4 solutions written, but mostly they were about how to reach the solution instead of the description of the solution itself. It was the limitation of the virtual workshop that it was tough to keep the participants involved and focused.
Nevertheless, the resulting solution is as follows:
Create small “safety tasks” that the operator has to solve in “idle times”, for instance, counting passengers aboard, checking the status of batteries, etc.
Create a QGILD (Quickly-get-in-the-loop display) (T. Porathe, 2021).

Figure 4. 14 Solutions to the problem statements

Session 2. Review of Sketch #3

The sketch was digitally illustrated and improved slightly from the last step. A status panel screen and a map screen (Figure 4.15) for the wall mounted screen were shown and presented to the participants. The detail of one panel is shown in Figure 4.16, and described in detail in Table 4.4.

The goal of this sketch is to:
Give a clear and intuitive graphics, visualization
Help in a quick understanding of each vessel and overview

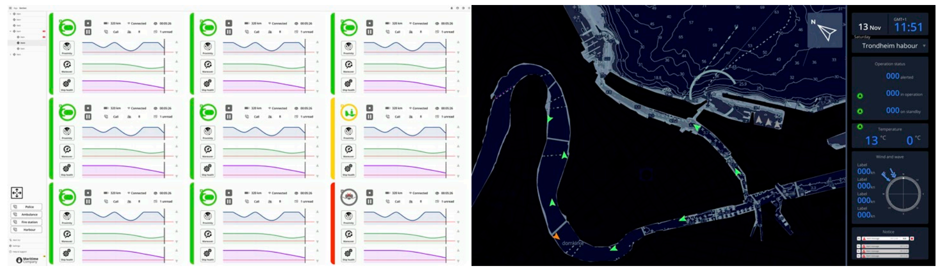


Figure 4. 15 Sketch #3 for the wall screens

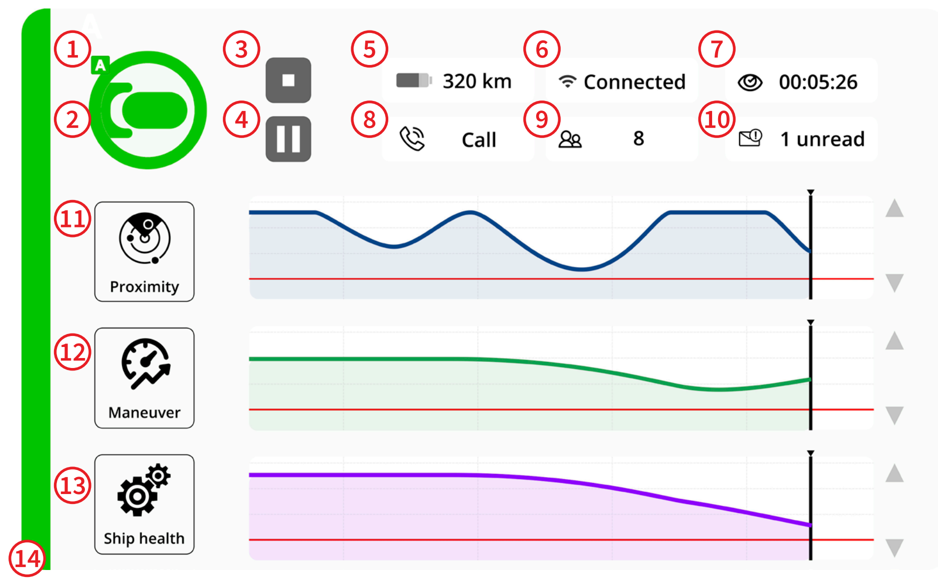


Figure 4. 16 Details of the vessel status panel

Table 4.4 *Description of Sketch #3*

	Compo-nent	Description	Feedback	To-do
1	Operation mode	Color code has been changed to green and gray. The initial alphabets for each mode are added.		
2	Operation phase	Illustrated with a design tool. Green and gray colors are applied.	Icons shall be more clear	Revise the design
3	Fail-to-safety mode	Icon developed		
4	Pause button	Added		
5	Battery gauge	Shows battery percentage through illustration and operable distance in text side by side		
6	Network	Icon developed		
7	Check up timer	Added To let the operators monitor each vessel at a certain time (to keep the operator-in-the-loop)		
8	Call button	Icon developed		
9	No. of passenger	Icon developed		
10	Message	Added To notify if there is any minor note from the vessel, for example, the lens of the rear camera has low visibility.		
11	Proximity	Icon and color added		
12	Maneuver	Icon and color added	Graph is not intuitive.	Consider other medium
13	Ship health	Icon and color added		
14	Alarm	Left border only		

Feedback

Most of the participants agreed with the concept of showing status panels and a whole map together, and thought positively about the contrast of color because the map was in dark mode.

However, there was an argument regarding the graphs, questioning whether it is the right medium to express the current moment and to project what will happen. Someone pointed out that the icons should be clearer.

They also provided their suggestions to add indicators of the vessel on the panels and map to identify the operator responsible for the vessel, and show which vessel is selected.

Findings

- Team coordination and situation awareness were selected as the focusing area to support remote operators.
- How to show indicator on the panel and map
- How to keep the operators in the loop
- How to show the emergency alarm in the most effective way
- Graph should be reconsidered
- Icons need to be clearer
- The color code (Green and Red) on the map should be examined as green and red represent starboard and portside on ECDIS which may confuse the operators

5

DEFINE

Problem Statement

From the findings of the Workshop, concerns for interface design in relation to function and usability convenience were derived.

- How to make the panels representing each vessel match the vessels distributed on the map understandable and easier
- How to indicate who is responsible for which vessels
- When more than one alarm arises, how to let the operators divide their tasks promptly and immediately
- How to show the status of the vessels intuitively and accurately
- How to help the operators project upcoming events of the vessels
- How to make the alarm signs noticeable so as to figure out the cause expeditiously
- How to help the operator quickly grasp a situation that a vessel is confronting

These concerns have been redefined as the detailed project aims below:

1) A GUI for multiple remote operators monitoring multiple ships
- An indicator that can distinguish each remote operator shall be needed.
- The operators shall be able to recognize their roles and responsibilities.
- In the event of an emergency, the operators should be able to quickly and clearly identify the vessel they are responsible for.

2) Well-organized GUI for the information distributed across multiple screens
- The information distributed across multiple screens shall be well-organized and recognized
- Only necessary information shall be visible on the screens to reduce mental overload

3) An accurate and effective emergency alarm system
- The operators shall identify the subject of the emergency accurately and quickly
- The alarm shall stand out effectively
- The monitoring system shall convey the cause of the alarm accurately and noticeably
- The monitoring system shall provide multiple angles of the object to be observed by the operator

User scenario and System architecture

At the workshop, a whole work process of remote operation was roughly envisioned.
This helped to structure the whole monitoring system as shown in Figure 5.1. These are the pages that remote operators can individually manipulate and view from their desk screen.
Making the pages of the system helped to understand the user's duty and overall flow (Figure 5.2).
Designing all the pages within the project period is not sufficient and understanding all the system management is challenging, so the overview of the vessel's maneuvering was selected to develop further.

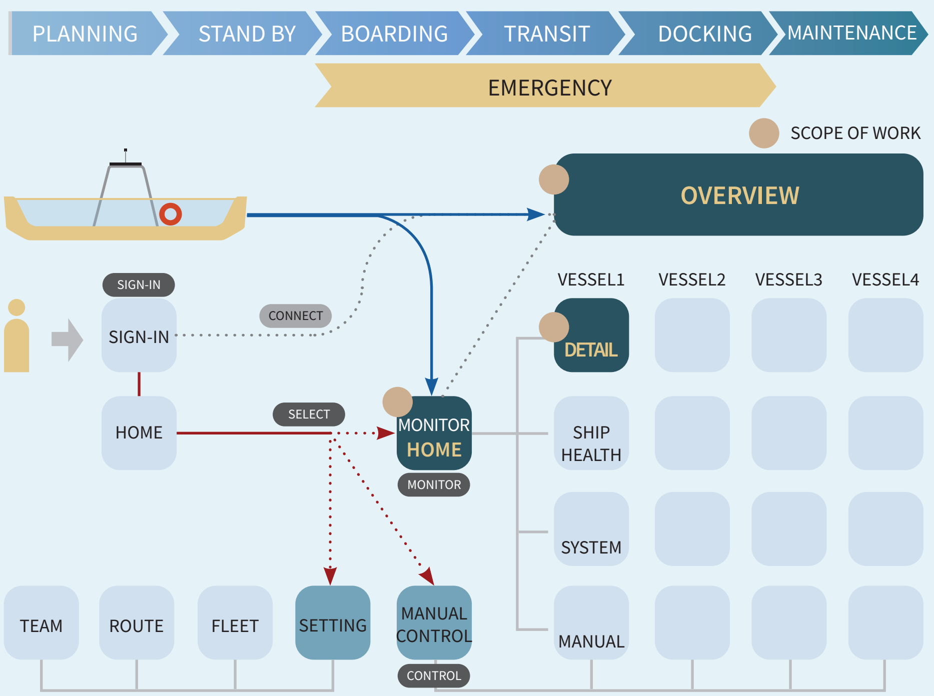


Figure 5.1 Vessel operation flow and system architecture

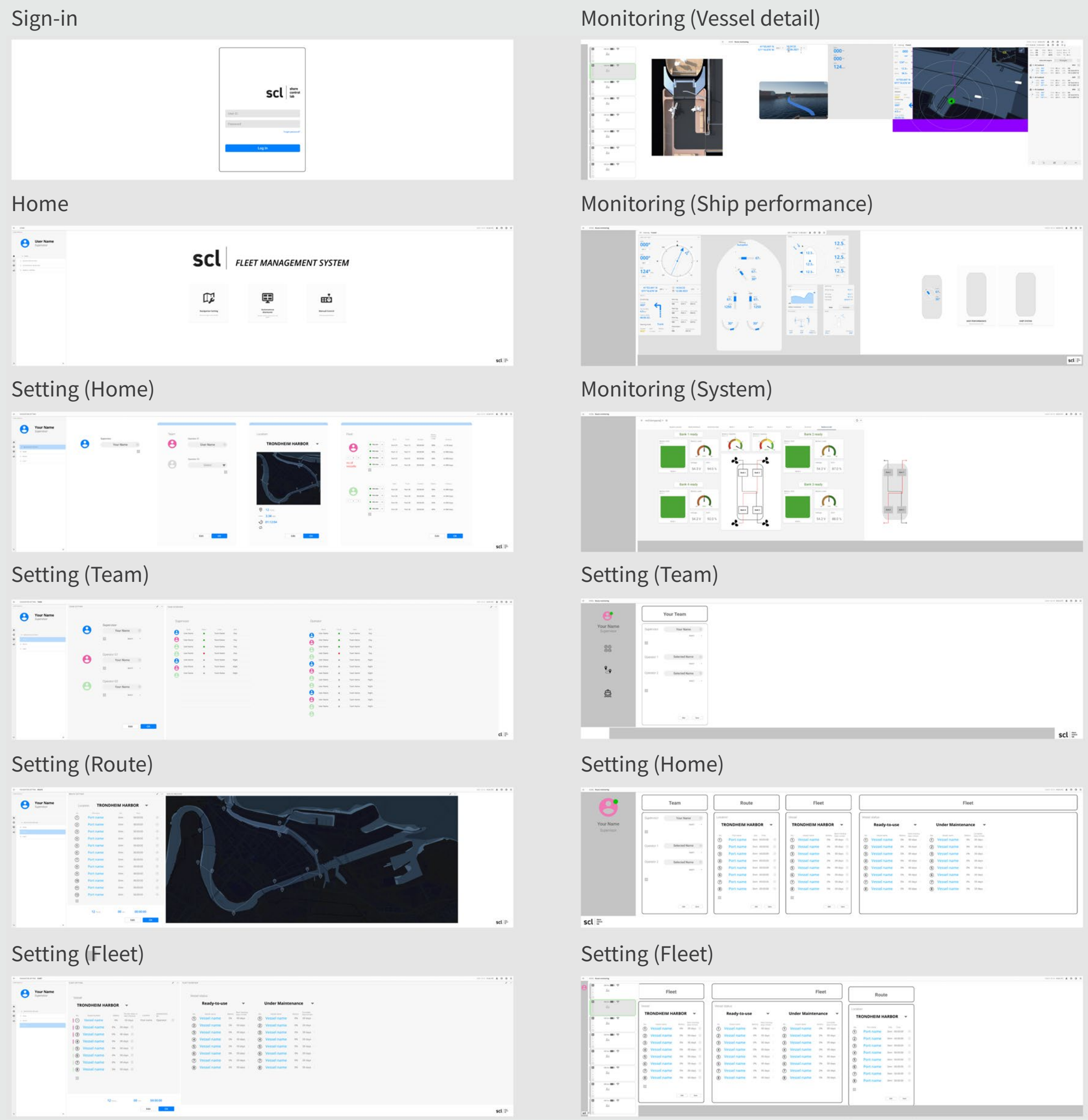


Figure 5.2 Preliminary sketches of overall flow (Design system of OpenBridge (2018) applied)

6

DEVELOP

This chapter shows the three iterations of development of the prototype. Once a sketch or a prototype has been developed, a verification with the navigator(s) was performed.
These processes enabled this project to be a human-centered design, and improved the level of perfection by discovering improvements.

Sketch #4 (Iteration 1)

Based on all the processes so far, the sketch #4 was created: a sketch for two wall screens (Figure 6.1) and several pages of desk screens (Figure 6.2 and Figure 6.3). How the essential functions should be displayed and how the user should use them were taken into consideration.

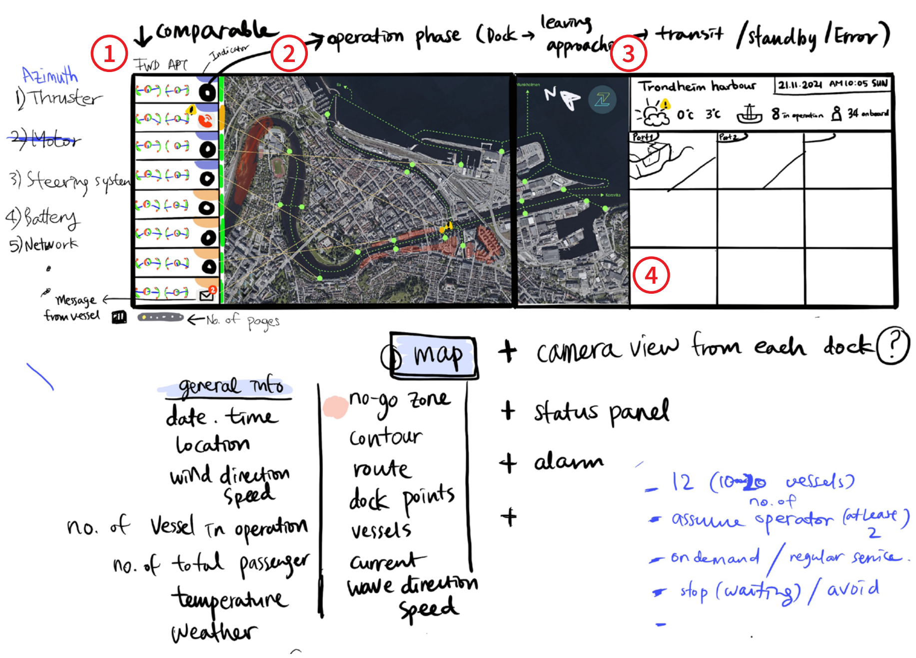


Figure 6.1 Sketch #4- Wall screens

Table 6.1 *Description of Sketch #4- Wall screens*

	Component	Description	Feedback
1	Vessel status	• The panels of vessel status on the wall mounted screen should be comparable to one another to be noticed by an operator when abnormal situations happen. • Due to the space of the CCTV screens, the vessel status panels have become smaller. Thus, there are several pages to generate information : state of azimuth thrusters (on the sketch), steering system, battery, network, etc. • The components described in the sketch #3 are included.	Too small, too much information
2	Entire site map	• In the middle, occupying the largest area, there is a map showing the entire route. • To match the vessels on the status panels and on the map, thin lines are applied: when vessels are moving on the map, the lines will follow.	Does not fit in one screen. Thin lines will not work.
3	Information bar	• The information bar is to state the common local information	
4	CCTV screens	• Due to the result of the survey and interviews, the operators need to concentrate more on the vessel when she is at a dock: there are many interactions between vessels, passengers and the vessel, passenger and the dock, as well as the vessel and the dock. • Thus, CCTVs are needed to monitor all the interactions at the dock. • When a vessel appears on the screen, the screen will be highlighted.	Takes up too much space

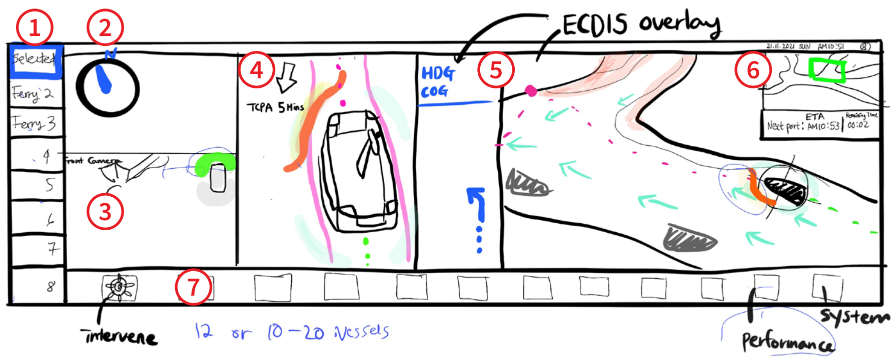


Figure 6.2 Sketch #4- Desk screen (Vessel overview)

Table 6.2 *Description of Sketch #4-* Desk screen (Vessel overview)

	Component	Description	Feedback
1	Vessel status	• Vessel status panels are arranged on the left side, and each panel becomes a button that connects to the detail page of the corresponding ship. • When a page of a certain vessel is opened, the corresponding panel is highlighted.	
2	Conning display	• To show the maneuvering state such as heading, speed, etc.	
3	Camera view	• A view from one of the cameras equipped on the vessel is also displayed	
4	Bird's-eye view	• To show the vessel status in real-time so that a view of the deck, and its close surroundings can be observed. • Alarms such as proximity warning will be displayed	
5	ECDIS-ish screen	• To show the detailed information of the vessel and the target vessels. Radar and lidar overlay is possible	
6	Navigation map	• The navigation of the whole route within the rectangle shows where the vessel is located on the route.	
7	Menu buttons	• At the bottom of the screen, there are buttons linked to the other detailed information pages such as ship performance, system, etc. and manual control	

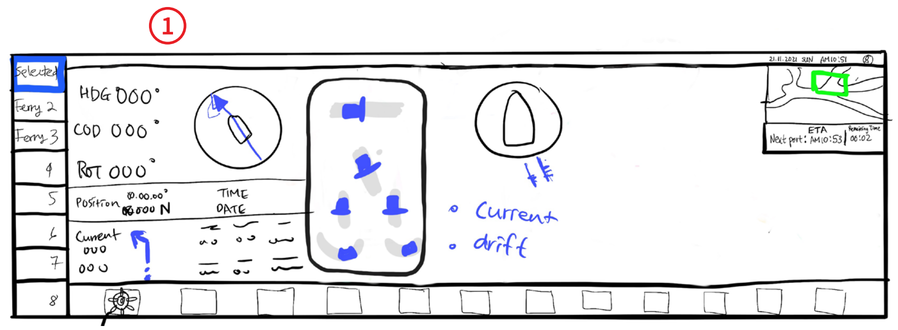


Figure 6.3 Sketch #4- Desk screen-(Maneuvering)

Table 6.3 *Description of Sketch #4-* Desk screen-(Maneuvering)

	Component	Description	Feedback
1	Maneuvering page	• An example for one of the detailed pages is drawn. • Information simplified in the overview page is described in more detail.	

Feedback and findings

When the sketch is done, the 7-year-experienced navigator, who was an interviewee for the interview #1, reviewed and gave feedback as below:

- The structure and function make sense.
- TCPA must be shown with CPA.
- The more information displayed along with the ECDIS, the better to understand the situation.
- Regarding the icon at the dock, it would be better to split it when the vessel is docking and passengers are boarding.
- The map/ nautical chart normally displays north-up, but can be changed to head-up if an operator manipulates with help of a button.
- The thin lines are distracting; hence, a new solution seems to be needed.

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.

2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)

3. Eliminate or suppress unnecessary information.

4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs

5. Detailed navigational information should be shown on the desk when needed

6. A means to help operators' understanding is needed when the vessel is at the dock

7. ECDIS or similar is needed to be displayed on the screen.

8. The number of vessels that one operator can monitor at the same time should be below five.

9. Screens with different perspective shall support the remote operators' situation awareness along with the cameras

10. The screen shall show the status of the system and machinery

11. TCPA must be shown with CPA

12. The map/ nautical chart normally displays north-up, but can be changed to head-up if an operator manipulates with the help of a button.

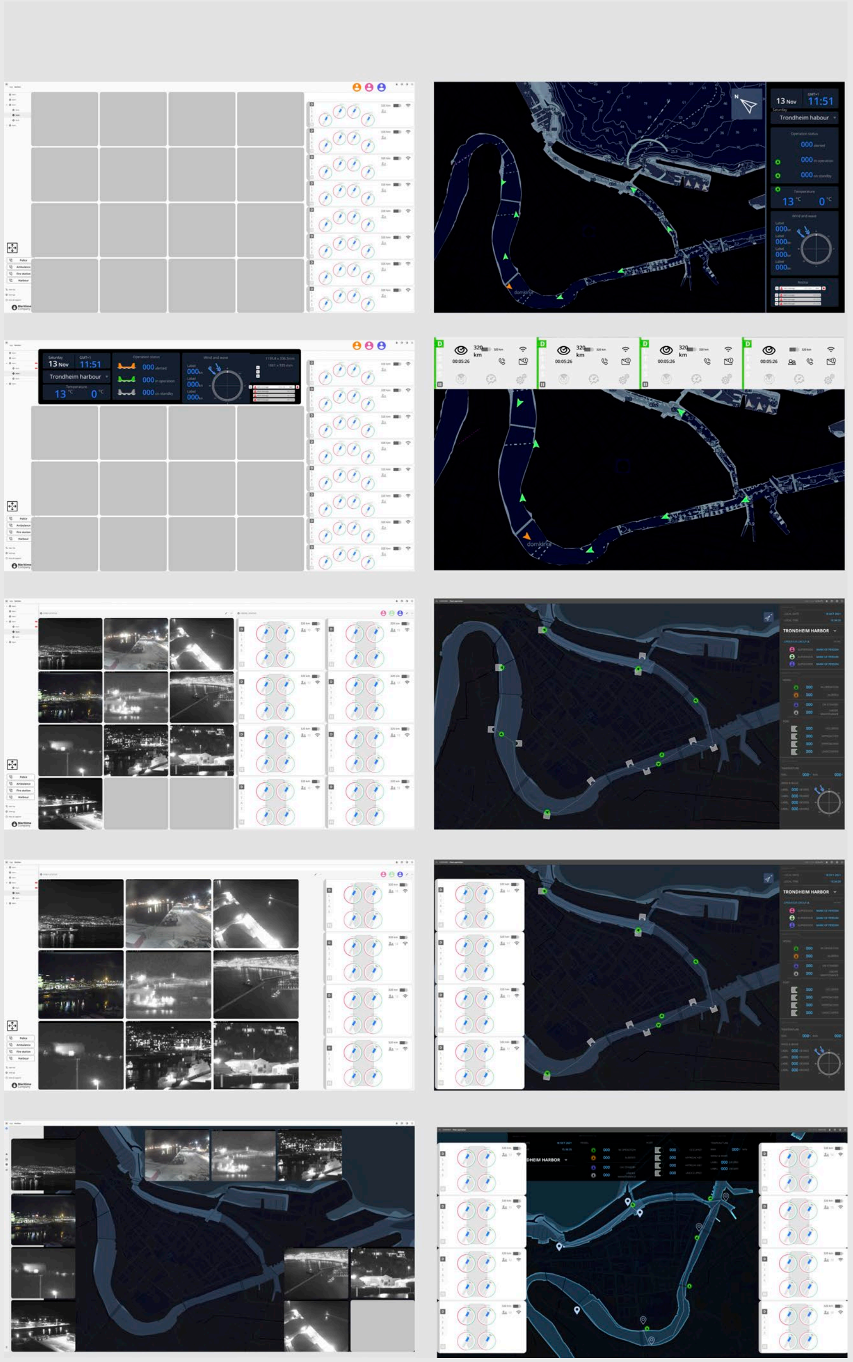


Figure 6.4 Various layout trials

Prototype #1 (Iteration 2)

Throughout the various trials of arrangement (Figure 6.4), the first clickable and functional prototype was made as shown in Figure 6.5. It followed the no.2 of the Design Principles that more imortant component is allocated to the larger area.

A prototype tool, Axure, enabled the prototype to be functional, and most of the ideas are visualized with hover effects, pop-ups, transitions, animated elements, etc.

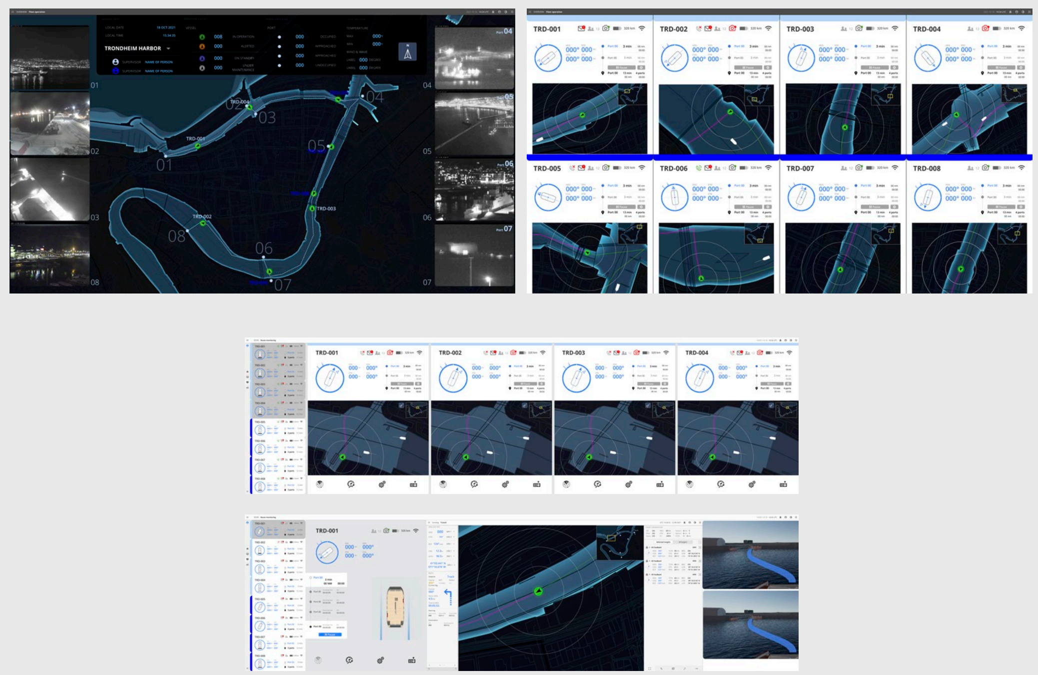


Figure 6.5 Prototype #1- Overview

Naturally, as the usable area of vessel status is increased due to the CCTV space was combined with the map, route information and maps were added.
The information about the system and machinery which were in the Sketch #3 were moved to the detail page. (Detail pages are not included in the prototype)

Figures 6.6 and 6.7 show the wall mounted screen in detail, and the description for them are in Tables 6.4 and 6.5; and Figures 6.9 and 6.10 illustrate the pages of the desk screen. Also, Tables 6.6 and 6.7 describe the Figures 6.9 and 6.10 respectively.

The map screen (Wall mounted screen)

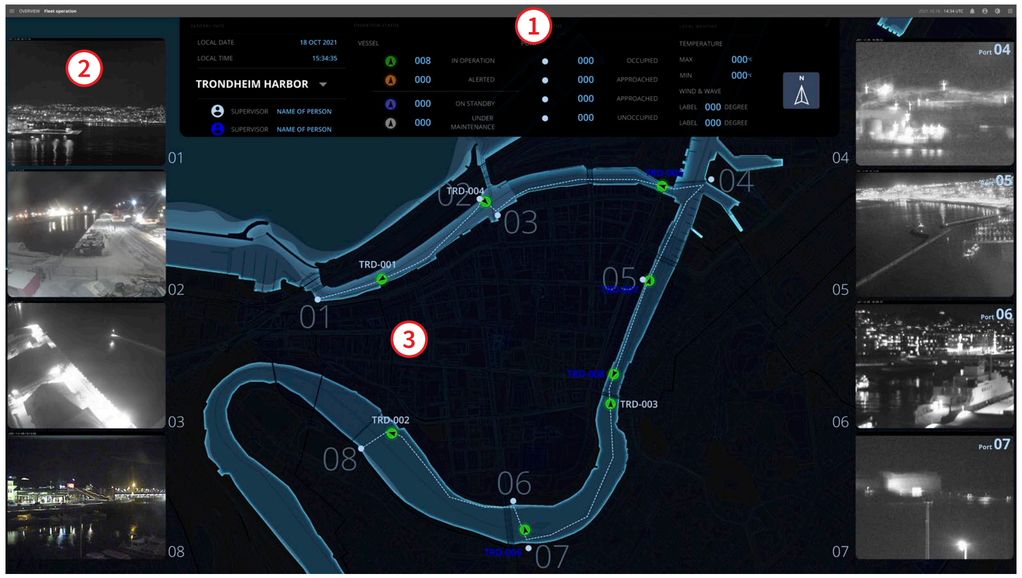


Figure 6.6 Prototype #1- The map screen (Wall screen)

Table 6.4 *Description of Prototype #1 - The map screen (Wall screen)*

	Component	Description	Feedback
1	Information bar	Information bar is located at the top middle of the page, containing information about local conditions, vessels and ports.	See the result of Survey #2
2	CCTV screens	• The CCTV screens are combined with the map screen. When they were viewed on the other screens, the operator should look at both screens going back and forth to match the location of the port and the cctv screen. • Ports which have the CCTV screens on the left are marked with solid colored icons. On the other hand, the other ports are marked with outlined icons, where the CCTVs are on the right	See the result of Survey #2
3	Map	The map is changed to north-up	

Vessel status screen (Wall mounted screen)

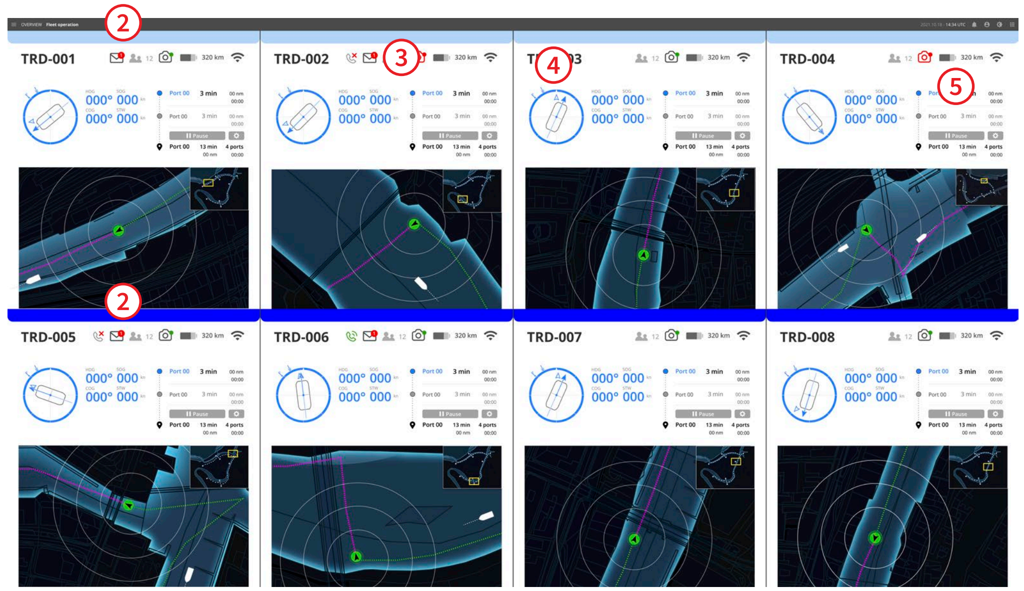


Figure 6.7 Prototype #1- The vessel status screen (Wall screen)

Table 6.5 *Description of Prototype #1 - The vessel status screen (Wall screen)*

	Component	Description	Feedback
1	Overall	The panel status screen shall have one of the whole screens. It contains more information about each of the panels.	See the result of Survey #2
2	User indicator	• On the top, there is a narrow rectangle showing the vessels monitored by each operator. • By the color code, the operators to the vessels can be distinguished.	
3	Icons	Name of the vessel and other icons showing the status of passenger's number, camera, battery and network connection are displayed. Not to interrupt the operator, the icons for calls from the passenger and message box from the system are hidden. When a new call or message comes, they will be visible.	
4	Operation phase icon (Figure 6.8)	Icons are redesigned, which are inspired by the conning display. Conning display is an essential information that shows the maneuvering of the ship, however, it seems unnecessary when the vessel is preparing for docking, at the dock, or preparing for leaving. Therefore, the operation phases of approaching, berthing, leaving, and stopping for emergency reasons are combined with the conning display.	
5	Route information	Route information is added to show the current, next and the final destination, and each of the remaining time and distances. Buttons for pause and setting are added to adjust the route and the course.	

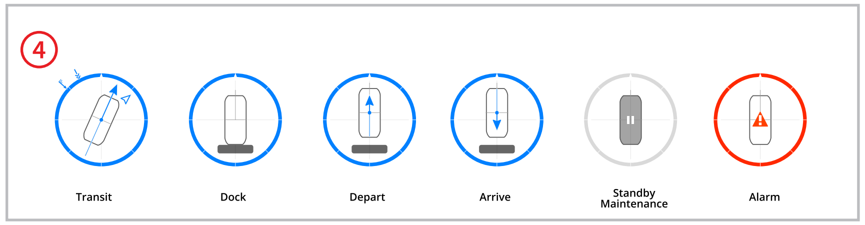


Figure 6.8 Operation phases and icons accordingly

Home (Desk screen)

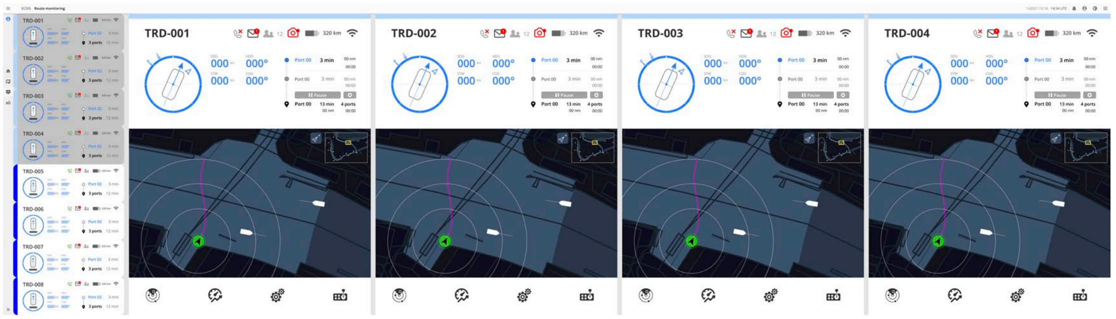


Figure 6.9 Prototype #1- Home (Desk screen)

Table 6.6 *Description of Prototype #1 - Home (Desk screen)*

	Component	Description	Feedback
1	Overall	• If an operator is responsible for four vessels, the vessels will be displayed on the screen. The page with four status panels is the home screen. • Each panel is the same with the one on the Vessel Status screen, except the four buttons underneath. • With the buttons, the operators can view the gist of proximity and maneuvering (as shown in the Figure 6.9), and ship performance of each machinery equipment. • The setting button allows them to adjust the route, speed, etc., and the manual control button will lead them to a control page.	See the result of Survey #2

Detailed page (Desk screen)

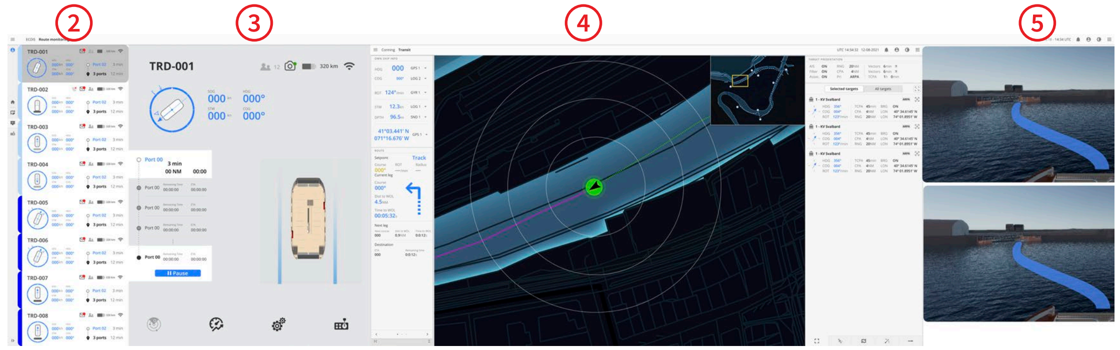


Figure 6.10 Prototype #1- Detailed page (Desk screen)

Table 6.7 *Description of Prototype #1 - Detailed page (Desk screen)*

	Component	Description	Feedback
1	Overall	When the operator selects a vessel on the homepage, then the detailed page appears.	See the result of Survey #2
2	Status panel list	• Simplified form of the Vessel status panel • Buttons to see the detailed pages of each vessel	
3	Status panel	It is almost similar to the Vessel status screen, except the map. Instead of the map, there is a longer and detailed route information and a bird's-eye view of the vessel.	
4	ECDIS-ish panel	In the ECDIS-ish panel, the nautical chart which can be fused with radar and lidar screens is in the middle. The left column shows the navigational details and the right column shows the target details.	
5	Camera panel	To show the camera views from the forward and aft cameras attached to the vessel.	

Survey #2

Survey #2 was conducted to verify if the components are understandable, if the participants recognize what the icons and symbols are, if a certain vessel's maneuvering information on the Vessel Status panel matches its position on the map, and if the prototype functions as intended.

Participant

The survey was conducted during the year-end holidays, therefore, a lesser number of participants were able to participate. Some experienced functional prototypes, while others were given screenshots. This is tabulated in Table 6.8.

Duration : 22.12.21.-12.1.22. via Google survey

Table 6.8 *Participant of Survey #2*

	Occupation	Features	Type of prototype
1	Experienced navigator	Interviewee of the interview #1	Functional prototype
2	Experienced navigator	Participant of the survey #1	Captured screenshot
3	Experienced navigator	Participant of the survey #1	Captured screenshot
4	Designer (at the Shore Control Lab)	Participant of the workshop	Functional prototype
5	Engineer (ROV technician)		Functional prototype
6	Engineer (Re-motely manages a floating buoy)		Functional prototype

Survey structure

The main reason for this survey is to verify the components, therefore, the questionnaires were to ask the necessity, validity, practicality of the components, and also request suggestions for a better revision, if required.

The questionnaire is composed of six parts: demographic, the map screen (wall mounted screen), vessel status screen (wall mounted screen), desk screen, alert/alarm warning notification, and icon.

Result

The prototype worked fairly fine, however, it needs to be supplemented according to the useful suggestions from the participants.

CCTV screens
66% of respondents said they are necessary
All the navigator-experienced respondents answered that they should be displayed constantly.
One suggested that the CCTV screen should be observed on the desk, and the operator should be able to adjust the angle and range of it.

Vessel symbol and location
Half of the navigating-experienced respondents did not recognize the vessel symbol as vessel on the vessel status screen, and their location on the map.
One navigator suggested splitting the map and compartmentalizing zones with numbers or codes.

Desk screen
The navigator-respondents wanted more specific information.
In Particular, the rear camera, which is important to detect a dangerous situation, needs to be zoomable and bigger.

Alarm
When a situation occurs, the symbol should be bigger to be more distinguished.
Alarm should be flickering.

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.

2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)

3. Eliminate or suppress unnecessary information.

4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs

5. Detailed navigational information should be shown on the desk when needed

6. A means to help operators' understanding is needed when the vessel is at the dock

7. ECDIS or similar is needed to be displayed on the screen.

8. The number of vessels that one operator can monitor at the same time should be below five.

9. Screens with different perspective shall support the remote operators' situation awareness along with the cameras

10. The screen shall show the status of the system and machinery

11. TCPA must be shown with CPA

12. The map/ nautical chart normally displays north-up, but can be changed to head-up if an operator manipulates with the help of a button.

13. The symbols should be clearly understandable for the users.

14. Compartmentalized zones- splitting the map should be applied to help the users recognize the locations of each vessel

15. The symbols should be clearly noticeable when a situation occurs

Prototype #2 (Iteration 3)

A revised prototype was created by reflecting the valuable opinions gathered from the survey #2 and design principles. The main components remain the same, but the size and color are adjusted to improve users' perception. In addition, details were added to create a more realistic prototype.
The revised components for each page are organized into figures (Figures 6.12, 6.13, 6.14 and 6.15)and tables (Tables 6.9, 6.10, 6.11 and 6.12).

Prototype #2- Overview

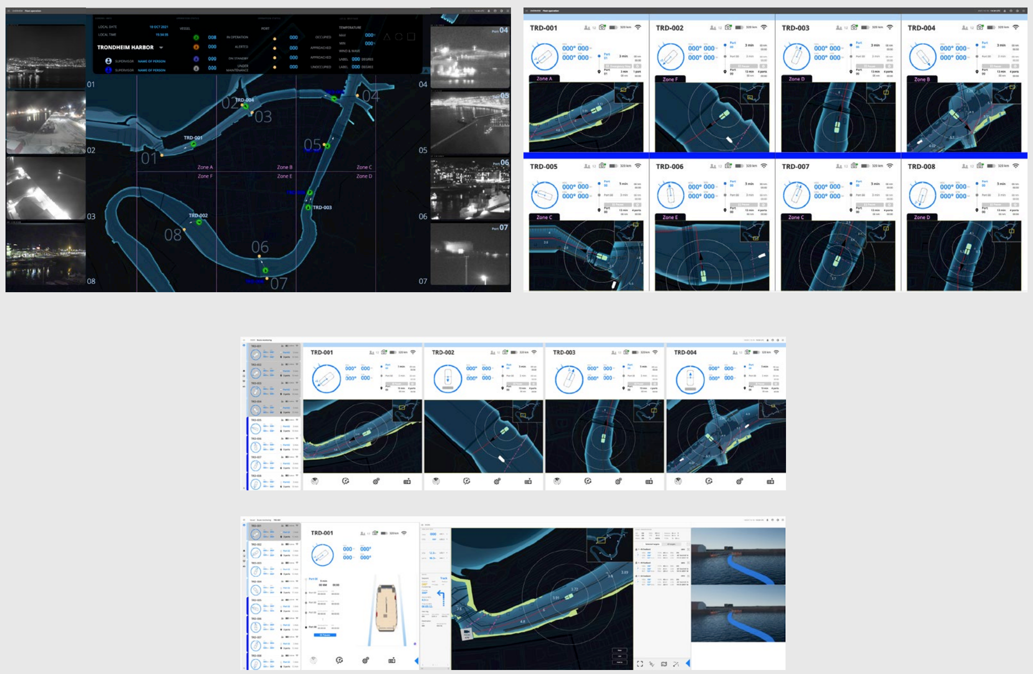


Figure 6.11 Prototype #2- Overview

Prototype #2- The map screen (Wall screen)

Figure 6.12 Prototype #2- The map screen (Wall screen)

Table 6.9 *Revised components of the map screen (Wall screen)*

	Component	Description	Feedback
1	CCTV screens	Revised to be shown or hidden altogether as well as individually.	
2	Information bar	The bar can be collapsed to generate more space on the map by the handle	
3	Zone	Six zones from Zone A to Zone F have been applied along the route.	
4	Alarm notification	The alert and alarm notifications are added to warn about the situation on the information bar. Short descriptions are listed below the notifications, and when the operator takes the vessel to solve the problem, the corresponding icon shall be displayed.	
5	Ports	The color of the ports are changed to yellow to be more noticeable.	

Prototype #2- Vessel status screen (Wall screen)

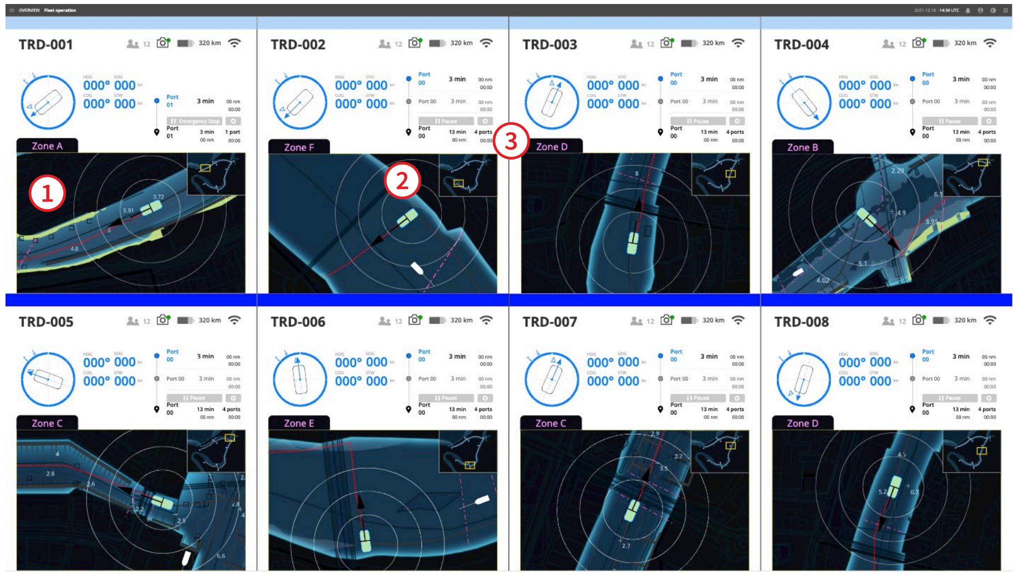


Figure 6.13 Prototype #2- Vessel status screen (Wall screen)

Table 6.10 *Revised components of the vessel status screen (Wall screen)*

	Component	Description	Feedback
1	Map	The map has been illustrated to convey more information similar to the nautical charts.	
2	Vessel symbol	The vessel symbol on the map has been revised in accordance to the Guidelines for the presentation of navigation-related symbols, terms and abbreviations (IMO, 2019).	
3	Zone	In addition to the thumbnail map, six zones have been applied to show where the vessel is located on the route.	

Prototype #2- Home (Desk screen)

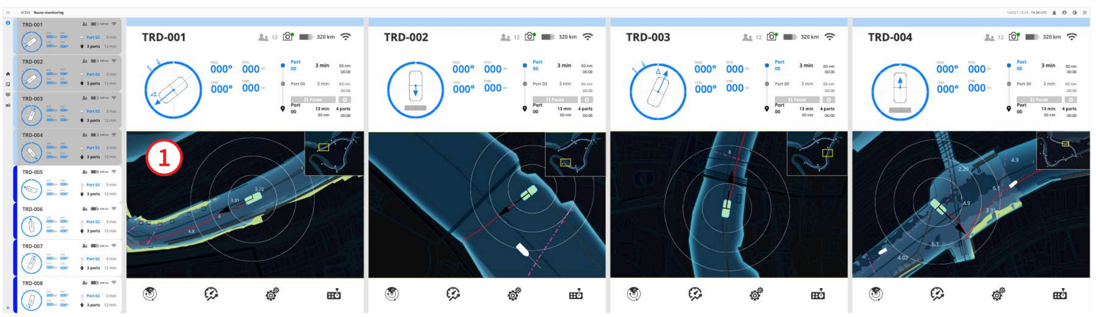


Figure 6.14 Prototype #2- Homescreen (Desk screen)

Table 6.11 *Revised components of the home screen (Desk screen)*

	Component	Description	Feedback
1	Map	The map has been illustrated to convey more information similar to the nautical charts.	

Prototype #2- Detailed page (Desk screen)

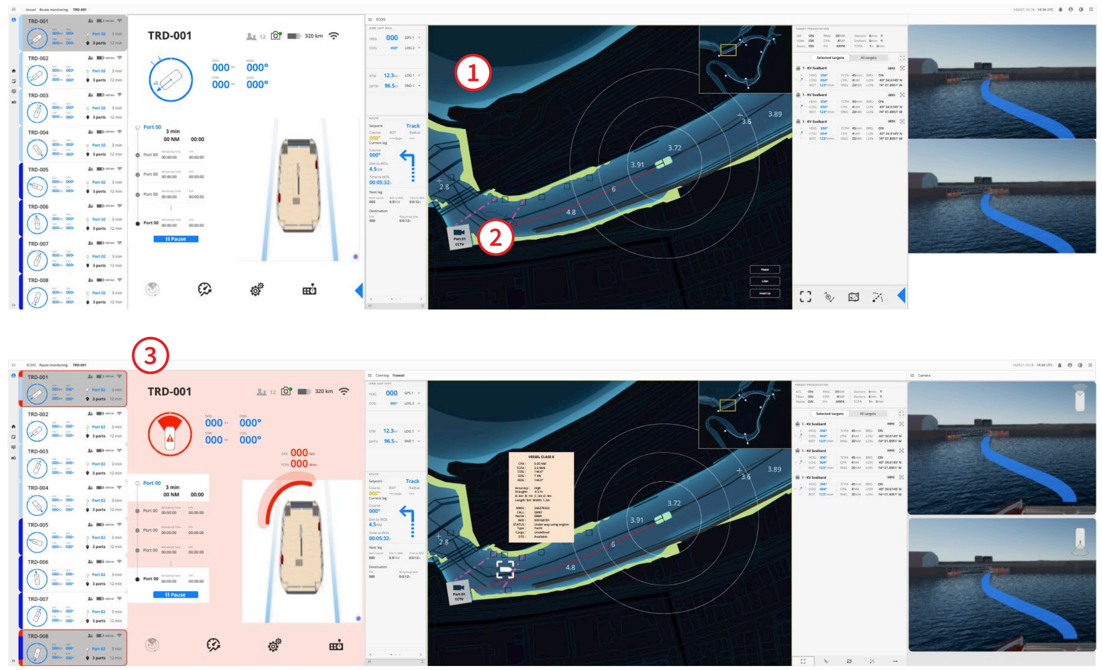


Figure 6.15 Prototype #2- Detailed page (Desk screen)

Table 6.12 *Revised components of the detailed page (Desk screen)*

	Component	Description	Feedback
1	Map	The map has been illustrated to convey more information similar to the nautical charts. To fuse it with the rada, lidar screen Head-up	
2	Port CCTV	CCTV screen is available at a desk screen	
3	Alarm page	A detailed page when proximity warning occurs	

Figure 6.16 Usability Test

Usability Test

The test was conducted at the Shore Control Lab, where a concept control room has been built (Figure 6.16). The prototype was displayed on the screen of the control room, the application site set up at the beginning of the project.
The initial user was selected as one of the researchers, who has been studying the autonomous ferry for 3 years.

He was asked to perform in accordance with the 20 tasks that were prepared in advance for testing:

- **whether the user perceives the information correctly**
- **whether the user uses the functions as intended**

The result was positive and satisfactory.
A participant and spectators quickly understood the concept, visualization, and details of this prototype, and showed a positive response to the function.
In only one of the 20 tasks (Appendix 3), the participant did not perform correctly, which was to pick out Depart and Arrive modes by looking at the conning shaped icon.
The participant was unable to distinguish Dock, Depart, and Arrive. He recognised the dark rectangle as a dock, but the arrows in the vessel symbol were not found.

Findings

- By displaying the prototype on the actual sized devices, the participants were able to experience it in reality.
- As detailed functions and information were added, it was possible to produce it more realistically.
- A minor modification of the operation phase icon is still needed.
- Minor mistakes in the arrangement order of interface elements that were not visible during the work were easily found on the large screen.

7

DELIVER

Design Premises

1. A fleet of milliAmpere2 ferries is operating around the central Trondheim area stopping at eight ports.

2. The vessel is operated in constrained autonomous mode.

3. The operation is monitored at the SCC in Nyhavna so that the operators can intervene the control when needed.

4. The remote operator should have professional navigation knowledge, trained at the operational site with the GUI.

5. The traffic at the Trondheim canal is not busy. (The span of the canal is not wide, so if there are people watching the ferry, they can do it from the shore.)

The Operator

In this project, the user has as much knowledge as a navigator, has a lot of experience in navigation, and is an expert trained to monitor in the SCC.
Remote operators shall have the same knowledge, experience and training as navigators.

In particular, it is necessary to fully understand and adapt to the new working environment and working methods that are different from those of the navigator.

Specific working conditions such as continuous working hours, shifts, and working methods need to be stipulated in the same manner as the rules and regulations of the relevant institution.

Number of Vessels

In this project, two operators and one supervisor work as a team to monitor eight ships.

One supervisor is the manager and oversees the work of the entire team.
The two operators will be in charge of four vessels each, which was determined by considering the following factors:

1) The survey result shows that there are fewer than five ships that are to be monitored by current navigators;
2) The supervisor oversees and can distribute work if necessary;
3) The condition that the vessel continues to operate repeatedly on the set route

Design Principles

1. Keep the consistency in design for error prevention and expanding users recognition.
2. Arrange the areas according to the importance of the information. (The more important the information, the larger the area is allocated.)
3. Eliminate or suppress unnecessary information.
4. The GUI must effectively display an alarm when threats to passengers' safety and system error occurs
5. Detailed navigational information should be shown on the desk when needed
6. A means to help operators' understanding is needed when the vessel is at the dock
7. ECDIS or similar is needed to be displayed on the screen.
8. The number of vessels that one operator can monitor at the same time should be below five.
9. Screens with different perspective shall support the remote operators' situation awareness along with the cameras
10. The screen shall show the status of the system and machinery
11. TCPA must be shown with CPA
12. The map/ nautical chart normally displays north-up, but can be changed to head-up if an operator manipulates with the help of a button.
13. The symbols should be clearly understandable for the users.
14. Compartmentalized zones- splitting the map should be applied to help the users recognize the locations of each vessel
15. The symbols should be clearly noticeable when a situation occurs

Design Outcome

The main purpose of this prototype is to present alarms in a way that the remote operators recognize and understand. Highly developed autonomous systems can make monitoring tedious and lead to out-of-the-loop syndrome. Nevertheless, if an alarm system accurately indicates the main cause and the corresponding vessel where an emergency has occurred, operators will be able to quickly intervene and control the situation. In addition to its main purpose, the system provides an orderly and accurate operational situation. The overview is shown in Figure 7.1.

In order to generate solutions to the problems identified above, the following was considered:
- The various information was arranged through concise and clear icons without confusion.
- The notation, screen layout, and information components were designed and arranged in a way that the navigators were familiar with.
- The monitoring system was organized in an intuitive and clear flow.
- Design premises and design principles were reflected.

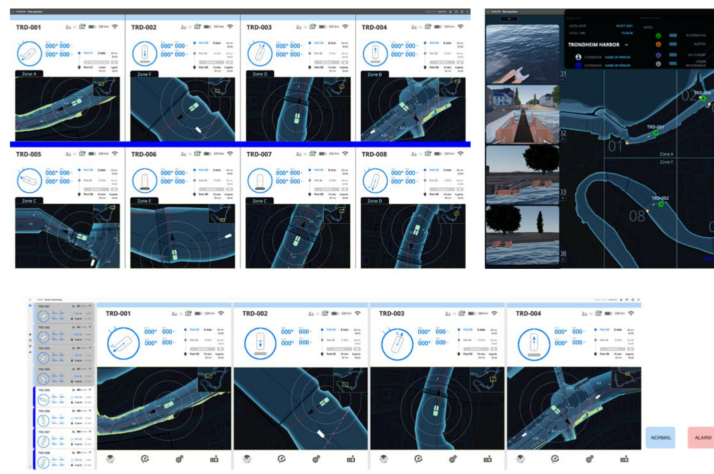


Figure 7.1 Final prototype- Overview

Vessel Status Screen (Wall mounted screen)

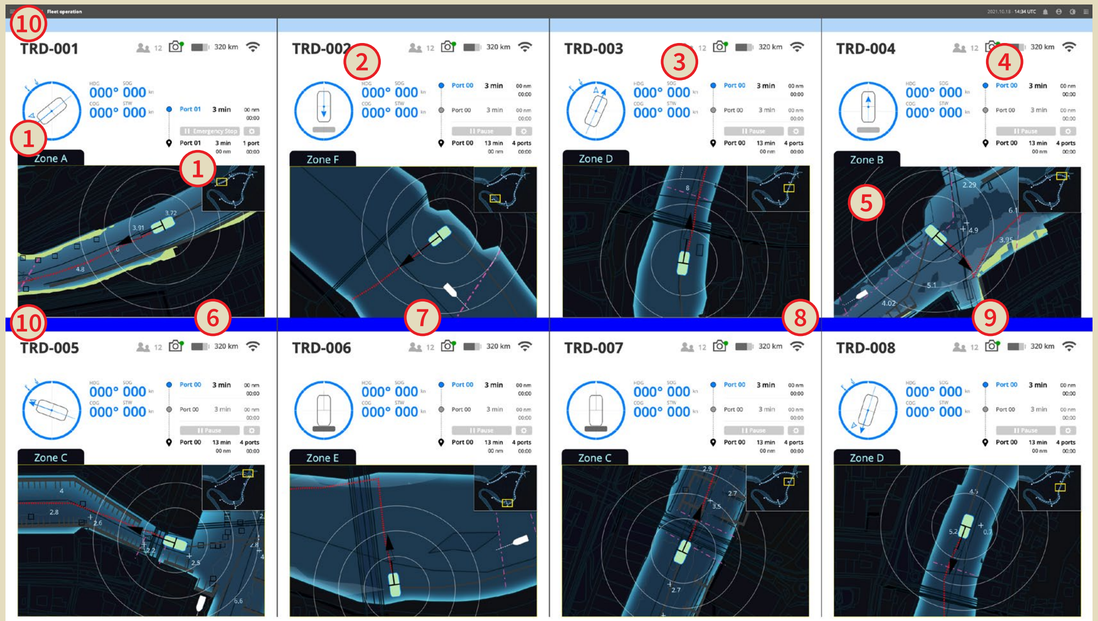


Figure 7.2 Final prototype- Vessel status screen

Each panel on the screen contains plenty of information of the state of the vessel (Figure 7.2);

1. Vessel's location (zone, map navigator)
2. Heading (Heading and course over ground)
3. Speed (Speed over ground and speed through water)
4. Route (current, next and final destination; distance and estimated arrival time)
5. Surroundings, contour, and course on the nautical charts
6. Battery gauge and measurement of navigable distance utilizing the battery gauge
7. Number of passengers onboard
8. Network status
9. Camera status
10. Operator in charge

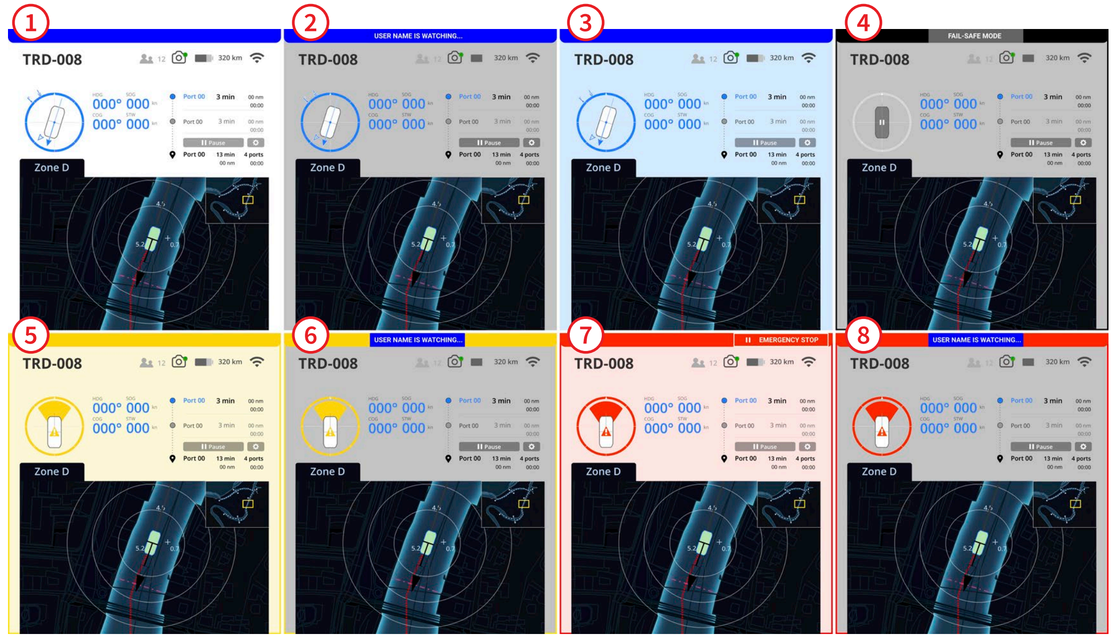


Figure 7.3 Variants of the status panel

In each situation, the background of the panel, operation phase icon, and the identification of the operator change (Figure 7.3).

1. Normal
2. Selected (The blue operator is looking at the vessel TRD-008)
3. Hovered (When a mouse enters in the TRD-008's panel or symbol on the Map screen)
4. Fail-to-safety mode (Emergency stop activated)
5. Alert notification
6. Selected when alerting
7. Alarm notification with a button- Emergency Stop
8. Selected when alarm sounds

Map Screen (Wall mounted screen)

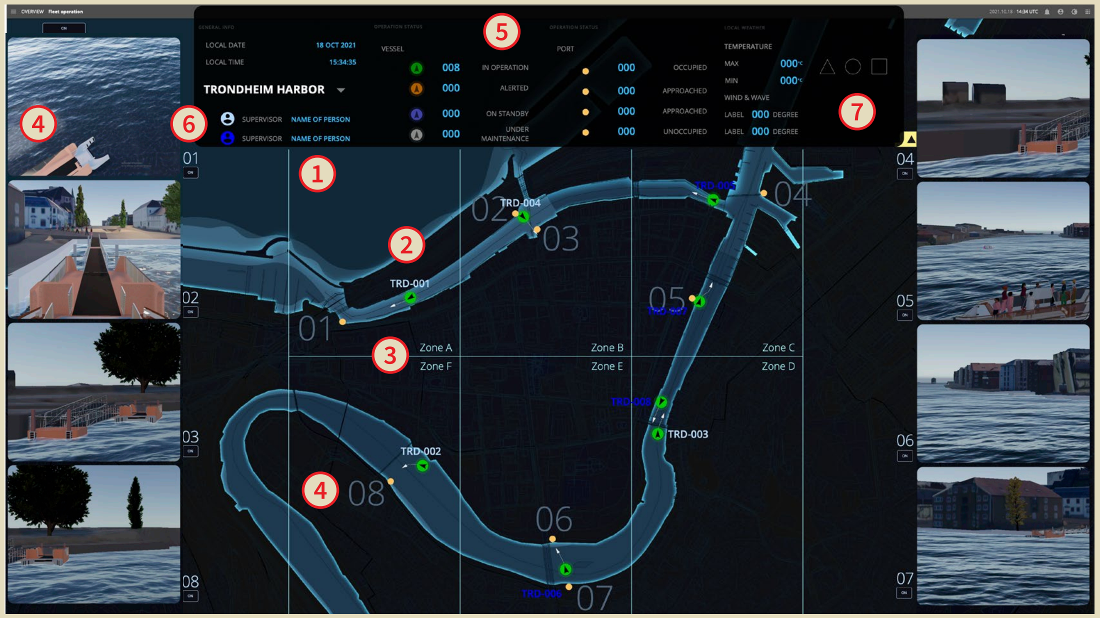


Figure 7.4 Final prototype- Map screen

Next to the Vessel status screen, the map screen shows common and local information of the route (Figure 7.4);

1. Entire route
2. Vessels' location, vessel name
3. Compartmentalized zones
4. Ports and their CCTV screens (Images from the Simulator at SCL)
5. Collapsible local information bar; date, time, weather, etc.
6. Operators
7. Alarm notification

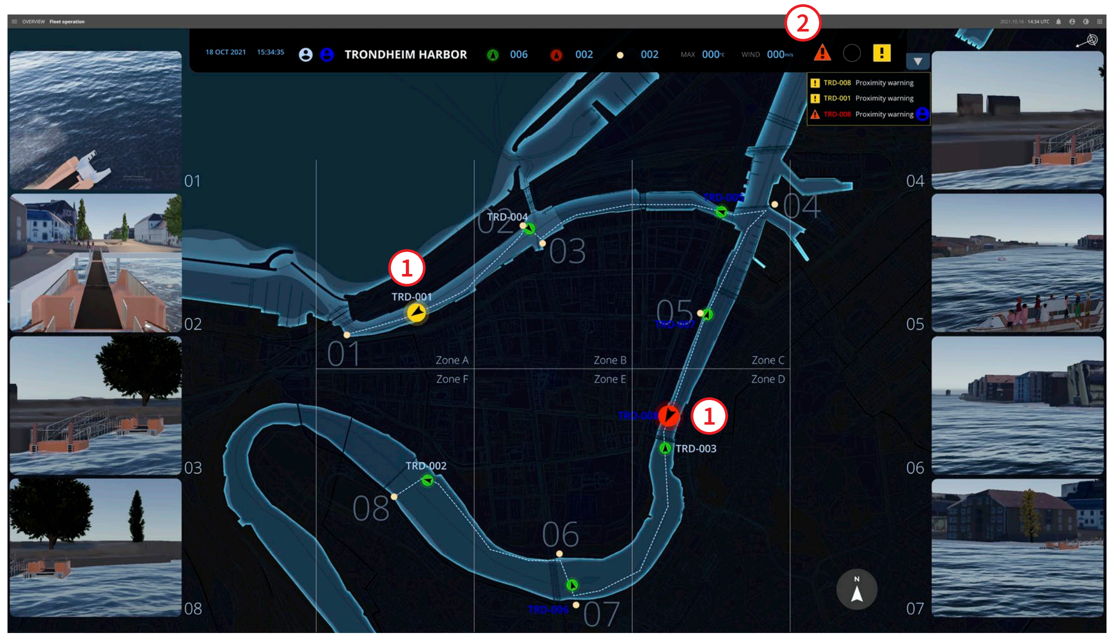


Figure 7.5 Map screen in an alarm situation

In an alarm situation (Figure 7.5),

1. A bigger red or yellow symbol flickering
2. Alarm panel (Figure 7.6) is activated, the cause is stated, the identification of the operator who has taken this case appears

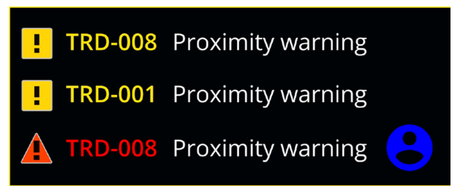


Figure 7.6 Alam panel

Desk Screen

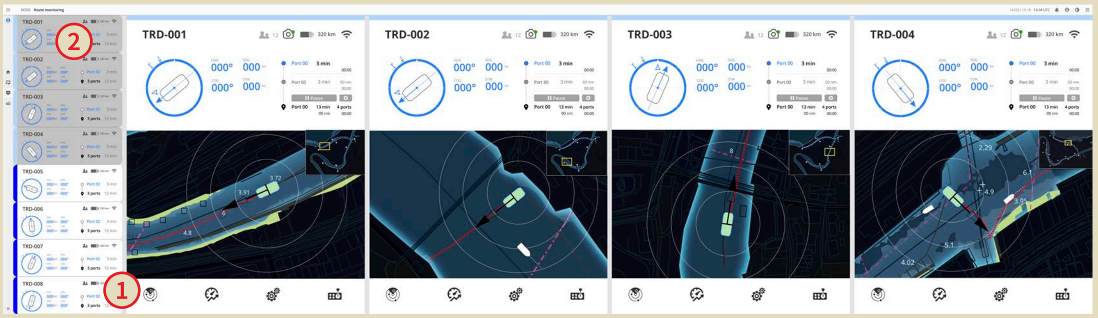


Figure 7.6 Final prototype- Home screen

On the desk screen, the operator can monitor the vessels in more detail at his hand. Figure 7.6 illustrates the home screen which shows all the vessels that one operator is in charge of.

The panels are the same with the ones on the Vessel status screen on the wall

1. Buttons for ship performance, ship system, and manual control
2. Simplified vessel status panel buttons for detailed pages of each vessel

Figure 7.7 Final prototype- Detailed page

When the operator selects one of the vessels on the home screen, the detailed page pops up (Figure 7.7) which includes:

1. Information that are on the vessel status panel
2. Bird's eye view of the vessel
3. A larger and more detailed nautical map with buttons of radar and lidar to fuse, and a head-up button (Figure 7.8)
4. CCTV button which is activated when the port becomes visible on the map
5. Detailed navigational data
6. Target vessel data
7. Views from the camera, size is adjustable

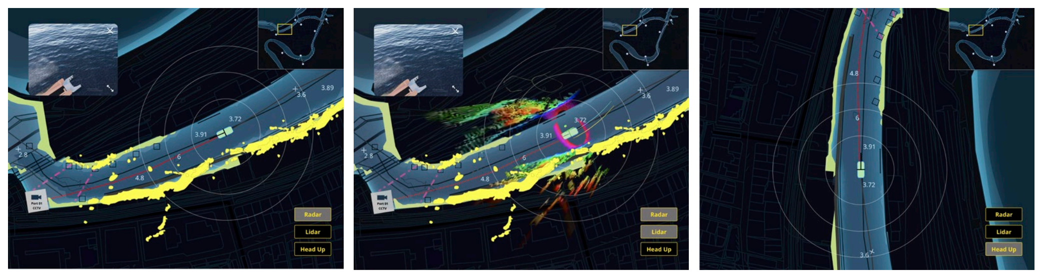


Figure 7.8 Map variants- radar overlay with a CCTV view, radar and lidar overlay with a CCTV view, and head-up

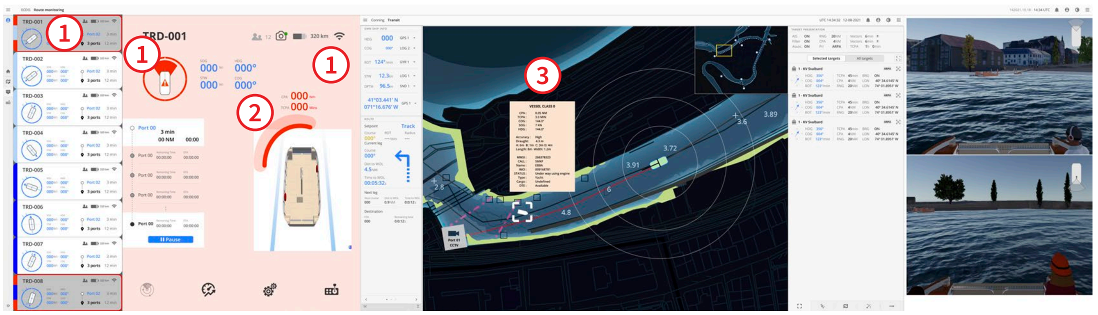
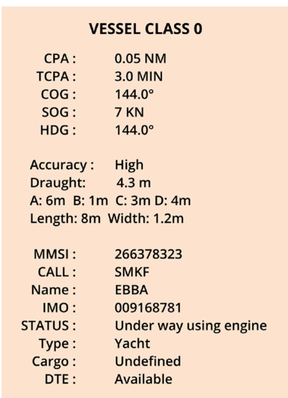


Figure 7.9 Final prototype- Alarm screen

In an alarm situation, the detailed page also shows the alarm notifications (Figure 7.9) to let the operators recognize what is happening and why it is happening:

1. Alarm notifications on the panel list, phase icon, and background
2. TCPA and CPA of the bird's-eye view indicating the direction of the target
3. Target information (Figure 7.10)


VESSEL CLASS 0

CPA : 0.05 NM
TCPA : 3.0 MIN
COG : 144.0°
SOG : 7 KN
HDG : 144.0°

Accuracy : High
Draught: 4.3 m
A: 6m B: 1m C: 3m D: 4m
Length: 8m Width: 1.2m

MMSI : 266378323
CALL : SMKF
Name : EBBA
IMO : 009168781
STATUS : Under way using engine
Type : Yacht
Cargo : Undefined
DTE : Available

Figure 7.10 Details of target information (example)

Icon Design

Most of the icons are designed by the author influenced by OpenBridge (2018) the conning displays, ECDIS symbol guidelines, and Tesla UI.
The main focus was to make it clearer, simpler, and more noticeable.

Phase icon

The icon design is inspired by conning display. Phase icons show the vessel's operation phases and alert notifications in a way that makes the navigator more familiar with the icons because conning displays are used in conventional ship operation.

As the vessel transits, the icon acts like a conning display - indicating wind, waves, heading and COG. At different phases, the icon shows the status of the vessel.

Designing the 'alarm icon' can only notify 'Something went wrong'. In order to inform the urgency and cause, the 'Proximity warning' and 'Offtrack' alarms, which can be the most problematic in maneuvering, were designed (Figure 7.11).

However, caution should be exercised as too many alarm types affect the mental burden of remote operators.

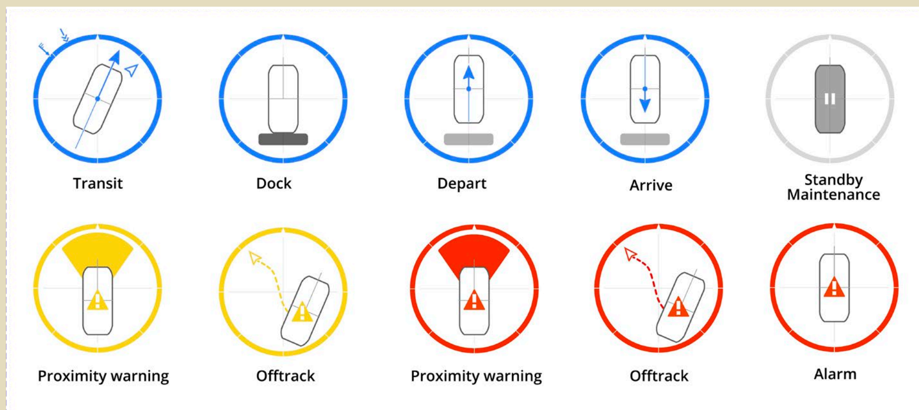


Figure 7.11 Operation phase icons

Other Icons

Figure 7.12 illustrates the other icons on top of the vessel status panel.
The first row is a normal outfit of the panel. When they are in a different state, the icons change as Figure 7.12.

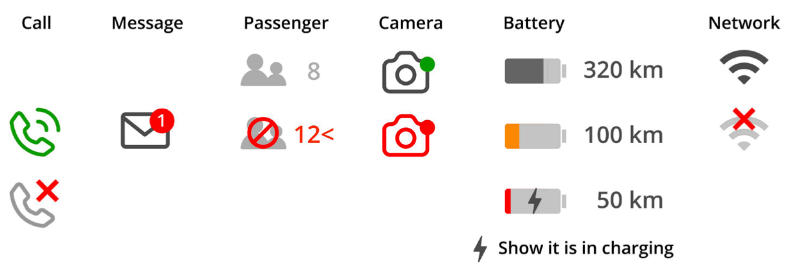


Figure 7.12 Other icons and changes in a different state

The icons are small and the color or state changes are insufficient to be noticed. Therefore, when some minor problem happens, the caution message box will appear and then disappear (Figure 7.13). The message will be saved in the message icon until solved.

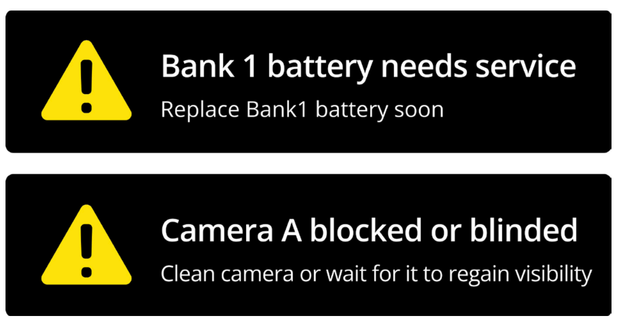


Figure 7.13 Examples of caution message

To let the operators notice the alarm promptly and accurately, several methods are applied to each panel.

Vessel status screen
- Color changes in the background, border, and identification bar of each panel
- Vessel operation icon changes

Map screen
- Bigger size, color change and flickering lights on the corresponding vessel's symbol
- Alarm notification on the information bar

Detailed page
- Color changes in the background, border, and identification bar of each panel
- Vessel operation icon background color changes
- Target indicator, TCPA and CPA appear around the bird's-eye-view

The functional prototype allowed testers to experience how the all components work and react to each other (Figures 7.14 and 7.15).

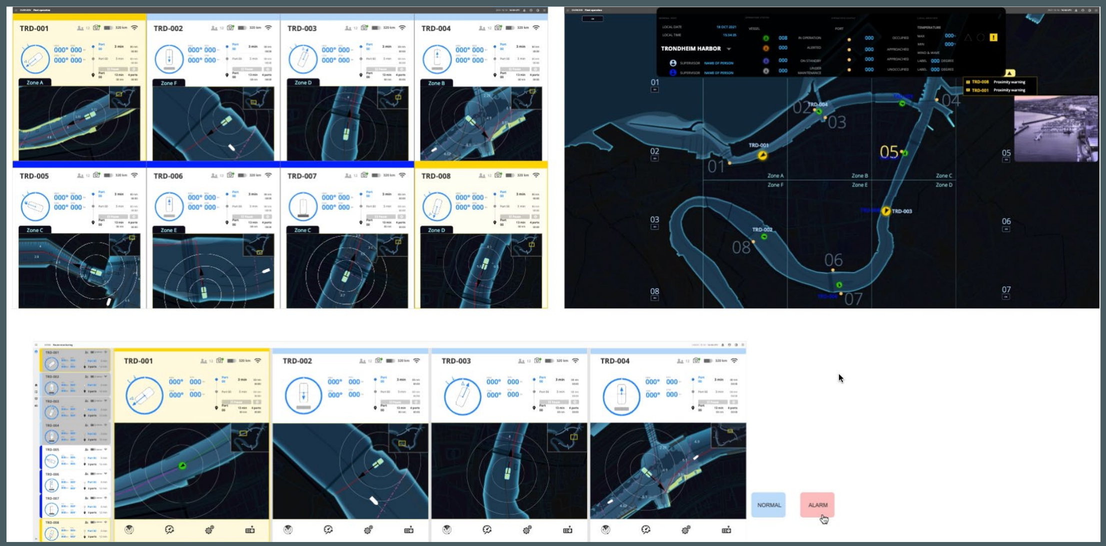


Figure 7.14 An example of alert situation
(A screen shot of the prototype animation)

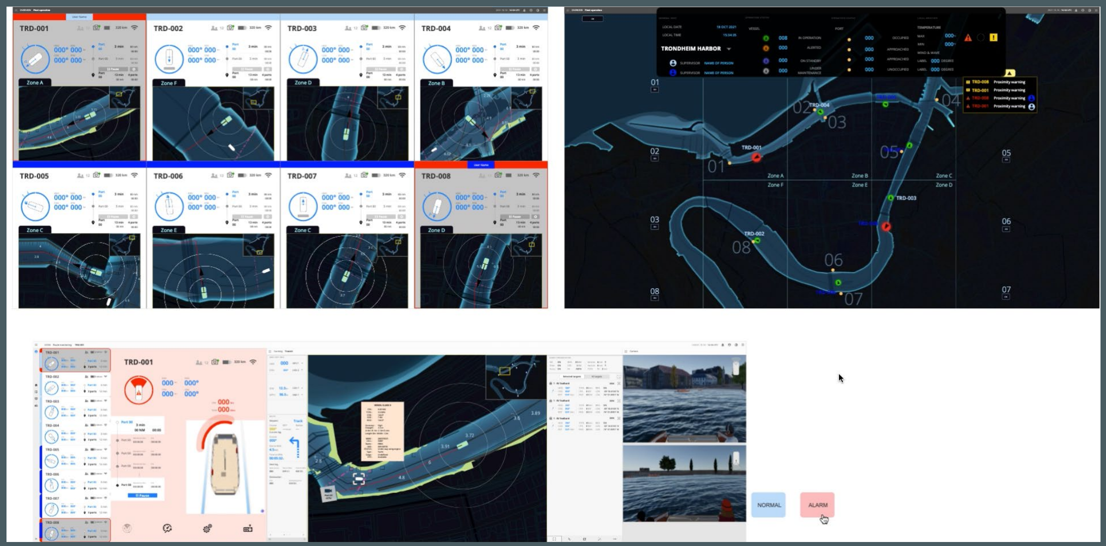


Figure 7.15 An example of alarm situation
(A screen shot of the prototype animation)

Prototype Implementation

With the prototype made by Axure, the user can experience hover, collapse, new/detailed page open, etc. on the three interconnected screens. In addition, with the Normal and Alarm buttons, the user can watch how the function works.

Figure 7.16 Prototype is being tested in the control room of SCL (January 2022)

8 REFLECTIONS

Reflections

This project was very challenging to begin with. It started with two concepts: designing a GUI for monitoring MilliAmpere2, and one operator in a team to be in charge of more than one vessel. The project required reading various papers and documents to understand the background; it was vague due to there being no operation concept, user, or installation location. In order to successfully complete the technology of autonomous navigation, numerous research has been conducted on various topics in various fields. By reading the related papers, knowledge on autonomous navigation was gradually gained. However, in terms of the project, it became more vague because it was hastily desired that the GUI contain all the contents that had been read.

However, regular supervisory meetings and design research processes helped to refine and narrow the topic. The supervisor focused on the topic of designing a GUI for monitoring multiple vessels simultaneously while presenting a variety of ideas. Design study processed through three iterations. Once a sketch or prototype is created, a verification is conducted by seeking advice and feedback from navigators with years of experience and researchers with years of research in the field of autonomous navigation. It was also a process of developing design principles. Although there were restrictions on meeting people in person or conducting various research due to COVID-19, the valuable and professional advice of the participants was a great help to the project.

The biggest worry while working on the project was to implement the prototype function. This is because the user does not directly operate the prototype, but sees and understands when an alarm occurs while monitoring the prototype. Also, the three screens had to react to each other. This was solved by a tool called Axure, which was introduced by a doctoral student who is currently researching at SCL. Various reactive effects were also easily implemented, and above all, triggers and results could be displayed seamlessly like a simulator or animation. Experiencing this prototype virtually is available via https://2o6ovt.axshare.com/.

Thankfully, this project is expected to contribute to the next phase of research. When I visited Nyhavna for a usability test and displayed the prototype on the target device and implemented the function, the evaluation of the prototype by the researchers was immensely positive. They will use this GUI for the simulator of milliAmpere2.
The Supervisor also used it as the basis for the TPD4167 Information visualization assignment in the spring semester of 2022 to collect new ideas from the students.

Figure 8.1 The prototype is being used for further research at SCL (January 2022)

References

Barzun, J. & Graff, H. F. (1977) *The Modern Researcher*, 3rd ed., New York and London, Harcourt Brace Jovanovich, 1977

EdTech (2019, September 6). *How to Conduct Design Thinking Workshop.* https://www.youtube.com/watch?v=Ryen3Pj1Pps

Ellingsen, H. M. & Glesaaen, P. K. (2020). Design av Brukerreise og Brygger til Autonom Passasjerferge. *Master's Thesis, NTNU*

Endsley, M. R., Bolte, B. & Jones, D. G. (2003). *Designing for Situation Awareness: An approach to User-Centered Design*. New York: CRC Press.

Endsley, M.R. & Jones, D.G. (2012). *Designing for Situation Awareness : An Approach to User Centered Design* (2nd ed. ed.). Boca Raton, Fla: CRC Press.

Havdal, G., Heggelund, C. T. & Larssen, C. H. (2017). Design of a Small Autonomous Passenger Ferry. *Master's Thesis, NTNU*

IDEO (n.d.). *How Might We.* Design Kit. https://www.designkit.org/methods/how-might-we

IMO (2018, May 25). *IMO Takes First Steps to Address Autonomous Ships.* https://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx

IMO (2019). Guidelines for the Presentation of Navigation-Related Symbols, Terms and Abbreviations. *SN.1/Circ.243/Rev.2*

IMO (2021A, May 25). *Autonomous Ships: Regulatory Scoping Exercise Completed.* https://www.imo.org/en/MediaCentre/PressBriefings/pages/MASSRSE2021.aspx

IMO (2021B). Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS). *MSC.1-Circ.1638*

Johnson, J. (2014). *Designing with the Mind in Mind_ A Simple Guide to Understanding User Interface Design Rules.* Morgan Kaufmann Publishers/Elsevier

Kim, M., Joung, T. H., Jeong, B. & Park, H. S. (2020). Autonomous Shipping and its Impact on Regulations, Technologies, and Industries. *Journal of International Maritime Safety, Environmental Affairs, and Shipping, 4:2, 17-25,* DOI: 10.1080/25725084.2020.1779427

Kongsberg Gruppen (2020, February 13). *Automatic Ferry Enters Regular Service Following World-First Crossing with Passengers Onboard.* https://www.kongsberg.com/maritime/about-us/news-and-media/news-archive/2020/first-adaptive-transit-on-bastofosen-vi/

Kongsberg Gruppen (2020, May 19). *Webinar - Autonomous vessels - A concept in the making*. https://www.youtube.com/watch?v=-Et5oNg5XfI&t=712s

Man, Y., Lundh, M. & Porathe, T. (2014). Seeking Harmony in Shore-based Unmanned Ship Handling - From the Perspective of Human Factors, What Is the Difference We Need to Focus on from Being Onboard to Onshore? AHFE 2014

Man, Y., Lundh, M., Porathe, T. & MacKinnona, S. (2015). From Desk to Field - Human Factor Issues in Remote Monitoring and Controlling of Autonomous Unmanned Vessels. *AHFE 2015*

MUNIN (2016). *MUNIN Results*. http://www.unmanned-ship.org/munin/about/munin-results-2/

Mustvedt, P. (2019). Autonom Ferge Designet for å Frakte 12 Passasjerer Trygt over Nidelven. *Master's Thesis, NTNU*

OpenBridge (2018). *OpenBridge Design System.* http://www.openbridge.no

Oury, J. D. & Ritter, F. E (2021). *Building Better Interfaces for Remote Autonomous Systems - An Introduction for Systems Engineers.* Springer International Publishing. ISBN 978-3-030-47775-2 (eBook) https://doi.org/10.1007/978-3-030-47775-2

Parasuraman, R., Sheridan, T. B. & Wickens. C. D. (2000). A Model for Types and Levels of Human Interaction with Automation. *IEEE Transactions on systems, man, and cybernetics—Part A: Systems and humans, VOL. 30, NO. 3, MAY 2000*

Poranen, H., Marafioti, G., Johansen, G. & Sæter, E. (2018). User Interface Design Guidelines for Marine Autonomous Operations Involving a Large Number of Actors, Devices and Sensors. OMAE2018-78774

Porathe, T & Man, Y. (2013). D7.3. Technical Layout of SOC. *MUNIN – FP7 GA-No 314286*

Porathe, T & Man, Y. (2014). D7.5: HMI Layout for SOC. *MUNIN – FP7 GA-No 314286*

Porathe, T., Fjortoft, K. & Bratbergsengen, I. L. (2020). Human Factors, Autonomous Ships and Constrained Coastal Navigation. *ICMASS 2020*

Porathe, T. (2021). Human-Automation Interaction for Autonomous Ships: Decision Support for Remote Operators. *TransNav. Safety of Sea Transportation Volume 15 Number 3 September 2021.* DOI: 10.12716/1001.15.03.03

Rødseth, Ø.J., & Nordahl, H. (2017). Definition of Autonomy Levels for Merchant Ships. *Report from NFAS, Norwegian Forum for Autonomous Ships, 2017-08-04.*

Sarter, N.B. & Woods, D.D. (1997). Team Play with a Powerful and Independent Agent: Operational Experiences and Automation Surprises on the Airbus A-320. *Human Factors, 39(4), 553-569*.

Sharma, A., Nazir, S. & Ernstsen, J. (2019). Situation Awareness Information Requirements for Maritime Navigation: A Goal Directed Task Analysis. *Safety Science 120 (2019) 745–752*. https://doi.org/10.1016/j.ssci.2019.08.016

The Design Council. (2015). *The Double Diamond*. https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond

Veitch, E. (2021). Design for Resilient Human-System Interaction in Autonomy: The Case of a Shore Control Centre for Unmanned Ships. *ICED21 16-20 AUGUST 2021*

Yara International ASA (2021, November 19). *Yara to Start Operating the World's First Fully Emission-Free Container Ship.* https://www.yara.com/corporate-releases/yara-to-start-operating-the-worlds-first-fully-emission-free-container-ship/

Zeabuz (n.d.) *Our Technology.* https://www.zeabuz.com/technology

Appendix 1.

Survey #1 Results

- **Participant demographics**

1) 27 **seafarers** (30 participated, but 3 of them with less than 1 year experience were excluded) who have years of experience on large commercial vessels, mostly taking 5 month-long voyages. 72% of them are chief officers including 1 captain.
   All of them are in their 30's and graduated from the Maritime institute.

2) Experience

1-3 years	4
3-5 years	7
5-7 years	7
7+ years	9

3) Vessel type (check all that apply)

LPGC	12
Tanker	10
Cargo	9
LNGC	8
Container	6
Passenger ship	2
Offshore support vessel	2
Etc. (support vessels, patrol)	4

4) Average on-duty period

Less than 1 month	2
1-3 months	9
5+ months	14

5) (Final) position

Captain	1
Chief officer (first officer)	17
Second officer	5

Etc.	2

- **Navigation experience**

In this section, questions were given to explore the competency, task, routine, and perception of seafarers.

1) Main competences to be a navigator (graded each question from 1 (not at all) to 5 (very important))

1	Situational judgment and coping ability	116
2	Understanding nautical chart (ECDIS, Radar, AIS, etc.)l	112
3	Communication (Radio, VHF)	107
4	Rule & regulation	104
5	Understanding the equipment or systems of the vessel	104
6	Collaboration in team	99
7	Physical function (vision, audition,...)	93

2) Important information to navigate at the bridge (graded each question from 1 (not at all) to 5 (very important)), listed from the highest to the lowest

	Information	Score
1	ECDIS	117
2	Route	116
3	Position	114
4	GPS	110
5	Nautical charts (contour, proximity)	110
6	Target speed, SOG	107
7	Keel clearance	107
8	Heading, COG	106
9	Radar screen	102
10	Alarm signal	101
11	Arrival port info. (port, contour, traffic, etc.)	101
12	Departure port info. (port, contour, traffic, etc.)	100
13	Draft	99
14	ETA	97
15	Weather- Wind (Speed, direction)	94
16	Current or tidal stream	94
17	Distance to waypoint	93
18	Weather - Wave (Speed, direction)	92
19	System - Engine (Motor) RPM	92
20	System - Steering system	92
21	Operation mode - Autonomous, Manual	91
22	Air draft	89
23	VHF	87
24	Trim	86
25	System - Generator for propulsion (Battery)	81
26	System - Thruster	77
27	Weather - Air pressure	75
28	Weather - Water temperature	72
29	Weather - Air temperature	71

3) Degree of concentrate in each of the voyage phase (graded each one from 1-not at all to 5-very much)

	Voyage phase	Score
1	Port departure/ arrival	125
2	Archipelago	117
3	Coast	95
4	Mooring (docking)	91
5	Open sea	62

4) Effective notification means for an alarm situation (graded each one from 1-not at all to 5-very much)

	Means	Score
1	Alarm light (flickering) on the screen or panel	86
2	Alarm sound	84
3	Verbal caution from colleagues	62
4	Witnessed myself	54

- **Autonomous ferry**

In this section, questions were given to collect navitors' opinions about remotely operating autonomous ferries.

1) Please anticipate the level of concentration required for the remote operators at each phase of navigation. (graded each one from 1-not at all to 5-very much)

	Voyage phase	Score
1	Takeoff	99
2	Transition (lowering speed for docking)	89
3	Docking (Passengers boards and alight)	95
4	Dockside (Battery charging, maintenance)	91
5	Transit (Traveling at constant speed)	62

2) If you are a remote operator, what information do you think should be displayed on which screen?

2-1) Information shall be displayed on the Wall screen #1 (Vessel status screen)

	Information	Score
1	GPS (Lat./Long.)	16
2	Alarm signal	15
3	Route	14
4	Heading, COG	13
5	ECDIS	13
6	Arrival port (contour, density of traffic)	12
7	Target speed, SOG	12
8	Radar screen	12
9	Nautical chart (contour, surrounding vessels)	12
10	System : Engine (Motor) RPM	12
11	Ship mission status (Takeoff, transit, transition, docking, dockside)	12
12	System : steering system	11
13	Departure port (contour, density of traffic)	10
14	Estimated time of arrival	10
15	Distance to waypoint	10
16	VHF (communication channel to other vessel or VTS)	9
17	Keel clearance	8
18	System : Generator for propulsion (Battery)	8
19	Weather / wind (speed, direction)	7
20	Draft	7
21	System : Thruster	7
22	Operation mode (Autonomous/ manual)	6
23	Trim	6
24	Weather / wave (speed, direction)	5
25	Air draft	4
26	Current or Tidal stream	4
27	Weather / air pressure	2
28	Weather / air temperature	2
29	Weather / water temperature	2

2-2) Information shall be displayed on the Wall screen #2 (Map screen)

	Information	Score
1	Current or Tidal stream	13
2	Draft	13

3	Distance to waypoint	10
4	Trim	10
5	Estimated time of arrival	9
6	Keel clearance	9
7	Air draft	9
8	Weather / wave (speed, direction)	9
9	Arrival port (contour, density of traffic)	8
10	Route	8
11	Operation mode (Autonomous/ manual)	8
12	Nautical chart (contour, surrounding vessels)	8
13	Departure port (contour, density of traffic)	7
14	System : Thruster	7
15	Ship mission status (Takeoff, transit, transition, docking, dockside)	7
16	Target speed, SOG	6
17	Heading, COG	6
18	Weather / wind (speed, direction)	6
19	Weather / air temperature	6
20	Radar screen	6
21	ECDIS	6
22	VHF (communication channel to other vessel or VTS)	6
23	System : Engine (Motor) RPM	6
24	Weather / air pressure	5
25	Weather / water temperature	5
26	GPS (Lat./Long.)	5
27	System : steering system	4
28	Alarm signal	4
29	System : Generator for propulsion (Battery)	3

2-3) Information shall be displayed on the desk screen

	Information	Score
1	Weather / wind (speed, direction)	10
2	Weather / air pressure	9
3	Weather / water temperature	9
4	Operation mode (Autonomous/ manual)	9
5	Air draft	8
6	Weather / wave (speed, direction)	8
7	Weather / air temperature	8
8	System : Generator for propulsion (Battery)	8
9	Target speed, SOG	7
10	Radar screen	7
11	VHF (communication channel to other vessel or VTS)	7
12	System : Thruster	7
13	Estimated time of arrival	6
14	Heading, COG	6
15	Keel clearance	6
16	Current or Tidal stream	6
17	ECDIS	6
18	System : steering system	6
19	Departure port (contour, density of traffic)	5
20	Distance to waypoint	5
21	Nautical chart (contour, surrounding vessels)	5
22	Ship mission status (Takeoff, transit, transition, docking, dockside)	5
23	GPS (Lat./Long.)	4
24	Trim	4
25	System : Engine (Motor) RPM	4
26	Arrival port (contour, density of traffic)	3
27	Route	3
28	Alarm signal	3
29	Draft	2

2-4) Information that is not necessarily to be shown but is needed for a log

	Information	Score
1	Weather / air pressure	7
2	Weather / air temperature	6
3	Weather / water temperature	6
4	Air draft	4
5	System : Generator for propulsion (Battery)	4
6	Departure port (contour, density of traffic)	3
7	Weather / wave (speed, direction)	3
8	VHF (communication channel to other vessel or VTS)	3
9	Trim	3
10	System : Thruster	3
11	System : steering system	3
12	Arrival port (contour, density of traffic)	2
13	Keel clearance	2
14	Weather / wind (speed, direction)	2
15	Current or Tidal stream	2
16	Operation mode (Autonomous/ manual)	2
17	System : Engine (Motor) RPM	2
18	Alarm signal	2
19	Draft	1
20	Estimated time of arrival	0
21	Route	0
22	Distance to waypoint	0
23	Target speed, SOG	0
24	Heading, COG	0
25	Radar screen	0
26	GPS (Lat./Long.)	0
27	ECDIS	0
28	Nautical chart (contour, surrounding vessels)	0
29	Ship mission status (Takeoff, transit, transition, docking, dockside)	0

2-5) Information which is not necessary

	Information	Score
1	Weather / air temperature	3
2	Weather / water temperature	3
3	Weather / air pressure	2
4	Draft	2
5	Trim	2
6	System : Generator for propulsion (Battery)	2
7	System : Engine (Motor) RPM	1
8	System : Thruster	1
9	System : steering system	1
10	Alarm signal	1
11	Ship mission status (Takeoff, transit, transition, docking, dockside)	1
12	Departure port (contour, density of traffic)	0
13	Arrival port (contour, density of traffic)	0
14	Estimated time of arrival	0
15	Route	0
16	Distance to waypoint	0
17	Target speed, SOG	0
18	Heading, COG	0
19	Keel clearance	0
20	Air draft	0
21	Weather / wave (speed, direction)	0
22	Weather / wind (speed, direction)	0
23	Current or Tidal stream	0
24	Operation mode (Autonomous/ manual)	0

25	Radar screen	0
26	GPS (Lat./Long.)	0
27	ECDIS	0
28	Nautical chart (contour, surrounding vessels)	0
29	VHF (communication channel to other vessel or VTS)	0

3) The competencies that the remote operator shall have

	Competency	Score
1	Situational judgment and coping ability	25
2	Understanding nautical chart (ECDIS, Radar, AIS)	23
3	Understanding the equipment or systems of urban ferry	22
4	Understanding rules & regulations	21
5	Communication (Radio, VHF)	19
6	Physical function (vision, audition,...)	10
7	Collaboration	9

3-1) In addition to the competences above, the respondents said the remote operators would be required to have abilities as follows:

- Multi-tasking
- Experience and understanding of navigation
- Experience and knowledge on the route
- Concentration
- Responsibility
- Knowledge of each of the ports

4) If you were a remote operator, how many autonomous ferries can you monitor alone?

	Number of ferry	Score
1	2-5 ferries	11
2	1 ferry	10
3	5-10 ferries	4

Appendix 2.

Workshop Outline

Time	Cumulative time	What happens	Item
5	5	Introduction	Consent form, snack
		Stage1	
3	8	Identifying challenges - an ideal day	Large paper on the wall, post-it (color1), marker
3	11	Identifying challenges - a busy day	Large paper on the wall, post-it (color2), marker
7	18	Identifying challenges - an abnormal day	Large paper on the wall, post-it (color3), marker
10	28	Identifying challenges - emergency	Large paper on the wall, post-it (color4), marker
		Stage 2	
15	43	Sorting and grouping the challenges and define each clusters	Large paper on the wall, post-it (color5), marker
2	45	Individually, select the 3 most important and 3 most urgent challenges	Dot sticker
3	48	#Picture	
5	53	A problem statement	paper, marker
		Stage 3	
7	58	3 HWM questions	paper, marker
10	68	Ideate solution (visualize it)	paper, marker
10	78	Pitch the idea within 2 minutes each	
		break	
		Stage 4	
10	88	Presentation of my prototype	projector, laptop
		Stage 5	
10	98	Feedback	worksheet
2	100	Wrap up	

Appendix 3.

Tasks for Usability test

Usability test

Imagine that you are an operator in the remote control room.
There are two operators monitoring the fleet of autonomous ferries, and you are the one of them.

1. Can you distinguish what vessels are your responsibility and your colleague's?
2. If your indicator is the color of light blue, can you tell me the names of vessels that you are in charge of?
3. Can you indicate where they are on the map?
4. Can you pick out which vessel(s) are at the dock?
5. Can you pick out which vessels are approaching and leaving the dock?
6. There are ports on the map. Can you recognize them well?
7. Each of the docks has a CCTV camera and you can watch it whenever you want. Can you turn on the CCTV screen?
8. Open a page to see the TRD-001 in detail.
9. Can you move on to the detailed page of TRD-002?
10. Let's go back to the main page, which has four dashboards.
11. Go back to the detailed page of TRD-001.
12. Can you make the camera view larger?
13. To make space, let's collapse a column of target vessels.
14. You can see the head-up view for the ECDIS screen.
15. Back to the north-up map, you can turn on the radar screen and overlay it.
16. You can turn on the lidar screen as well.
17. Now let's move on to the alarm situation.
18. Can you guess why the alarm was raised?
19. What do you think when watching the NORMAL situation?
20. What do you think when watching the ALARM situation?

NTNU

Norwegian University of Science and Technology