Joachim Ullmann Miller

Automation transparency in the maritime domain

How autonomous ships can use external human-machine interfaces to communicate with their surroundings

Master's thesis in Cybernetics and Robotics
Supervisor: Thor Hukkelås
Co-supervisor: Øystein Andreassen
June 2022

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Engineering Cybernetics

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Problem description

Fully autonomous vehicles have made the human operator superfluous. Even though the technology may perform better on efficiency, fuel consumption, and safety, the surroundings are not familiar with accounting for them in traffic. Besides driving, the human operator plays a crucial role in making the passengers feel safe, communicating with other vehicles, and taking action on unexpected events. Automation transparency may play a crucial role in softening the transition from human-operated vehicles to fully autonomous vehicles.

This thesis will investigate the importance and effect of automation transparency for Maritime Autonomous Surface Ships (MASS). The main objective is to design and test solutions for how MASS can communicate its status and intentions to the outside world. This task is substantiated with the following research questions:

- What kind of information should automation transparency include?
- How to communicate automation transparency in the maritime domain?
- Can automation transparency help to build trust for passengers and conventional ships?
- What are the consequences of using automation transparency?

Choose a case and show through examples how automation transparency can be used to answer the research questions above. The following tasks are proposed:

- Develop a ship simulator for testing automation transparency concepts.
- Perform a literature study.
- Design and implement user interface and interaction methods.
- Test the developed solutions and evaluate the results.

Preface

This thesis finalizes my master's degree in Cybernetics and Robotics at the Norwegian University of Science and Technology (NTNU). The course *Human-machine interaction in cyber/physical system* (TTK30) in fall 2021 inspired me to research the interaction between humans and machines in autonomous systems. Unfortunately, this research field is given little attention in my degree, even though the increaseness in autonomous systems will largely affect humanity in the future.

The master's degree is completed with the cooperation of the Department of Engineering Cybernetics (ITK) and NTNU Shore Control Lab (SCL). Thank you for giving me the resources and facilitating me to accomplish my work. I am grateful to the external partner Zeabuz for giving me access to their codebase from the TRUSST research project.

I want to express my appreciation to the people who have helped me achieve my master's degree. First and foremost, I would like to thank my supervisor Thor Hukkelås and my co-supervisor Øystein Andreassen. Their support, assistance, and advice have been highly appreciated. In addition, I am grateful to Ph.D. candidate Leander Spyridon Pantelatos for his help and guidance. I appreciate your dedication and effort and wish you all the best in the future. I have been lucky to share the office with great people; thank you for the excellent work environment and valuable discussions. To my friends who have made my time as a student so enjoyable, thank you for the good memories and laughs; I can't wait to create new memories with you in the future. Finally, I would like to thank my family. Your never-ending support has been and is invaluable.

Trondheim, June 2022
Joachim Ullmann Miller

Abstract

The interaction between autonomous ships and conventional ships needs to be solved to achieve the full potential for autonomous vehicles in the maritime domain. Automation transparency has the potential to play the leading role by softening the transition from human-operated vehicles to fully autonomous vehicles. External human-machine interaction (eHMI) concepts for the maritime domain have been developed to test the potential of automation transparency.

The International Maritime Organization (IMO) works to simplify this interaction with the e-navigation project, but essential stakeholders are left out. Leisure vessels do not have the required equipment to participate in the project. How passengers will react to human operators being replaced by technology remains identified. Case studies for leisure vessels and passengers are performed using the immersive technology Virtual Reality (VR). There have been developed both eHMI passenger concepts and eHMI boat driver concepts, where each concept is designed to be transparent, understandable, intuitive, and increase the situational awareness for the end-user.

An user test was performed in a VR simulator to test the concepts. Given the results from the user test, automation transparency has the potential to ease the introduction of new technology into the maritime domain. The solutions should contain information about the status and intention of the maritime vessel as the information needs are higher for autonomous vessels than conventional vessels. Real-life test experiments are necessary to confirm, but the results are promising.

Sammendrag

Det store potensialet til autonome skip kan kun oppnås hvis samhandlingen med konvensjonelle skip fungerer. Automatiseringstransparens kan være en viktig brikke i å løse denne utfordringen, ved å lette overgangen fra menneskestyrte kjøretøy til autonome kjøretøy. Konsepter for ekstern menneske-maskin interaksjon (engelsk forkortelse: *eHMI*) har blitt utviklet for å teste om automatiseringstransparens kan være en del av løsningen.

Den internasjonale sjøfartsorganisasjonen jobber for å forenkle denne interaksjonen gjennom *e-navigasjonsprosjektet*, men viktige interessenter er utelatt. Blant annet kan ikke fritidsfartøy delta grunnet mangel på nødvendig utstyr. Hvordan passasjerer vil reagere på at menneskelige operatører blir erstattet av teknologi trengs å identifiseres. Virtuell virkelighet (VR) har blitt brukt for å lage scenarioer for fritidsfartøy og passasjerer. Det har blitt utviklet eHMI konsepter for både passasjerer og fritidsbåtførere, hvor hvert konsept har blitt designet for å være transparent, forståelig, intuitivt og øke situasjonsforståelsen.

Det ble gjennomført en brukertest i VR simulatoren for å teste konseptene. Basert på resultatene fra brukertesten, har automatiseringstransparens potensialet til å lette innføringen av ny teknologi i den maritime sektoren. Løsningene bør inneholde informasjon om status og intensjon til det maritime fartøyet fordi informasjonsbehovet er høyere for autonome fartøy enn konvensjonelle fartøy. Det er nødvendig å gjennomføre fysiske eksperimenter for å bekrefte resultatene, men de er lovende.

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Chapter 1

Introduction

1.1 Background and motivation

New technology in the maritime field creates opportunities and new approaches for navigating at sea. The more mature the technology becomes, the more human tasks are automated. Automation has the potential to reduce the number of accidents at sea (Hoem et al., 2020). This could decrease human, environmental, and economic damages, as human errors cause most collisions (Dimmen and Langemyr, 2014). The human factors which increase the risk for collisions are distractions, speeding, inexperience, misinterpretation, and miscommunication (Vlakveld, 2015). Automated driving will never be influenced by the same human risk factors and can make decisions with sensors programmed to follow the "rules on the road" - The International Regulations for Preventing Collisions at Sea (COLREGS). Automated technology systems have the advantage over human operators by detecting and processing large quantities of data in a short amount of time. As a result, the chance for faults in the technology which could lead to failures is smaller than the chance of human mistakes (RM, 2022).

Maritime Autonomous Surface Ships (MASS) is an extensive research field, and there are multiple commercialized projects planned to be available for the public in the near future. The motivation for developing MASS is to decrease the cost and improve safety on board. Human faults stand for 75-96% (AGCS, 2017), and the industry is confident that the number can be drastically reduced with autonomous ships replacing conventional ships. In Norway, there are multiple projects; Yara Birkeland and Asko Maritime are two projects in the autonomous cargo field. The Autoferry project is an autonomous passenger ferry planned to be available for the public soon in the commute field. For all these vessels their route will be within the coast where traffic consists from larger motorboats to kayaks.

The challenge of interaction between autonomous ships and conventional ships needs to be solved to achieve the potential of autonomy in the maritime domain. The International Maritime Organization (IMO) launched a concept to simplify this interaction, e-navigation. The goal of e-navigation is to share and present information to enhance safety and security with electronic equipment.

The key point is that every agent shares their information about the situation so that everyone can base their next action on the same situational awareness. Common situational awareness would be achieved if the vessels could share their status and intentions with all vessels, e.g., radio contact distance. From the international convention of Safety of Life at Sea (SOLAS), all larger vessels must be equipped with an Automatic Identification Systems (AIS) to transmit their status to other vessels and the Vessel Traffic Service (VTS). Route exchange is a system (under research) for sharing plans or segments, essentially the intentions with other vessels and VTS.

Most leisure vessels do not have the required equipment to participate in the e-navigation system. Instead, they have to trust that the MASS takes action according to the convention on the International Regulations for preventing Collisions at Sea (COLREGS). Since leisure vessels can not obtain the information from the e-navigation system, a reassuring factor could be to know the situation awareness of the MASS, and planned actions. The same is maybe valid for the passengers onboard MASS. Today passengers are used to trusting human operators; how the trust will be affected when the human operators are replaced with technology remains to be identified. Automation transparency has the potential to be the solution to these challenges, but to this date, little research has been performed on automation transparency in the maritime domain.

1.2 Scientific relevance

The interaction between autonomous systems and humans will be inevitable in the future. This has led to increasing research interest in autonomous transparency. The research on automation transparency in the maritime domain started extensively a few years ago, but automation transparency, in general, is a mature research field.

There is a lot to learn from other traffic domains on automation transparency. (Hodne and Skåden, 2021) completed a literature review of automation transparency in autonomous systems with the focus on utilizing the information for MASS development. The literature review identified 355 studies with "Autonomous" AND "External Human-Machine" as search criteria. The studies were compromised to 34 studies given the inclusion and exclusion criteria and then analyzed. Their findings were that egocentric communication combined with passive behavior towards secondary users seems promising. Furthermore, when developing eHMI for MASS, standard colors, symbols, and text are recommended. The authors concluded that the findings for Autonomous Vehicles (AVs) are transferable to MASS, but more research is required in this field.

A systematic literature review was conducted to investigate automation transparency in the maritime domain with respect to interaction between convectional ships and autonomous ships. Table 1.1 shows the literature review protocol for the literature study. The focus has been on how humans and machines can communicate with each other through transparency. The filtering was done by reading each paper's title, keywords, and abstract. If necessary, further screening was completed. Additionally to the papers from the online search, relevant papers from reference lists were included. This research methodology follows the process of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021). An overview of the studies reviewed is shown in figure 1.1.

Subject	Description
Database	Web of Science
Search strategy	("unmanned ship" OR "autonomous ship" OR "maritime autonomous surface ships") AND ("transparency" OR " automation transparency" OR "human centered design" OR"communication" OR "hmi" OR "e-hmi" OR " e-navigation" OR "external human-Machine" OR "human-automation interaction")
Publication type	Journal and conference papers
Time interval	All years (1945-2022)

Table 1.1: Literature review protocol.

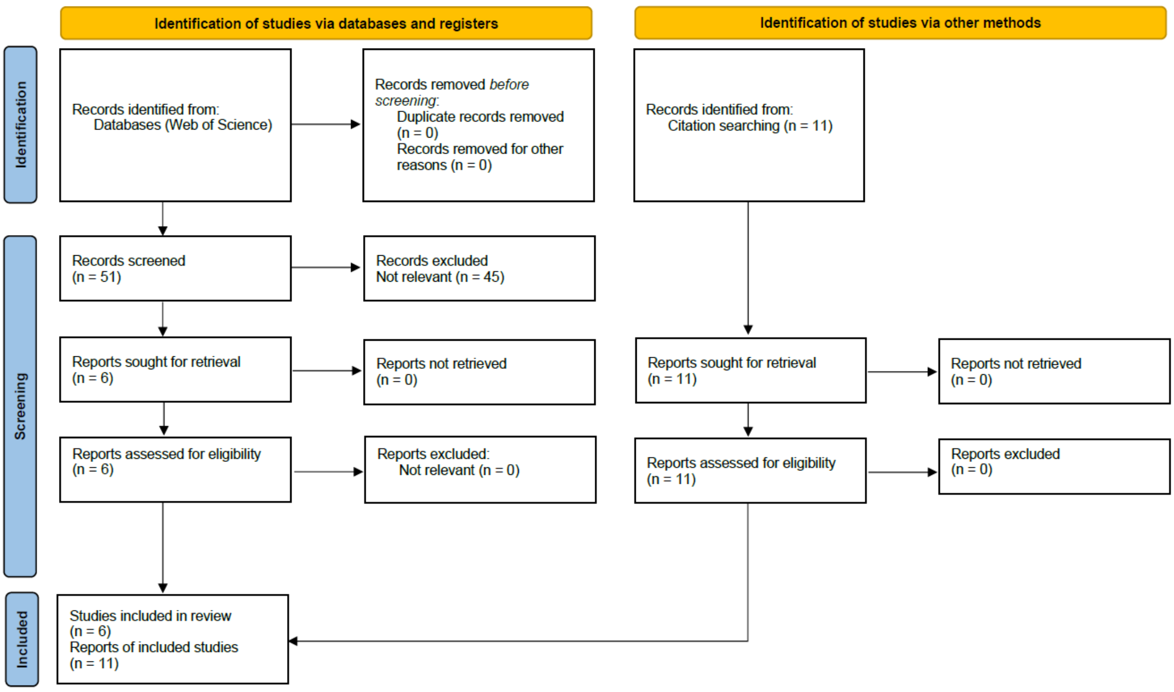

Figure 1.1: Literature review.

(Høklie, 2017) focus on how autonomous ferries should be designed to increase trust for passengers. It is explored different concepts for expressing situation awareness and design concepts for testing the amount of necessary information to increase trust.

(Kooij et al., 2018) outlines the challenges to be solved before autonomous shipping can be implemented. The main challenges identified are maneuvering, situation awareness, communication, and safety.

(Porathe, 2018) argues for transmitting that the ship is autonomous to the outside world. Methods for displaying automation transparency for non-SOLAS vessels are presented. Lights that only are visible if the vessel is detected, a smartphone app used for communicating from non-SOLAS to autonomous ship, a web portal, and lights showing the intentions of the autonomous ship are given as examples of automation transparency. Finally, (Namgung et al., 2018) illustrates message handling procedures for collision avoidance between autonomous ships and conventional ships. The conventional fuzzy inference system is used to assess collision risk. The target ship is alerted if the risk factor is above a predefined threshold.

(Porathe, 2019), (Porathe and Rødseth, 2019) discusses the challenges of collision avoidance algorithms with regard to the human interpretation of the maritime navigation rules; examples are "early" and "substantial". E-Navigation solutions, route exchange, and intended routes are examples of ship traffic management concepts presented. Methods for displaying automation transparency on ECDIS are shown, as well as a summary of an international project focusing on coordinating ship traffic.

(Kristoffersen, 2020) presents five guidelines for increasing the operator's situation awareness in the shore control center. The basis for the guidelines is human-centered design methods, where the goal is to reduce human errors in complex systems.

(Ramos et al., 2020) introduce a framework for Human-System Interaction in Autonomy (H-SIA) for evaluating autonomous ships. (Huang et al., 2020) gives a summary of existing modes of human-machine interaction (HMI) for collision avoidance in the maritime domain and presents a framework of the HMI-oriented Collision Avoidance System (HMI-CAS).

(Veitch and Alsos, 2021) defines the "human-centered Explainable Artificial Intelligence (XAI)" concept. Their objectives are to expand the agenda of readability, understandability, and trust for interactions between autonomous vessels and non-expert end-users. (Porathe, 2021d) is concerned that Artificial Intelligence (AI) maneuvering could be counter-intuitive to nearby vessels. Different interaction designs and solutions are discussed with the enhancement of transparency to overcome this issue.

(Rødseth et al., 2021) provides a classification of primary causes that may arise between the interaction between autonomous ships and conventional ships. Finally, solutions for reducing the problems are proposed. This paper's motivation is the unexpected behaviors that can occur with autonomous ships.

(Porathe, 2021c) presents sketches for an autonomous passenger ferry designed in Norway, AutoFerry. Human factors regarding communicating intentions to other vessels, designing the shore control room, and interactions with the passengers with consideration of trust are discussed with proposed solutions.

(Han et al., 2022) identifies approaches for developing transparent systems for overcoming the challenges of human and machine interaction in the maritime transportation industry. Their suggestions display explicit information to the shore control center of the engine room.

(Alsos et al., 2022) focus on how MASS can express its state to the environment and perceive the state and intentions of nearby vessels. Existing communication methods are analyzed, and design recommendations for future MASS development are presented.

(Liu et al., 2022) predicts the errors in autonomous ships caused by a human-machine interface (HMI) to develop safer ships for the future.

1.3 Thesis outline

This thesis is divided into eight chapters. Chapter 2 describes the relevant background information. Chapter 3 presents the two case studies, where one is for passengers, and the other is for leisure vessels. Chapter 4 describes the process from research to implementation to the final design of the eHMI concepts. Chapter 5 evaluate the test results from the user test. Chapter 6 discuss the findings and answer the research questions defined in the problem description. Chapter 7 contains the conclusion and chapter 8 provides future work recommendations.

Chapter 2

Background Theory

This chapter will provide the relevant background information in this thesis. The chapter begins with an introduction of situation awareness and decision making. Then the term automation and automation transparency are described. The chapter continues with historical, current and future technology for enabling communications at sea. How to make human centered design is revised. Finally, the main technology used in this thesis, Virtual Reality (VR) is described.

2.1 Situation awareness

The formal definition of situation awareness (SA) is "situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (M. R. Endsley and Kiris, 1995). The human brain goes through three stages to achieve situation awareness:

1. Perception of the elements in the environment: Humans use their senses and machines use their sensors to register and measure the relevant parameters in the environment. Example; observe the current speed of a car.
2. Comprehension of the current situation: Putting the information in a context and understanding how the perception of elements affects the task trying to be achieved. Example; check if the current speed is within the range of acceptable speed.
3. Projection of future states. Predict how the information will affect the situation for short-term and long-term. Example; understand how the speed will affect the car and predicts how possible problems can be solved.

Figure 2.1 shows the relationship between SA, decision-making, workload and performance. The quality of the SA is affected by the person's characteristics, experience, preconceptions, workload and objectives. In a complex and dynamic environment, the decision is based on the foundation of how the current situation is understood and how the states of the situation will change in the near future. Decision-making is therefore dependent on situation awareness to make the cor-

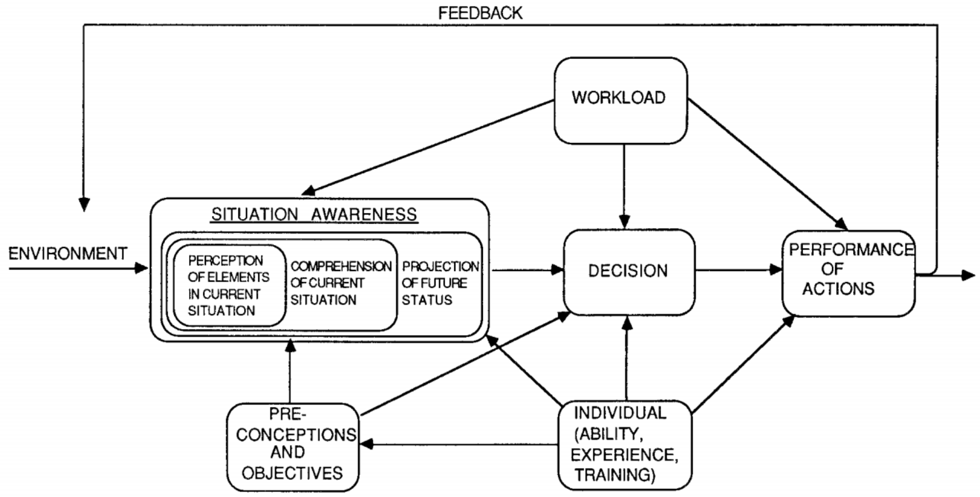

Figure 2.1: Decision model (M. R. Endsley and Kiris, 1995).

rect decision, but it is important to be clear of the differences. A person can can make the wrong decision because of inaccurate SA. On the other hand good SA does not mean that the correct action is obvious. Most problems with SA occurs in stage 1, where the cause could be that the right information is not provided, information is forgotten or key information is not detected (M. Endsley, 2012).

2.1.1 SAGAT

One of the parameters for validating successful automation is the the degree of Situational Awareness (SA) (Parasuraman et al., 2000). There are multiple tools for testing and evaluating the degree of SA. A popular tool is the Situation Awareness Global Assessment Technique (SAGAT). SAGAT was original designed to evaluate which pilot vehicle interface design performed the best for air-to-air fighter missions, but has in later years been changed to be more general (M. R. Endsley and Kiris, 1995). The work flow of SAGAT is that the simulation is freezed at random times and than the test person needs to answers a set of random questionnaires. The reason for the random freezes are to overcome the limitations with work-load, memory and re-construction (SkyBrary, 2022). The participant's answers are than compared with the current SA requirement and evaluated. The main disadvantage is the multiple stops to answers questions. The advantages of SAGAT are the following(M. R. Endsley and Kiris, 1995):

- Provide current "snapshot" of the mental model.
- Global measure of SA by looking at all the SA requirements.
- Directly measures the knowledge of the situation.
- Objectively collected and objectively analysed.

2.2 Decision-making

It is important to understand how the process of decision-making works to learn why humans make errors and to avoid these in the future.

2.2.1 The way of thinking

Humans have two separate decision approaches; inductive and analytic. These are similar to the two decision systems defined by (Kahneman, 2011):

1. Intuitive and fast. Most of the thinking is done here. The actions are made of our first impression.
2. Analytical and slow: This system is active if something unexpected happens or a task demands critical and analytical thinking.

Both of the system operate at the same time and work together. System 1 feeds system 2 with information of the current status and future intentions. If the arise an issue for system 1 which can't be solved automatically, system 2 is activated. Generally is system 1 successful, but is prone to biases and making decisions based on experience, assumptions and tries to make an explanation of what is going on quickly. This can lead to a jump in conclusions, "(...) it automatically and effortlessly identifies causal connections between events, sometimes even the connections is spurious" (Kahneman, 2011).

System 1 has potential errors because of:

- Too much trust in small data sets.
- Natural looking for an explanation to a random event.
- Too much confident in their own understanding.
- Prone for retrospects and biases.
- Looking for explanation which confirm their belief.
- Too much trust in themselves and to optimistic.

This could explain why people perceives the same event differently and taking to fast decisions instead of analyzing the situation thoroughly.

2.2.2 Decision process

The decision process for how humans make decisions can be described by four steps according to John Boyd: Observe, orient, decide and act. These steps repeats it selves and is named the OODA loop, shown in figure 2.2. It has it origin from research on American fighter pilots, but is applicable in modern events on both individual and group level (Lewis, 2022). The OODA loop is a continuous and iterative feedback model and is a popular decision-making framework (Luft, 2020). The OODA problem-solving method starts by observing and identify the situation to gain an understanding of the environment. The orient step takes the information gathered and put it in context. It is highly dependable on situation awareness (SA) and is often done by making mental models. A mental model is the thought process on how the physical world works (Wikipedia, 2022b). The decide phase is where the actions are planned. Finally, the planned actions are executed in the act phase. Than the process repeats itself. Even though the OODA loop seems like a simple model, the original model is less linear and is a cybernetic process with multiple feedback loops, where the four steps are not isolated from each other (Luft, 2020).

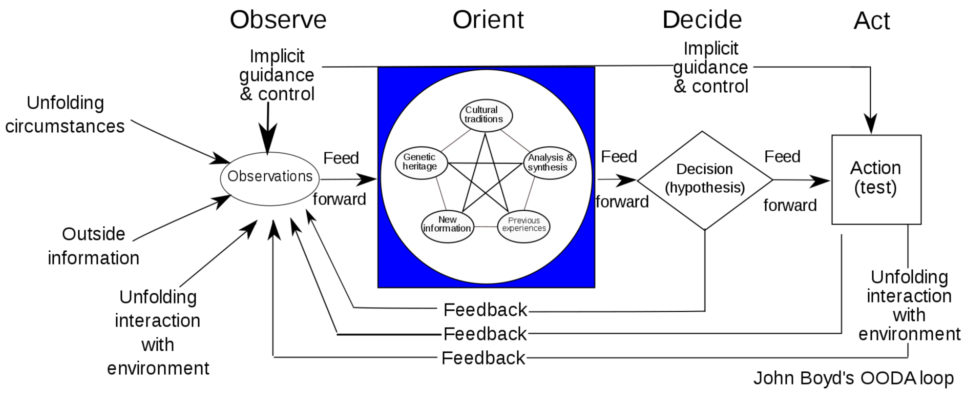

Figure 2.2: OODA loop (Wikipedia, 2022c)

Another problem-solving method is the Situation Awareness-Decide-Act (SADA) loop which has many similarities with the OODA loop. The SADA loop, shown in figure 2.3, is also an iterative feedback model, but where the steps observe and orient are merged together to a situation awareness block. The SA is understood in 3 steps as described in section 2.1. Then decision is made from multiple options and is activated on the environment. Than the process repeats itself.

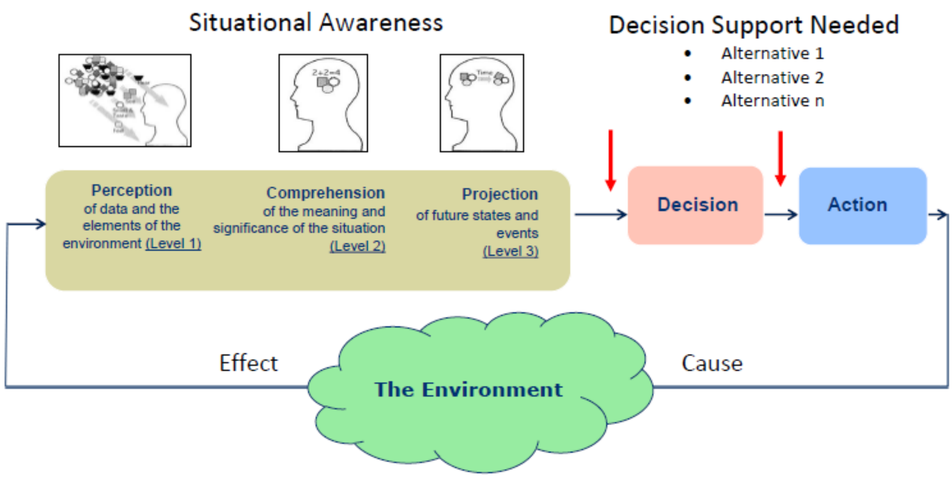

Figure 2.3: SADA loop (Hukkelås, 2021)

2.3 Automation

Automation is defined as the tasks that was previously solved by humans, but are now solved by technology (Madhavan and Wiegmann, 2007). Another definition of automation is technology that actively selects data, transforms information, makes decisions and control processes (Lee and See, 2004). The use of automation can replace human repetitive tasks, process large amount of data and accomplish assignments humans are not physical capable to accomplish (Adams et al., 2003). Autonomous vehicles will work by the steps: Sense, plan and act, then the process will repeat itself (Hukkelås, 2021).

Person(s) operating the automation system can become "out-of-the-loop". The phrase "out-of-the-loop" means the person operating the system is unable to take over the control over the system if an automation failure happens (M. R. Endsley and Kiris, 1995). It is important to keep the humans in the loop by giving them an active role. In many systems the machine has replaced the operator in the situation awareness block, and the machine is responsible for observing (with sensors), deciding (compute) and interacting (effectors) with the environment. If the automatic system fails, the human operator supervising the the automatic system needs to be able to take over control over the system in short amount of time. The human role becomes more important as the system gets more autonomous. This is known as the paradox of automaton. To avoid this, it is important to always keep the humans in control. According to the Yerkes-Dodson law, it is crucial to tune the operator's workload correctly for optimal performance of the system.

2.3.1 Degree of autonomy

Autonomous ships is defined as vessels over 15 meters with its own propulsion and navigation system, where automation controls the ship without human intervention (Rødseths and Nordahl, 2017). The ship autonomy types are decided by the operational autonomy level and bridge manning levels. The autonomous ship types is divided into unmanned underwater vehicles (UUVs) and autonomous surface vehicles (ASVs). In this thesis the focus will be on the subgroup of ASVs, maritime autonomous surface ship (MASS). MASS is divided into four different autonomy levels: Decision support, automatic, constrained autonomous and fully autonomous. The bridge manning levels can be divided into three levels: Manned bridge, Unmanned bridge - crew onboard and unmanned bridge - no crew on ship. By combining the manning levels with the autonomy levels the degree of autonomy is defined in figure 2.4.

2.3.2 Transparency

Transparency is defined as seeing into or through a system (Ososky et al., 2014). Automation transparency makes the process of how the technology works available to the outside world. The end user can understand how the system works and

Operational autonomy levels

Bridge manning levels

	Decision support	Automatic	Constrained autonomous	Fully autonomous
Manned bridge	Direct control	Automatic bridge	-	-
Unmanned bridge – crew on board	Remote control	Automatic ship	Contstrained autonomous	-
Unmanned bridge – no crew on board	Remote control	Automatic ship	Constrained autonomous	Fully autonomous

Figure 2.4: Levels of automation for marine surface vehicles. Inspired by (Rødseths and Nordahl, 2017).

enhance the process of using it. The overtrust the end user can have in a automation system is prevented with transparency as the knowledge level of the machine works correctly can be observed (Lyons, 2013).

Automation transparency can be divided into two parts; situation awareness (defined in section 2.1) and Robot-to-Human Transparency. Robot-to-Human Transparency is that the automation shares the insights of the performance, planned actions and awareness. To share the world view from the robot's perspective, four different models are necessary (Lyons, 2013):

1. Intentional model: For the user to understand the reason for the robot's actions, it is important to know the purpose and intentions in a higher-level context. The model is more complex than only sharing *why* it operates in a particular way. Instead the model should represent the design, purpose, and intent of the system.
2. Task model: The task model gives detailed information of actions, goals, progress, awareness and capabilities. The robot communicates the situation awareness to the human which creates a shared awareness framework.
3. Analytical model: The robot has the capability to process and analyze large amount of data which often exceed human capabilities. The task model shares the underlying principles in the analytical process.
4. Environment model: To further enhance the situation awareness of the human, the robot should share constraints and understanding of the environmental.

(Lyons, 2013) is concerned in what way and how to enable this information without causing information overload for the user. If the raw data is displayed without any filtering, the time it takes to understand and analyze the data can work against its purpose. There need to be further researched on how to show cast this information as their is no standardized way of making a system transparent (Fleischmann and Wallace, 2005).

The complexions in the machine models as well as the complex rule system can make it hard for the end user to grasp the displayed information (Lim et al., 2009). Therefore fine tuning of what kind of information and how to display the information is necessary. (Lim et al., 2009) concluded that explanation on why the system behaved in a certain way gave better understanding, but trying to explain why the system is *not* working in certain way resulted in confusion and lower understanding.

The positive consequences of automation transparency are the increase in acceptance rate, because of better insight in the system (Herlocker et al., 2000). It is tempting to think that transparency is always helpful, but transparency is *only* successful if it is designed effectively (Bunt et al., 2012).

2.3.3 Trust

Trust is defined as the trustor's willingness to be vulnerable to a trustee's actions, expecting that the trustee will act in a way important to the trustor (Mayer, Davis et al., 1995). The aspects which influence trustworthiness are experienced capability, goodwill and integrity (Mayer and Davids, 1999).

The trust human have in machines are defined by the extent to which an user is confident in, and willing to act on the basis of the recommendations, actions, and decisions of an artificially intelligent decision aid (Madsen and Gregor, 2000). The trust includes the confidence and willingness to act on the system's conclusions. The confidence and willingness will for each person have individual differences and depend on experience, risk, skill set, personal traits and that the mental model coincides with the actions from the automation system.

The model for Human-computer trust can be divided into cognition-based trust and affect-based trust (Madsen and Gregor, 2000). Cognition-based trust is a rational assessment and the willingness to act is based on perceived understandability, perceived technical competence and perceived reliability. Affected-based trust is feeling of emotional fondness and is based on personal attachment and faith.

The trust in automation resembles the trust humans have to each other (Nass et al., 1996). To best quantify trust there should be situations which consists of both uncertainty and vulnerability, where the user compare expectations with actions made by the automation system. A three-dimensional model of trust consists of (Lee and See, 2004):

1. Performance: The user's goal is fulfilled by the system.
2. Process: The system is able to complete its task in the given situational context.
3. Purpose: The intention of the system is achieved.

The level of trust is dynamic: "Maintaining trust is critical, since it is potentially harder to gain, easier to loose and even more difficult to recover when lost" (Atoyan and Shahbazian, 2007). The degree of trust humans have in automation can influence the usage (Lee and See, 2004). When humans trust more in the system than in them selves, over trust can occur. The consequences are automation bias (prefer recommendations from the automated decision-making system over other information sources), automation failures and automation misuse (Mosier et al., 1999). On the other side can to low trust in automation cause reduced use of the automation technology, where manual control replace automation control. Therefore an appropriate calibrating of trust is important. The users trust are better calibrated if the inner working of the systems are understood (Wang et al., 2011).

Testing for trust

There are mainly two methods for testing for trust in automation: Objective and subjective tests. Objectively tests observe the test user with numeric scales, frequency of actions, heart rhythm and other objective measurements. In subjective tests, the test user takes an active role and answer questionnaires, rating scales and write down their thoughts and comments. A famous method for testing trust between people and automation is developed by (Jian et al., 2000) where the foundations for empirically determined scale are defined. The checklist used for testing trust is found in appendix A.

The relationship between transparency and trust is interesting. For example investigated (Verberne et al., 2012) the correlation of trust and acceptance rating in adaptive cruse control (ACC) systems with respect to different automation levels. Automation is divided into six levels: No driving automation (level 0), driver assistance (level 1), partial driving automation (level 2), conditional driving automation (level 3), high driving (level 4) Automation) and full driving automation (level 5) (Synopsys, 2022). The automation level of fully autonomous ships (level 4 and 5) and ACC (level 2 and 3) are different, but the study regardless gave indications of the relationship between trust and transparency in fully autonomous vehicles. (Verberne et al., 2012) compared ACC systems which displayed information about driving task with ACC which did not. The ACC system which were transparent gained higher trust and acceptance among the test persons. The transparent ACC system scored higher in trustworthiness in situations were no actions were needed, but nevertheless information of the situation awareness were displayed. (Beller et al., 2013) investigated also how trust for ACC were affected when the ACC performed insufficient in self-driving mode. The ACC indicated to what extent the planned actions were insufficient by displaying warnings with uncertainty indicators. The ACCs which gave uncertainty warnings scored higher in subjective trust than ACCs without warnings.

2.3.4 Beware of the unexpected

There are a lot of criticism that replacing human drivers with automation are to optimistic and will not perform as well as intended. Even though the automation may reduce the human collision factors it is possible that it will introduce new type of errors causing dangerous situations. David Lorge Parnas (early pioneer in software development) described the difficulties of develop new technology: "As a rule, software systems do not work well until they have been used, and have failed repeatedly, in real applications." Even though systems have been thoroughly tested, it is very hard to completely exclude faults in the system. James Reason's Swiss Cheese Model emphasizes that a system with multiple safety barriers can never be completely safe because of possible weaknesses in the series of barriers, just like holes in Swiss cheese slices. Automated systems have a hard time dealing with inconsistent behavior which often occur with human drivers (mcKinsey Digital, 2016). For example do many conventional ship not comply to COLREGS. This represents a challenge to the technology as it can not be rule-based, but instead have to adapt to each situation which is much more complicate.

2.4 Exchange of information at sea

From its early days of transporting people and goods, communication has been key to travel safely. Poor communication can be the leading cause for accidents to happen. It is therefore important to transmit information clearly without any chances for misunderstanding. Semaphore systems were the first method to convey information over long distances by using visual signals such as flags, rods and hands. Radio and newer technology has replaced visual signals, but semaphore systems are still used during underway replenishment and emergency situations (Wikipedia, 2022a). Communication by radio is not trouble free because of vessels often travel outside terrestrial network ranges which can lead to information getting lost. The information exchange needs to be standardized to avoid misunderstandings. The IMO Standard Marine Communication Phrases (SMCP) are made for the purpose of decreasing misunderstandings due to language barriers (Pinpoint, 2022).

2.4.1 Communication

Very High Frequency (VHF) radio and Automatic Identification System (AIS) are the basis of ship-to-ship and ship-to-shore communication at sea today. The task of the Vessel Traffic Service (VTS) is to coordinate ships in congested waters to avoid collisions and groundings. The VTS uses AIS data with electronic navigational chart to understand the situation and communicate the recommended actions of control over VHF radio. For ship-to-ship communication, VHF radio are used to communicate to each other. The challenges with verbal commutation are the language barriers as well as the bandwidth can be limited in congested waters which may cause low quality (Akdağ et al., 2022). The standard solution to the challenge are to communicates its intentions to other vessels by changing course and speed according to COLREGS rule 8 (b): "A change in speed and/or course must be large enough to be observed visually or by radar" (IMO, 1972).

AIS is designed to work within the VHF bandwidth and is a tool for increasing situation awareness to avoid collisions. The International Convention for the Safety of Life at Sea (SOLAS) has determined that all vessels over 300 tons must be equipped with an AIS class A transponder and for smaller vessels it is optional to be equipped with an AIS class B transponder. The difference between class A transponder and class B transponder are the frequency of transmitted data (Akdağ et al., 2022):

- Class A transponder: Transmits dynamic data every 2-10 seconds and static data every 3 minutes underway and every 6 minutes when anchored.
- Class B transponder: Transmits only when the transmission slot is available, which can cause low frequency of transmitting in congested waters.

It is not recommended to solely navigate after AIS data as it is prone for hacking and could consist of outdated information. Instead it should be used as a guidance simultaneous with other information sources (BigOceanData, 2022).

2.4.2 Data exchange

The original idea of VHF mobile band was verbal communication, but has in later years been extended with designated data transmission channels. The AIS messages use these channels which may cause problems due to the widely use of AIS systems as the VHF mobile band is not intended for such large amount of data in these channels. This has led to congestion of data and therefore has the VHF Data Exchange system (VDES) been developed to solve this issue (IALA, 2019).

VDES consist of two sub modules: Application Specific Messages (ASM) and VHF Data Exchange (VDE). The ASM channels transfer standardized messages and takes away the burden of VHF mobile channels the AIS system original used. VDE enables high speed transfer and is safer to use because of the included integrity checks system (IALA, 2019).

2.4.3 Route exchange

IMO launched the concept of *e-navigation* to apply the opportunities new technology enables for enhance safety and efficiency, while cutting down on the administrative work load. IMO defines e-navigation as "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment". The goal of e-navigation is to enhance the digital advantages to the marine shipping industry. It is based on the present and future user needs by unite different navigation and shore system to make maneuvering simpler and more efficient (IMO, 2018).

Route exchange is a concept in e-navigation where the idea is to replace verbal communication with broadcasting waypoint and intentions through digital aids. The route exchange file consists of standard information about the planned route, waypoints, legs, turn radius and planned actions (Akdağ et al., 2022). Route exchange can be divided into two parts (Porathe, Lützhöft et al., 2012):

- Tactical route exchange: Only broadcast a few waypoints ahead to reduce the risk of collision for navigating safely. The usage is meant for ship-to-ship

  and ship-to-shore communication.
- Strategic route exchange: Broadcasting all waypoints from the entire voyage plan. The usage is only meant for ship-to-shore communication because of voyage plans may contain classified information.

E-navigation and route exchange has been tested out in bridge simulators. The operators found it confusing to see the ship's position and intentions simultaneously. Instead it was recommend to make it optional to display the route exchange information on the Electronic Chart Display and Information System (ECDIS) (IMO, 2015). The confusion this added information operators had to deal with made route exchange not suitable in close encounters (Porathe, 2015). Instead the Sea Traffic Management (STM) recommend to use route exchange plan route alternatives ahead of time before close encounters become an issue (Akdağ et al., 2022). Another consequences of route exchange was that it influenced the decision making. The operators did not follow COLREGS as often as they used to when information from route exchange was available (Lindborg et al., 2019).

2.5 User-centered design

User-Centered Design (UCD) is defined by the International Organization for Standardization (ISO) with its own standard, 9241-210:2019. UCD is a design process for developing new systems where the main focus is on the users. The users requirements and needs are taken care of by considering human factors, usability knowledge and techniques while developing new systems (ISO, 2019). There are four main activities in designing iterative UCD systems.

1. Understand the context of use.
2. Define user requirements.
3. Develop design solution.
4. Evaluate the design solution.
5. The team should consist of team members with different skills and backgrounds

UCD can seems as the natural design process when developing new systems, but often developing is focused on technology rather than humans. The abilities with with new technology and the search for how this technology can be implemented in existing system has given an increase in information where the human operators try to keep up with. People's attention span is limited and to much information could be overwhelming. It is therefore not necessary true that increase in data equals increase in information. UCD tries to solve this *information gap* with better system designs. The available information need to be precisely tuned which is challenging (M. Endsley, 2012). It is natural to think that more automation lower the risk for human errors, but the consequences have instead been increase in complexity and cognitive load which has led to loss in situation awareness with serious consequences (M. R. Endsley and Kiris, 1995). To better understand how to design for UCD, a start is to exclude what is *not* UCD (M. Endsley, 2012):

- Ask the users and give them what they want: Users have trouble being creative and often recommend solutions are based on past experiences. “If I had asked people what they wanted, they would have said faster horses.” - Henry Ford. Their abilities of how to design information in an informing design is limited for a complex system.
- Only display the exact information when needed: The challenge of displaying just the information needed has been proven to be difficult in a dynamic system. The task and goals often change during the session. The desired information depends on the situation and the user will have a hard time keeping up with the consistently change in available information. Another issue is the preparing for future scenarios is lost.
- The system controlling the decision for the user: Research has concluded that systems advising actions for the humans have not given an increase in performance.
- Take over for the user: This will lead to the "out-of-the-loop" issue which should be avoided.

The goal of UCD is to create more effective systems and make the systems on human premises. This can be achieved by following these principles when developing new systems (M. Endsley, 2012):

- Focus on the user’s goals, tasks and abilities.
- The human way of processing and making decisions should be the basis of the technology.
- The user shall stay in control and know the status of the system at given time.

UCD has design principles standardized by ISO. The following key principles for UCD are (NIST, 2021):

- Based on the understanding of the user, user’s task and the environment
- Throughout the design process, the user has an active role and is participating in development phase.
- The current solutions are evaluated by the user and changed accordingly.
- The execution is iterative.
- The user is the main focus for every stage of development

2.5.1 Design method

The user interface design process consist of different blocks: Requirements definition, technology analysis, system design, development, integration and testing. Depending on the overall system development life cycle, these blocks could be separated or overlapped given for example the waterfall model of design, concurrent engineering model or the spiral design process (M. Endsley, 2012). The situation awareness (SA) is the basis for user-centered design and interface design blocks can be sorted within SA shown in figure 2.5. For a system which shall be within a dynamic environment, the SA is the key for decision making and performance.

This is explained by SA is goal oriented, supports the cognitive process of the user and the user is in control.

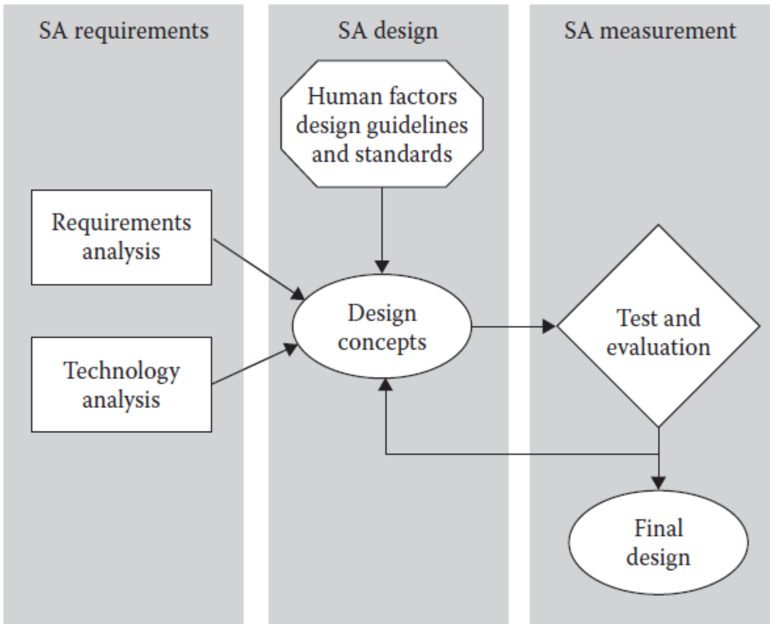

Figure 2.5: User interface design process (M. Endsley, 2012).

2.5.2 eHMI

The maritime domain will in the future, consist of both conventional ships and maritime autonomous surface ships (MASS), which will share the same space. These stakeholders need to communicate with each other. External human-machine interface (eHMI) may play an active role for them to coexist in the same environment. eHMI enables communication between conventional ships and MASS which is crucial in decision-making. The automotive industry has been testing autonomous cars for years in conventional traffic, resulting in a comprehensive eHMI framework for cars.

Communication can either be implicit or explicit. Implicit communication is information understood by the receiving part which is not extensively expressed. The opposite is explicit communication, where the information is expressed intentionally. The main challenge with the introduction of autonomous vehicles is the interaction between the agents in the traffic (Tabone et al., 2021). In the maritime domain, there are different methods to communicate with each other depending on the types of vessels shown in figure 2.6, where the communication methods vary in range and characteristics.

eHMI can improve the interaction and collaboration between man and machine. It is a general belief that eHMI will improve trust in automated vehicles and the sense of security and make it clearer to understand the intentions of

	Non-SOLAS vessels		SOLAS vessels		MASS today	
	Perceive	Express	Perceive	Express	Perceive	Express
Shouting	•	•	•	•		
Hand movements	•	•	•	•		
Day shapes			•	•		
Flag signals			•	•		
Searchlights	•		•	•		
Ship horn	•	•	•	•		
Navigation lights	•	•	•	•		
Daylight signalling lamp			•	•		
Ship movement (visual)	•	•	•	•	•	•
Radio (VHF)	•	•	•	•		
AIS (VHF)			•	•	•	•
Ship movement (radar)		•	•	•	•	•
Radio (MF/HF)			•	•		
AIS (Satellite)			•	•	•	•
VDES			•	•	•	•
Satellite phone			•	•		

Figure 2.6: Ship-to-ship communication for different types of vessels (Alsos et al., 2022).

automated vehicles (Ortega, 2022). In the automotive industry, the pedestrians preferred a signal to know if the car was in autonomous mode and its intentions (S. M. Faas et al., 2021). In general, automation transparency can be communicated openly or addressed individually. Communicating only to individuals has its pros, but because communicating openly (broadcasting) is easy to scale up, it is the preferred method. The broadcasted messages should be restricted to the status and intentions of the vehicle (Dey et al., 2020). The communication methods can be sorted by the characteristics: Analog, digital, broadcast, direct, continuous and occasional and the range varies from 0.05 NM to global distances (Alsos et al., 2022).

The messages broadcasted by the autonomous vehicle can be divided into two categories based on the communicated information. Firstly, allocentric messages communicate information about the environment to other agents. The message can be either advisable or contain situation awareness data (Dey et al., 2020). Example of MASS communicating advice to other vessels nearby: "I have the right of way." An example of situation awareness could be " I have seen you." Secondly, egocentric messages where the message contains data of the ship itself. The data could communicate information about the status or current action intentions. Example of status message: Current course over ground is 22 degrees, and current speed over ground is 20 knots. Example of current action message: Overtaking vessel on the starboard side. Example of intention message: "I will decrease my speed." The essential type of message is to communicate situation awareness, state, and intentions for autonomous vehicles (Ortega, 2022).

2.6 Virtual reality

Virtual Reality (VR) is a real-time 3D simulation where the user interacts with the environment visually and through haptic feedback. There are three ways of displaying these environments: Handheld, projection, and Head-Mounted Display (HMD). For this thesis, only HDMs will be considered. The HMDs track the user's position, speed, angle, and rotation with sensors (gyroscope, accelerometer, and magnetometer) which creates an immersive experience for the user with the feeling of being present in the digital environment (Lowood, 2022).

VR is great for simulating real-life activities, which may be dangerous, expensive, and physically demanding in the real world. Through computer modeling, the VR environment can be made very realistic. This gives possibilities to train or experience real-life situations with both reduced risk and costs. In addition, the technology can be used as a training tool for improving skills in various professions. For example, researched Elinor Clarke if VR simulation could be the future of orthopedic training. The conclusion was that the trainees gained confidence and skills with immersive training with the modern teaching tool. However, there is still a need for further investigation on the long-term effects to determine if the skills are transferable to actual surgeries (Clarke, 2021).

VR is commercially available today, and numerous companies are developing their own HMDs. The technology has taken significant steps recently; the cost has been reduced, the battery time increased, and the equipment to set up the system has been simplified, making VR more accessible. The VR system consists mainly of three parts:

1. Input device
2. VR engine
3. Output device

The inputs are the user's position, angle, rotation, and button presses from the handheld controllers. The VR engine calculates the rendered 3D environment, and the environment is updated and displayed by the HDM where the user experience is changed in visuals, audio, and haptic (requires handheld controllers). The visual updates are displayed on a separate screen for each eye to create the effect of depth. The realism experience is dependent on the resolution, refresh rate, and field of view. The higher the resolution, the more pixels are displayed for the user, enhancing the details in-game experience. The refresh rate is how often the frame is updated per second. It is recommended that the refresh rate is at least 90 Hz to avoid motion sickness. The field of view (FOV) is the angle of how wide the user can see in the digital environment. The FOV varies from 89 degrees to 135 degrees in today's models (RoundtableLearning, 2022). For developing VR, there are mainly three game engines (software frameworks for developing games): Unity, Unreal Engine, and Cryengine. They are all capable of developing complex VR programs and are used widely in the industry.

Chapter 3

Case studies

The research approach taken in this thesis is based on the research questions in the problem description chapter.

In the maritime domain, multiple stakeholders are interacting with the MASS, which all have different requirements for automation transparency (Veitch and Alsos, 2021). The stakeholders can be split into groups:

1. Developer
2. Operator
3. Crew
4. Passengers
5. Non-SOLAS vessels
6. SOLAS vessels

There will be two different case studies in this thesis, where each consists of an autonomous ferry traveling in Trondheim, Norway. The case studies share many similarities but have different focus areas that embrace the multiple challenges in a broader aspect. Unforeseen events like fire, passenger overboard, collision and software/communication systems not working as intended are beyond the scope of the case studies.

The first one is for the passenger's stakeholder group. The case study will be on the interaction between an autonomous ferry and the passengers onboard. For the second case study, the non-SOLAS vessels are the scope. Here, the interaction between the autonomous ferry and conventional vessels will be researched. This research field is usually technology-driven (Porathe, 2021c), but the approach in this thesis will be on human factors.

3.1 Passengers

This case study will consist of ferry crossing under normal conditions. The challenge is to research if it is possible to make the passengers feel as safe with an operator in the shore control center as with a crew and a captain onboard. The interaction between the passenger and the technical system onboard the autonomous vessel needs to be intuitive and straightforward and should not be based on the passenger's amount of boat experience. There is little research on how to design user interfaces for the passengers as there are no operational autonomous ships transporting passengers, but earlier research on human-machine interfaces serves as inspiration.

Stakeholder	Passenger
Navigation experience	Minimum knowledge of COLREGS
Role	Passive. No actions are demanded
Goal	Feel safe and relaxed
Transparency requirements	Intuitive and enough information to built trust

Table 3.1: Case study overview for passengers

3.1.1 MilliAmpere2

In 2021 in Trondheim, Norway, a new research center for innovation of maritime vessels was founded. The goal is to develop new innovative, and creative technology for maritime purposes. One of these projects is the AutoFerry project which started back in 2018. The project aims to make the first autonomous urban passenger ferry. Furthermore, it serves as an ultimate tool for students, Ph.D. students, and industry partners to test and gain experience for the future of maritime transportation.

The AutoFerry project has so far developed two versions of the ferry. The latest version is called MilliAmpere2 and is a small electric ferry. It is 8.45 meters in length, 3.5 meters wide, and has capacity of 12 people shown in figure 3.1. The distance MilliAmpere2 will travel is from Ravnkloa to Vestre Kanalkai, approximately 100 meters long (figure 3.2), and the voyage will be completed within 1 minute with an average speed of 3 knots (Porathe, 2021c).

Figure 3.1: Model of MilliAmpere2 (Veitch and Alsos, 2021)

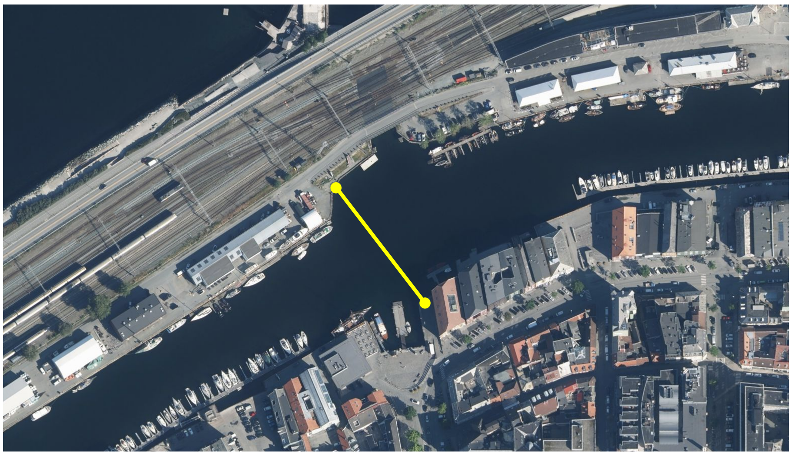

Figure 3.2: 100 meter long crossing over the canal

This sounds like a simple procedure, but the crossings have multiple challenges. The boat traffic in the canal consists primarily of vessels without an AIS transponder. In the summertime, the canal is popular for leisure vessels and tourists renting kayaks, where one can assume that they have little knowledge of COLREGS. MilliAmpere2 must be equipped with different sensors, cameras, and lidars to detect these vessels to take appropriate actions. The ferry is a constrained autonomous vessel, which means an operator on land will monitor the ferry and take over control manually if necessary. The passengers onboard and conventional vessels nearby can communicate with the operator through a microphone, speakers, and VHF radio (Porathe, 2021c). With MilliAmpere2, it is possible to test if human-centered design and automation transparency can build trust for the passengers.

3.2 Non-SOLAS

The motivation for researching the interaction between MASS and non-SOLAS ships is the lack of research in this field (Porathe, 2021a). Non-SOLAS vessels, compared to SOLAS vessels, are often smaller in size, have less experience crew, and do not have the extensive training as professional mariners. They can be simple leisure vessels such as kayaks, sailboats, motorboats, and smaller fishing boats.

MASS needs to follow the same regulation as all other vessels - COLREGS, but the use of subsequent changes in speed and course are not always enough to solve the situation (Rutledal et al., 2020). As for all other ships, non-SOLAS ships need to be able to interpret the intention of other vessels to avoid dangerous situations but do not have the same technological assistance in decision-making as SOLAS ships. SOLAS ships can for example, communicate to other ships with: Day shapes, flag signals, searchlights, daylight signaling lamps, AIS (VHF), radio (MF/HF), AIS (satellite), VDES, and satellite phone. None of these assistive communication devices are available for non-SOLAS ships, see figure 2.6 for a complete overview.

Stakeholder	non-SOLAS
Navigation experience	Familiar with COLREGS
Role	Road user. Share the navigation space
Goal	Avoid collision and grounding
Transparency requirements	Information to aid in decision-making

Table 3.2: Case study overview for non-SOLAS ships

3.2.1 Leisure boat

The next version of MilliAmpere2 and the potential world's first autonomous cargo ship, Yara Birkeland, inspires how the future of automation maritime transportation can look. In this case, a futuristic autonomous ferry will interact with other vessels and be able to perform ship-to-ship communication with non-SOLAS vessels even though there is no crew onboard the ferry. Today's ship-to-ship communication methods like shouting, hand movements, ship horn, and radio (VHF) will not work with autonomous vessels. Innovation and rethinking are necessary for conventional and autonomous ships to interact seamlessly with each other.

To illustrate this challenge, a case study of how a leisure boat can receive status and intentions from an autonomous ferry is researched. The scenario takes place near the coast of Trondheim, shown in figure 3.3, where the traffic consists of kayaks, sailboats, motorboats, but also larger ships like ferries and cruise ships. The ferry used in this case will be fully autonomous and the same size as today's conventional ferries. This case requires a different approach to communicating status and intentions of the MASS to the outside world compared to the case study of MilliAmpere2 (case 1). "The example with the autonomous urban ferry in Trondheim does not scale well for commercial coastal and ocean-going MASS where signage and voice-over loudspeakers cannot be used." (Porathe, 2021d).

There is a need for leisure vessels to receive information of the status and intentions of the autonomous vessel to avoid dangerous situations. From COLREGS rule 16: "Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear." (IMO, 1972). By representing the intentions of MASS to other vessels, they will be able to make decisions earlier with better situation awareness.

Figure 3.3: Route plan for leisure boat

Chapter 4

Concept development

This chapter describes the process from research to implementation to final design. There have been developed concepts for passengers onboard MilliAmpere2 (case 1) and leisure boats navigating nearby a full-scale autonomous ferry (case 2).

Ship movement serves as a good indicator to predict the future position of other vessels. Nevertheless, it has been shown that decisions based on ship movements are prone to errors and misunderstandings (Veitch and Alsos, 2021). The bridge/captain solves this misconception often by communicating with the approaching vessels through radio (VHF) or satellite phone. This can be used with MASS given that the radio communication is transferred to the operator at the shore control center. One problem is that the operator will (probably) monitor multiple MASS at once. Handling multiple radio conversations simultaneously is not possible, which means a ranking system is required. A ranking system will result in vessels waiting in line to get in touch while the situation keeps developing without a solution. The time for taking appropriate actions gets smaller while the vessels wait in line. This is not an ideal solution, especially in constrained waters. Nevertheless, verbally communicating is prone to language barriers and misconceptions. MASS could express status and intentions digitally by adding extra information to the AIS message. IMO requires only vessels over 300 gross tonnes and cargo ships over 500 gross tonnes traveling in international waters to be equipped with an AIS transponder and receiver (BigOceanData, 2022). This would mean many vessels are missing in the AIS tracking system. For non-SOLAS vessels, radio (VHF), satellite phone, or AIS is often not available options, making them excluded from the important systems for collision avoidance. In the future, VDES will play an active role as a communication and navigation platform, but non-SOLAS vessels are not planned to be included as users (IALA, 2022).

In an ideal world, the MASS should be able to communicate and broadcast relevant information to nearby vessels without any requirements of technical equipment onboard.

4.1 Theoretical grounding

In this thesis, there have been performed literature studies where the focus has been automation transparency, maritime autonomous surface ships, human-centered design, human-machine interaction, and trust. In addition, the literature defines the theoretical grounding for the development of designing new eHMI concepts. The section below, describes the findings of existing research of eHMI in the autonomous vehicle domain, mainly in the car industry, because of limited research in other domains.

The use of symbols, text, and color is the most common way to share information with users. These are usually shown on display, screens, and LED strips. Dynamically changing displays gave faster decision time for the user compared to static displays (Wilbrink et al., 2021). There have been numerous studies on how to decide what color to use. No difference was found as long as the color did not conflict with what the user usually associates the color with (given a context). For example, pedestrians waiting to cross the road are used to the green symbol meaning "please go ahead". Conflicting color choices gave longer decision time because of insecurity and a lower level of trust (Hochman et al., 2020). It is interesting to analyze if symbols, text, or color are preferred over the others. Text was found to be the most popular at short distance (Bazilinskyy et al., 2019) and symbols were preferred at a longer distance (Rettenmaier et al., 2020). Text has one main disadvantage, the possible language barrier, as symbols and colors are mostly uniformly designed. One possible solution could be to show the text, symbols, and colors simultaneously, but this can result in the unwanted effect of information overload. Given that eHMI is developed using the human-centered guidelines and used effectively, the users increased their trust and felt safer towards the automation vehicle (S. Faas et al., 2020).

Information from autonomous vehicles can also be given through audio signals. The literature and studies which examined the effect of audio signals as a communication method found that audio had little effect compared to visual communication (symbols, text, and color) (Soares et al., 2021). The different kinds of audio signals did not change how the users perceived the situation or did not help with decision-making (Deb et al., 2020). There is little research on audio used in eHMI, and the only available research found was about pedestrians crossing the road.

The main findings of eHMI for automation vehicles which may be used in the developing eHMI concepts for MASS are as follows:

- Dynamical information is preferred over static.
- Be aware of the risk of information overload.
- Status and intentions are the most requested information.
- Audio signals had little effect.
- Egocentric eHMI solved interactions most effectively.
- The combination of change in text and text color were preferred by the users.

- Text could be a language barrier.

The papers read in the previous section are mainly from urban traffic and have few similarities to the maritime domain. The distances are far greater at sea, and weather conditions are more challenging. The visual communication methods for cars are probably not applicable to ships. Users had highest interest in the vehicles' position, which may also be true for autonomous ships. The MASS should visually indicate the status and intentions because audio signals have limitations at large distances. The expected color, text, and symbols may be transferable to ships. From the reading on previous research in this field, the impression is that there is a lack of eHMI development in the maritime domain, and further research is required, which agrees with the heavily involved professor Thomas Porathe (Porathe, 2021b).

Thomas Porathe and Ole Andreas Alsos (both from the Norwegian University of Science and Technology) have published papers on human-machine interaction in the maritime domain regarding automation transparency for MASS. They address the challenges and possible solutions for how autonomous ships and conventional ships can interact in the future. Table 4.1 gives a summary of the different eHMI concepts they have proposed.

Concept	Type	Users	Equipment	Description
LED sign	Visual	non-SOLAS	None	Suggest next action
LED list	Visual	All	None	Status and intentions
e-navigation	Digital	SOLAS	AIS and ECDIS	Status and intentions
Live chart	Digital	All	Web portal	Status and intentions
App	Digital	non-SOLAS	Phone	Send position to MASS
Signal mast	Visual	All	None	Status and intentions
Augmented reality	Digital	non-SOLAS	Phone	Egocentric navigation
Signalling autonomy	Visual	All	None	Indicate autonomous driving
Moving haven	Digital	SOLAS	AIS and ECDIS	Indicate feature position

Table 4.1: Suggested eHMI concepts from literature

4.2 Pre-survey

With the limitation of research in this field, an online survey has been conducted to learn more about human-machine interaction and automation transparency in the maritime domain. Surveys are great for exploring new research fields in a fast and convenient way compared to face-to-face interviews (Lazar et al., 2010). The goal of the survey was to understand what information boats navigating nearby and passengers onboard MASS require to feel safe and comfortable. In advance were concepts for machine-interfaces defined. The concepts could be changed and adapted easily by getting feedback from the participants early in the design process.

The survey was made using Google forms and consisted of four parts. The first part gave an introduction about the master thesis and the motivation for performing an online survey, the second part was questionnaires about the participant, the third part about being a passenger on an autonomous urban ferry (case study 1), and the fourth part about leisure vessel interacting with MASS (case study 2). In appendix A, the survey (in Norwegian) is attached. The survey consists for the most of multiple-choice questions, grading scale questions, and open-ended questions. All the questions were mandatory, and the participant could not proceed before the question had been answered. The questions were written to be neutral, avoid misinterpretations, and not direct the participant in one direction. Given that the survey required the participant to have boat experience, the survey was posted in twelve different Norwegian Facebook groups for boat interested people. The survey was open and available for all group members, where the objective was to get as many answers as possible.

After the online survey closed, the answers were downloaded to an Excel spreadsheet for data preparation. For every participant, the answers were verified and checked for nonsensical answers. The answers were transformed to a numeric value for questions with text answers. For open-ended questions, it was essential to get the essence of the answer. Once all the answers had been checked, the next step was to analyze the data. The program language Python was used because of the knowledge and experience the undersigned has with the software. There were three pythons packages used for performing the data analysis:

- Pandas: Open-source data analysis tool.
- Numpy: Open-source mathematical functions.
- Matplotlib: Open-source visualizing tool.

There were 106 participants with a gender distribution of 6.6% women and 93.4% men. The level of participants with boat licence was high, 98.1%. The main findings from the online survey is given in section 4.2.1.

4.2.1 Results

Question for case 1	Yes	No	Don't know
Want to know status and intentions of MASS?	54.7%	34.0%	11.3%
Trust is increased given status and intentions of MASS?	59.4%	28.3%	12.3%

Table 4.2: Information needs for passengers

Question for case 2	Yes	No	Don't know
Information needs are higher for MASS?	66.4 %	15 %	18.6 %
Want to know if the ship is autonomous?	84.0 %	8.5 %	7.5 %

Table 4.3: Information needs for leisure vessels nearby MASS

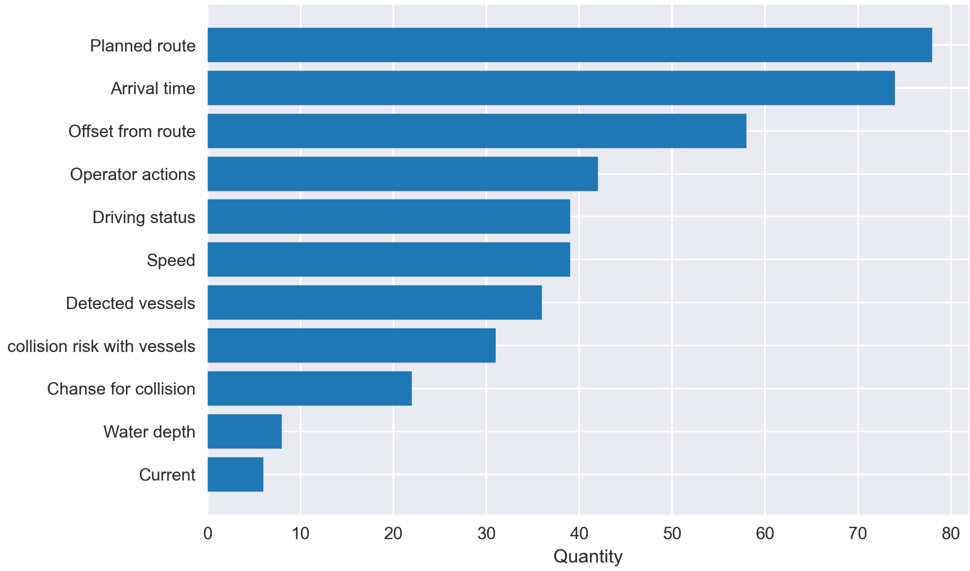

Figure 4.1: Information of interest for passengers

4.2.2 Discussion

As expected the passengers rate general information about the journey the highest, as shown in figure 4.1. This information can be categorized as the "big picture" information and answer the questions of *where are we going?* and *when will we be there?* On the other hand, information of *how the vehicle works?* and *why the vehicle behaves this way?* is of less interest. Information on detail level (chance for collision, water depth, and current) has little value to passengers. This is natural because the passenger's role is passive and has no responsible onboard. The majority wants to know the status and intentions of the MASS and believes that this will increase the trust and comfort level, shown in table 4.2. When analyzing the data, especially the open-ended questions, the participant either had strong information needs or wanted to know as little information as possible. It is challenging to make both parties happy when they strongly disagree. Fine-tuning and "just enough" information are essential to make everyone satisfied. The passenger eHMI concepts were relatively evenly rated, see figure 4.2. The screen concept scored the highest, and the reason could be that passengers are more familiar with this way of receiving information from other public transportation vehicles (car, train, airplane, and conventional ferry). The app and AR app had some negative comments about the cumbersome and the requirement of a phone. Sound signals scored the lowest of all concepts where the reason could be that participants thought that the update frequency would result in noise instead of being informative.

For boat drivers, the most important thing is to avoid collisions and grounding. This corresponds well with that the MASS's route is of most interest shown in figure 4.3. This enables the boat driver to take appropriate actions to avoid dan-

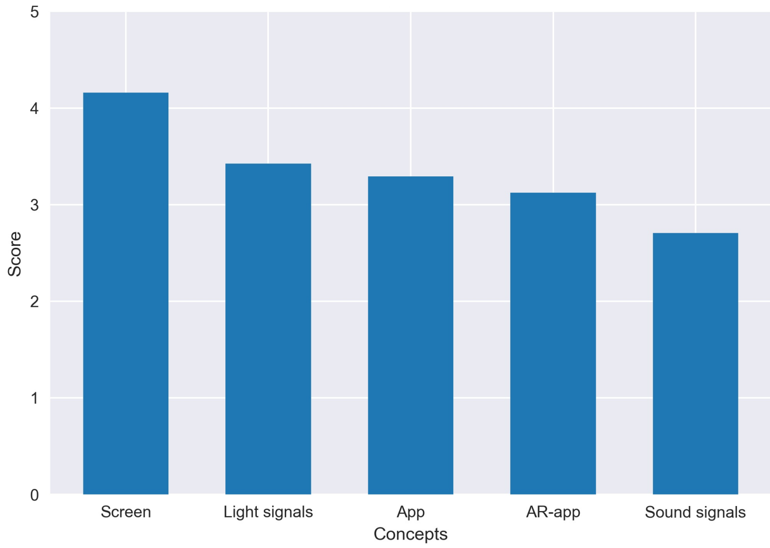

Figure 4.2: Rating eHMI passenger concepts

gerous situations. The second-highest ranked information is information about identified vessels. Naturally, other vessels want to know if they have been spotted and that the MASS takes their presence into account. Information with the lowest ranking (speed and current obstacle) is information that the driver can qualify to guess given the situation and do not need this information explicitly. There is great consensus that nearby boat drivers want to know if the vessel is autonomous, given in table 4.3. This coincides with the fact that the information need is higher for autonomous vessels than for conventional vessels. One reason could be that autonomous vessels are new, and therefore more information is required to reassure and confirm the situation awareness for nearby boat drivers is the same as for MASS. For the boat driver concepts, the light signals received the highest score shown in figure 4.4. Compared to the other concepts, lights are the only ones used at sea today and therefore are the most familiar. The concepts for app and AR-app had quite the same score. An explanation for the lower scoring is the requirement for a phone, and attention is drawn away from maneuvering. *Smart mirror* scored the lowest, and the reason could be that survey did not explain the concept thoroughly enough.

There are some obvious weaknesses with this survey. First, the participants are all from a minimal group of people. They are primarily men, interested in boats, and active on Facebook. This does not represent the standard passenger on the autonomous ferry. The reason for targeting Facebook groups was the need to get in touch with people with boat experience. From a retro-perspective, the best method would be to split up the survey into two surveys; one for passengers and one for boat drivers. These two surveys could then be distributed to two different groups of people, which had resulted in a more representative group of participants.

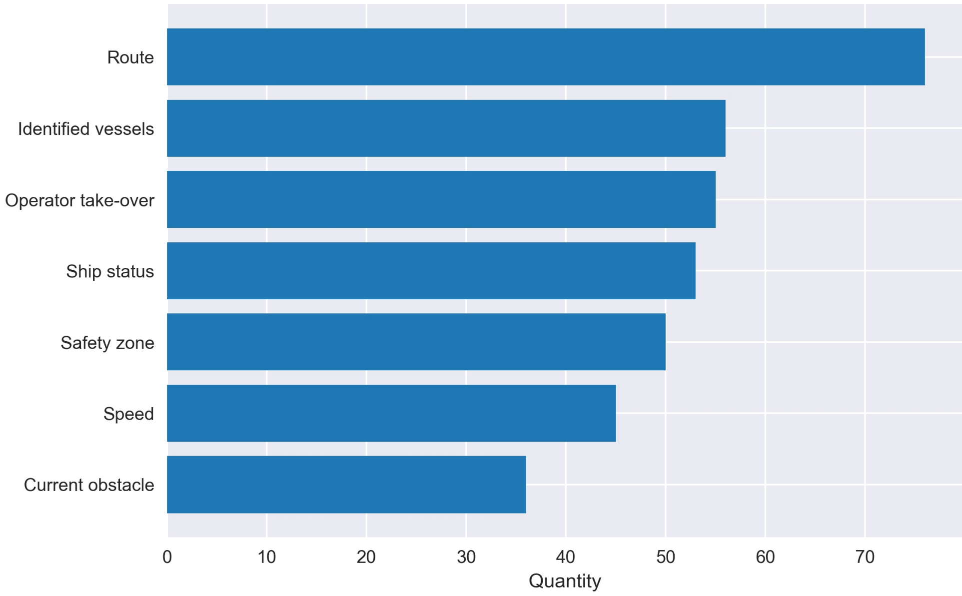

Figure 4.3: Information of interest for leisure vessels nearby MASS

4.3 Requirement and SA analysis

The requirement analysis is a helpful tool to improve the knowledge of how to operate a vessel safely. In the requirement analysis, the overall goals are broken down. This is achieved by completing an analysis of user characteristics, environmental conditions, and cognitive task analysis. User characteristics are the properties of the person interacting with the system. Environmental conditions describe the surroundings of where the system will be used. Operational requirements consist of how to complete the task, and what physical and mental abilities are required. By performing research on user characteristics, environmental conditions, and operational requirements, the system requirements can be defined (M. Endsley, 2012).

The case studies are the basis for analyzing the user characteristics, environmental conditions, and operational requirements. For the user characteristics, the only difference between passenger and boat driver is the ability to maneuver a boat correctly, shown in table 4.4. Dynamic parameters like energy level, focus, and influence of alcohol/narcotics are neglected. For the environmental conditions, the passengers focus more on what conditions affect the comfortable level of the ride, compared to the driver, which focuses on how to reach the destination safely, as shown in table 4.5. A cognitive task analysis (CTA) was performed to obtain the operational requirements. CTA is used to define goals, decisions, and situation awareness requirements (M. Endsley, 2012). The CTA was completed with relevant literature, but as stated in (M. Endsley, 2012), it is recommended to assist with observations and interviews as well. There is not performed a CTA

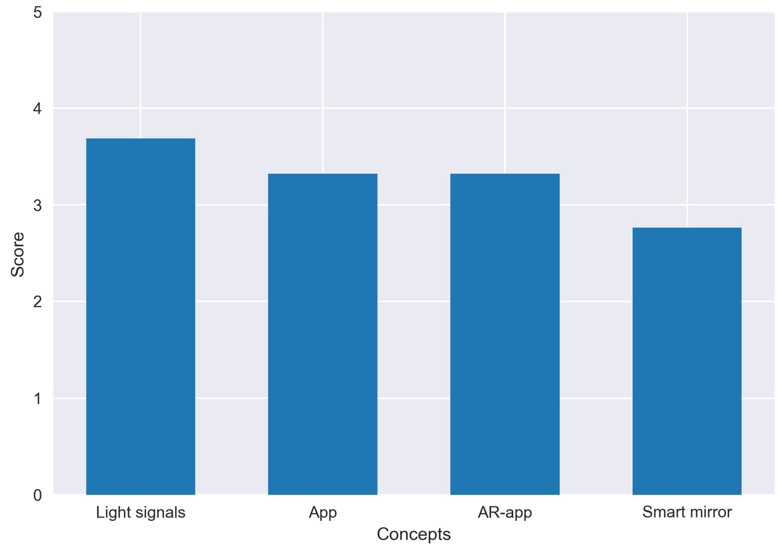

Figure 4.4: Rating of eHMI boat driver concepts

for passengers onboard the autonomous ferry because of their passive role. Instead, the overall goals for a conventional leisure vessel and an autonomous ferry are shown in figure 4.5. For conventional ships and MASS, situation awareness is key for decision-making. The situation awareness requirements can be defined by performing a CTA. In figure 4.6 are the situational awareness requirements for conventional ships and autonomous ships. The grey-outed text is specific for autonomous ships. The figure is inspired by (M. Endsley, 2012) and (Sharma et al., 2019).

User characteristics	Passenger	Boat driver
Gender	x	x
Age	x	x
Height and weight	x	x
Nationality	x	x
Skill level	-	x

Table 4.4: User characteristics

Environmental conditions	Passenger	Boat driver
Security requirements	x	x
Temperature requirements	x	-
Available space	x	x
Silent	x	-
Well lit	x	x
Privacy	-	x
Stress and workload	-	x
Seating comfort	x	x
Cleanliness	x	-
Equipment	-	x
Maintenance	-	x
Weather conditions	x	x

Table 4.5: Environmental conditions

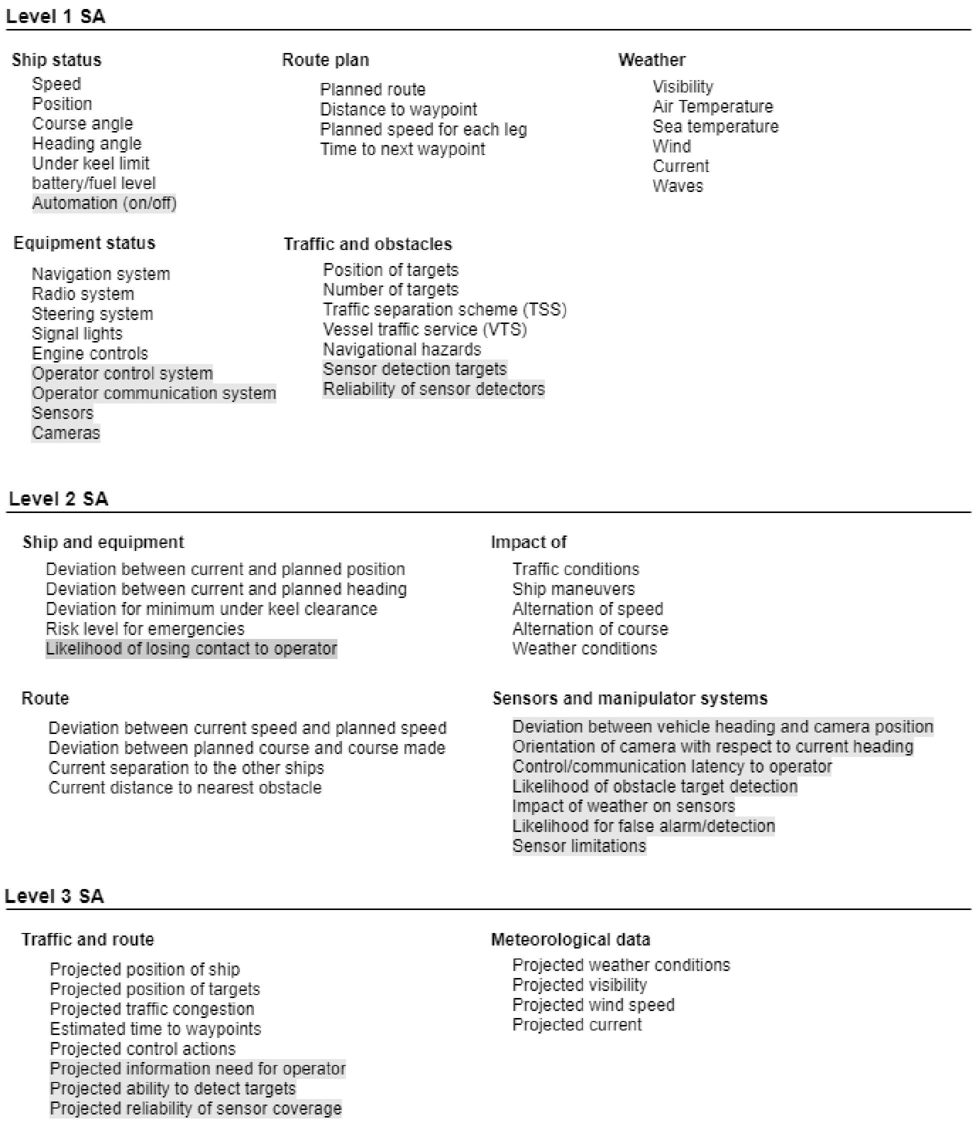

Figure 4.6: Situation awareness requirements

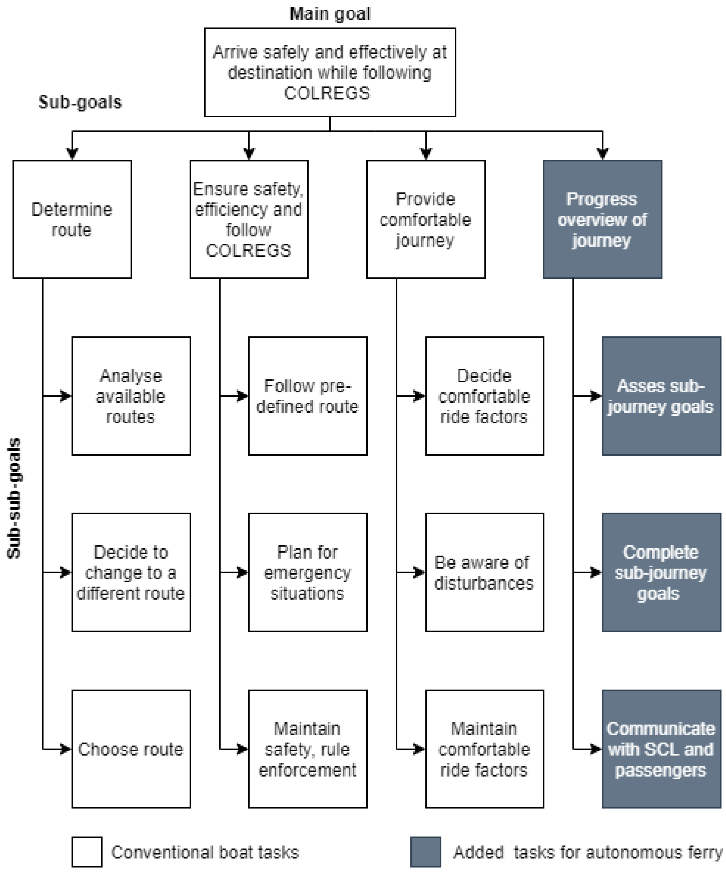

Figure 4.5: Cognitive task analysis

4.4 Design guidelines

The overall goal in designing human-machine interface devices is to assist the human in control. How the information is presented greatly impacts the situation awareness of the operator. This is not a straightforward task as the information should assist instead of deciding what the operator should do. Another challenge, displaying all available information simultaneously will work against its purpose because of the cognitive overload. Instead, the information displayed should decrease the workload and match the mental model in the current situation. In (M. Endsley, 2012) there are presented some general guidelines for designing for situation awareness. These guidelines will form the basis for the design principles used in this thesis:

1. Organize information around goals: The information should enhance the chance of achieving the main goal rather than displaying specific information. The importance of performing a cognitive task analysis (as shown in figure 4.5) will be to specify the overall goal, sub-goals, and sub-sub-goals. As knowing the goals makes it easier to choose what information to be dis-

played.

2. Present level 2 information directly - support comprehension: Humans have limited capacity to process information simultaneously. Instead of presenting raw data, the data should always be placed in a context. For example, should the deviation between planned course and current course be presented directly rather than calculated manually (as shown in figure 4.6).
3. Provide assistance for level 3 SA projections: Situation awareness projections are an important tool for decision-making when performed effectively. While it is crucial for the operator, it can also be of value for bystanders, for example, passengers. Passengers have less experience than the operator and can therefore easily feel insecure. It may be reassuring for the passengers to see the projections ahead.
4. Support global SA: This is the high-level progress of the primary goal. The high-level information should at all times be available. It is easy for humans to lose focus and instead concentrate on the small details rather than the primary goal. For example, the main goal for ships is to arrive at their destination safely. By providing information of the *big picture* at all times, the determination of which sub-goals (or sub-sub-goals) to concentrate on is more straightforward.
5. Support trade-offs between goal-driven and data-driven processing: There is a balance between the information to enhance principle 4 - global situation awareness and principle 1 - achieve goals. Global situation awareness requires data-driven information compared to achieving goals that require specific information. The end-user is another critical parameter. Passengers have less use of data-driven information and more use of goal-driven information than the operator.
6. Take advantage of parallel processing capabilities: Humans have limited processing abilities. By utilizing that the brain processes visual, auditory, and tactile information differently, the ability to process information can be extended. In the maritime domain, a boat driver can receive information visually with a display while hearing directions and at the same time feel power usage through the vibration in the steering wheel.
7. Use information filtering carefully: An immediate solution to information overload is to reduce the amount of available information. This must be done with special care, as this may work against its purpose. By excluding information, the global situation awareness could be harder to achieve. Another critical task for the operator is to plan ahead. This is only possible with the correct information available. Another challenge is the individual differences in what is considered essential. Therefore, only information that is not necessary should be excluded.

4.4.1 Trustworthy automation

Trust in autonomous systems is especially important for the end-users. The passengers on MilliAmpere2 (case study 1) need to trust and have confidence in the ferry. According to (Høklie, 2017) there are three principles to gain trust: Control, comfort, and transparency. The passengers need to feel that they have control over the situation even with their passive role. For instance, could the passenger communicate with the operator and perform an emergency stop if necessary. Designing MilliAmpere2 with human traits makes the unknown concept of autonomous transportation more familiar. Transparency may play an essential role in trust because it visualizes the system's working to its users.

(Hoff and Bashir, 2015) performed a systematic literature review with the focus on researching the factors which influence trust in automated systems. This resulted in a framework and design guidelines for achieving trust in automated systems. When developing eHMI concepts in this thesis, these design recommendations will serve as guidance. The guidelines are summarized in table 4.6.

Feature	Recommendation
Transparency	Real-time information of the reliability and the situation awareness
Communication	The style should be polite and informative
Simplicity	The interface should be easy to understand
Control	User should have some form of high-level control
Anthropomorphism [1]	Include anthropomorphic design features to increase trust

Table 4.6: Design recommendations for trustworthy automation

4.4.2 Design requirements

The eHMI concepts presented in this thesis strive to be transparent, understandable, and intuitive. Given the theory and research presented in this chapter, general design requirements are formulated. However, regardless of the concept, the overall goal is to present information of status and intentions clearly to the end-user. This is accomplished by following these requirements:

- The information presented is clear and gives immediately understanding.
- For a new user, the interaction concepts should be easy to learn.
- The information displayed adapts to the situation.
- The eHMI concepts should provide enough information for the user to make well thought decisions.
- The eHMI concepts should work in general situations, not just for the specific case studies.
- The eHMI concepts should be general enough to be integrated in other vessels than the MilliAmpere2 ferry.

[1] Anthropomorphism = Object with human characteristics

- Status and intention should be visible regardless of weather conditions and light conditions.

4.5 From design to implementation

VR is the chosen method for making the concepts. The motivation for choosing VR is the easiness of testing many concepts realistic, fast, effective, and cheap. Building physical prototypes of the concept would demand access to MilliAmpere2, leisure boats, and technical equipment. Instead, it is cost-effective to make the concept digital, evaluate the result, and make physical prototypes of only the highest-rated concepts. It is easy to adjust, adapt, and change the concept with digital prototypes without any extra expenses. Scenarios and the environment can easily be changed as well. For example, transforming the weather and ocean conditions in the environment is done by a simple button press. Additionally, MilliAmpere2 is currently under testing and is not yet ready to operate commercially. An important aspect of implementing and designing new concepts is how realistic the concepts mimic the potential finished design versus how much time it is worth investigating. Usually is time available limited. In this thesis, it has been desirable to make the concepts "realistic enough" without using too much time to make the concept "perfect".

In this thesis, Unity was chosen as the developing platform because of the free accessibility of higher-level education resources. Unity is a game engine that supports development on many platforms. It can be used for developing 3D, 2D, VR, Augmented Reality (AR), and simulation programs. The programming languages in Unity are C# and Javascript. One of the strengths of Unity is the mature community and the many learning resources available (Sinicki, 2021). The learning resources have been of great value. The undersigned had no previous experience developing VR programs or working in Unity. Skills and knowledge were learned by attending free online courses on Unity's website. The learning path started with completing the *Unity Essentials* course, followed by the *Create with VR* course. After completing these courses, the development process could start.

4.5.1 Setup

To be able to develop VR programs both hardware and software are required.
Hardware used:

- Computer - Dell G15 5520
- VR headset - Oculus Quest 2
- WiFi router - Netgear RAX20 AX1800

Software used:

- Unity Hub
- Unity 2020.3.32f1
- Oculus

For the VR headset to be integrated and playable with Unity, the packages below are required to be installed in the project:

- XR Plugin Management
- XR Interaction Toolkit
- OpenXR Plugin

4.5.2 VR environment

The virtual environments shown in figures 4.7 and 4.8 are developed to be authentic to the physical world. The user's movement needs to be tracked in real-time with no delay, the hand controllers shall interact with digital objects, and the environment needs to be as realistic as possible. Unity has an extensive library, *Unity Asset Store*, where assets can be downloaded for free or bought. In this thesis, only free assets have been used together with assets from *Zeabuz* - a spin-off company from NTNU:

- Trondheim (*Zeabuz*): 3D model of Trondheim. Mimic the environment for passengers traveling over the canal (case 1) and the leisure boat navigating outside the Trondheim's harbor (case 2)
- Water (*Simple Water Shader URP)*: Simulates realistic water. Account for the light reflection, water depth, and ocean dynamics.
- Water sound (*Zeabuz)*: The sound of vessels cutting through the sea surface.
- Sky (*AllSkyFree*): Include different weather and cloud types. A 6-sided cube map creates skies with textures up to 16k in size.
- Boats (*Zeabuz*): Models of different vessels. Include models of kayak, rib, sailboat, fishing boat, and MilliAmpere2.
- Commercial available ferry (*Regina calixta IV*): Low poly model of a conventional passenger ferry.
- Birds (*Simple Boids*): Animation of birds using basic boid rules.
- Bird sound (*Zeabuz*): Sound effect of seagulls.
- Passengers (*Banana Man*): Mannequin for all-purposes.
- VR hands (*Innocent Qwa*): Realistic hands. Undersigned animated each finger individually to make the VR hands behave similar to the user's physical hand movements.
- Path following (*Bézier Path Creator*): Objects follow predefined paths.

When the vessel moves, the user's position in the VR environment needs to be changed in the same direction with the same speed. The C# script *Camera Platform* transforms the position and rotation to a target position and target rotation every frame of the simulation. This keeps the user onboard the vessel at all times.

Figure 4.7: VR environment for case 1

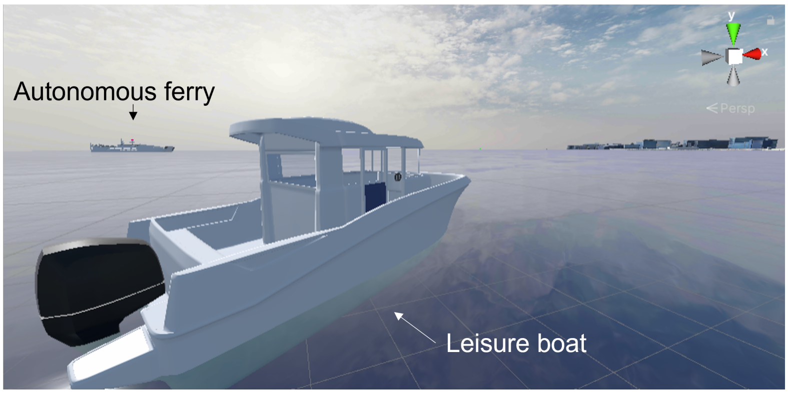

Figure 4.8: VR environment for case 2

4.5.3 Concept implementation

In total have five eHMI passenger concepts been developed. Each concept was designed to increase trustworthiness in MilliAmpere2 through automation transparency. An overview of the passenger concepts is given in table 4.7.

In total have six eHMI leisure boat driver concepts been developed. Each concept was designed to increase situational awareness and help in decision-making. An overview of the boat driver concepts is given in table 4.8.

For the concepts *fixed display*, *handheld display*, *GNSS*, *AIS*, *AIS+* and *web AIS+* the real-time map is implemented with the same procedure. A second camera is placed over and angled towards the object, showed in figure 4.9. The camera needs to be a child object to follow the object to be tracked. The culling mask setting is used to render only parts of the scene. For the camera to render and display particular objects, the object's layer needs to be the same as in the culling mask settings. The 3D model of Trondheim is duplicated, set to the correct layer, and changed to a grey color for not to take the attention away from the moving objects. The ocean is represented using a solid blue color in the camera environment settings. The vessels are visualised by using an arrow icons. The arrow is

Concepts	Information and features
Fixed display	Status, intention, emergency stop, operator communication
Handheld display	Status, intention, operator communication
AR	Status, intention, operator communication
Light circle	Identified vessels
Speaker	Identified vessels

Table 4.7: Overview of passenger concepts

Concepts	Information and features
GNSS	Own position
AIS	Own and nearby vessel's position
AIS+	For autonomous vessel: Special color, route plan and safety zone
Web AIS+	For autonomous vessel: Special color, route plan and safety zone
AR	For autonomous vessel: Identified vessels, route plan and safety zone
Light strip	For autonomous vessel: Signalling autonomously and upcoming actions

Table 4.8: Overview of boat driver concepts

a child object of the belonging vessel, and the layer setting is set to the same as the camera setting. The color of own ship's arrow is turquoise to be in great contrast to the water and Trondheim city. Other vessels are white to be in contrast to the background while differentiate from own ship's color. To display the planned route, the C# script *PathFollowers* from the asset *Bézier Path Creator* is changed, and a line renderer is added to the object.

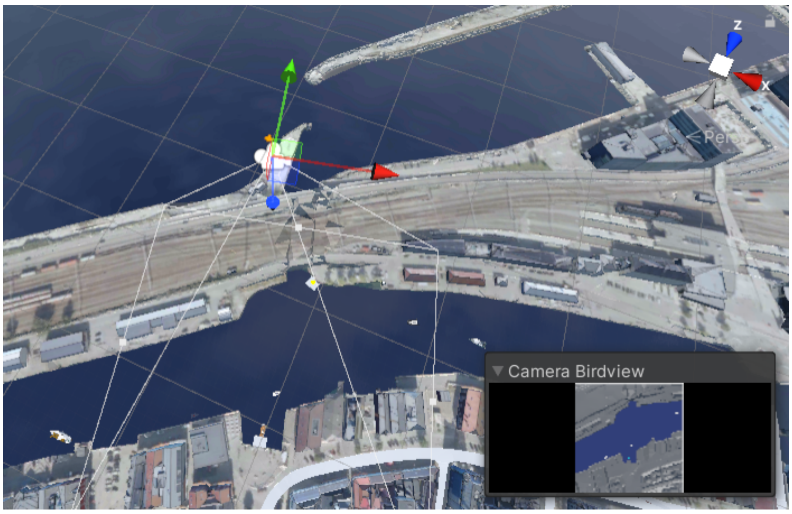

Figure 4.9: Implementation of map

For the concepts *fixed display*, *handheld display*, *AR (passenger and boat driver)*, *web AIS+* text and buttons are used. The buttons are represented by symbols from the asset *UX Flat Icons* from the Unity asset store. The colors are changed to be suitable for the scenario. For simplicity, the buttons are static and have no function except for giving a visual feeling of how the final design can look like. The text is implemented by using *TextMeshPro*, where the setting for softness and dilate is set to 0 and 1 respectively, for easier readiness.

The concepts *AIS+* and *web AIS+* display the autonomous vessel with a purple arrow and a safety zone made from the four corner icon, which forms a rectangular shape. The arrow and rectangular are set to the same layer as the camera settings to be shown at the display.

The concepts *handheld display*, *AR (passenger and boat driver)* and *Web AIS+* are grabbable objects in the VR environment. The user can interact with these objects with their VR hands. The concepts need to have the attributes: Rigid body, box collider, and the C# script *XR Grab Interactable*. The VR hands need to be within reach of the object's box collider to be picked up. When the objects are dropped, the gravitational force makes the object fall. When the objects are dropped, they immediately snap to a pre-set position using a sphere collider and the C# script *XR Socket Interactor* to make the VR program user-friendly.

The same methodology for making the maps is used for the AR concepts (both passenger and boat driver). A secondary camera is placed where the camera would be positioned in a physical phone. Given the settings for the camera, the camera will only render objects in the particular layers. The AR concepts will show the route plan, final destination, and identified vessels. When the camera is pointed towards the direction of travel, a yellow line indicating the route will appear on the screen. Yellow is chosen because it is the same color used for the route in other concepts. To see the route's destination, an upside-down cone is hovering over the pier. The camera can be pointed toward nearby vessels to confirm if the autonomous ship has identified them. A green outline will appear around the vessel to confirm that the ship has seen it. The C# script *Outline* computes the outline for the object, where the color and thickness can be set.

For the concepts *light circle* and *speaker* a sensor system is made. There are positioned cone colliders two degrees apart (180 sensors in total) around the ship with a range of 200 meters. If another vessel is within the zone of a sensor, the sensor will be triggered. The *lights circle* concept consists of eighteen lights that form a circle. For every light, there are ten belonging sensors. If one of the sensors are triggered, the light will light up and indicate that the vessel is identified. When no sensors are triggered, the light will remain off. The *speaker* concept also uses the same sensors to communicate if vessels nearby are identified. The sensors are divided into three groups: Ahead, left and right, while the sensors checking behind the ferry are excluded. The sensors for checking if a vessel is in front of the ship cover from -30 degrees to 30 degrees (shown in figure 4.10), while the left sensor group covers from -30 degrees to -110 degrees, and the right sensor group cover 30 degrees to 110 degrees. To avoid the speaker continuous communicate that the same ship has been spotted, the C# script *Audio ID* checks if a vessel already has been identified. The voice used in the speaker system is from the text-to-speech website *naturalreaders.com* which sounds close to human speech.

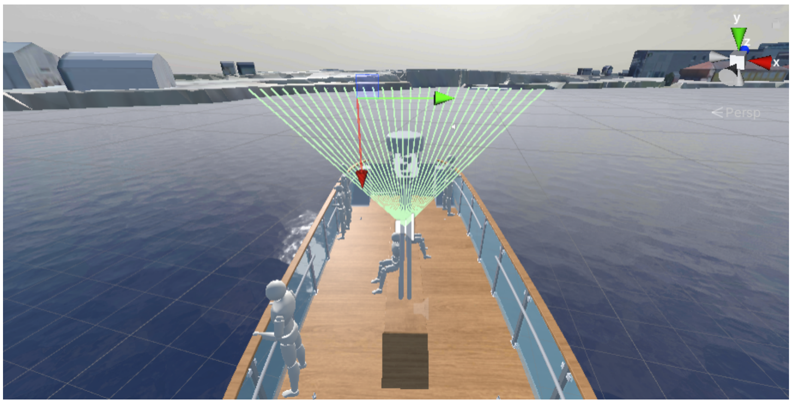

Figure 4.10: Sensor system for checking if vessels are in front of the ship

For the concept *light strip* there are added additional lights to the ferry (Regina calixta IV) using 3D sphere objects. Each light represents the planned action one minute into the future. The C# script *ColorForward* changes the color of the lights by iterating over the lights and waiting one second before activating the next color change. By following the conventional color code for starboard and port in the maritime domain, turning to the starboard side is green while turning to the port side is red. To indicate no change in course, the light will flash turquoise. In the maritime domain turquoise is rarely used, which reduces the chance to interpret the meaning of the light in another way as intended. To communicate that the ferry is autonomous, a light on the top of the mast change to purple every two seconds by the C# script *ChangeColor*.

4.6 Results

There is made a demonstration video showing the eHMI concepts in use. The reader is recommended to watch the video before reading further. The video is uploaded to YouTube (title: *External human-machine interfaces (eHMI) in the maritime domain*) - click here to watch the video.

4.6.1 Passengers

The first concept is a fixed display shown in figure 4.11, which displays information about the journey. As stated in figure 4.1, the most interesting information for the passengers was knowing the planned route. This is taken into account by integrating a real-time map of the route and the ferry's position and displaying the next stop on the route. In (Veitch and Alsos, 2021), it is argued that passengers only need to know if the ship has seen another vessel, compared to the operator, which needs to know the type, speed, direction, etc. Therefore, nearby vessels are displayed on the map only with their position. To give the passengers a sense of

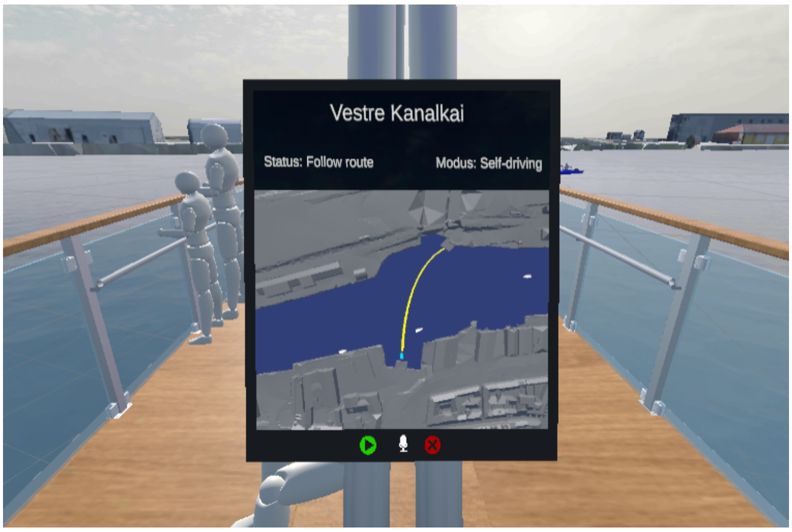

Figure 4.11: Fixed display

control, the display has three interactive buttons where the sense of control may have a positive impact on trust, as described in section 4.4.1. The buttons enable the passengers to start the journey, contact the operator on land and stop if there is an emergency. The motivation behind this concept is that screens today are the most traditional method for passengers to receive information about their journey when traveling by public transportation. By utilizing familiar ways passengers on other public transportation vehicles today receive information, the threshold may be reduced to try new public transportation methods like an autonomous ferry.

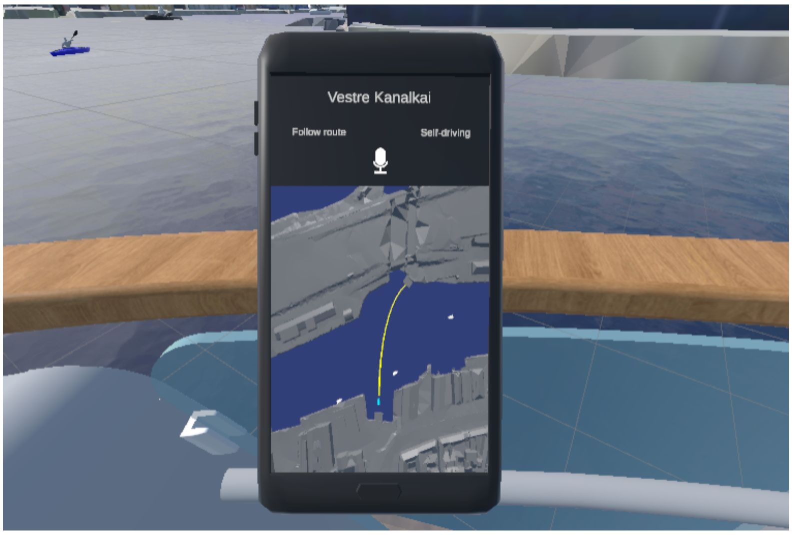

Figure 4.12: Handheld display

The second concept is a handheld display which is a more portable solution shown in figure 4.12. The vast majority walk around with a smartphone in their pocket. This is an excellent opportunity for displaying information directly to each passenger. The information displayed in this concept is similar to the fixed display but with a few changes. The screen size in smartphones is much smaller, so the same amount of information can not be displayed simultaneously. Nevertheless, smartphones can switch to other pages by touching the screen. To display more information to the passenger, multiple pages can be made. Every smartphone has a speaker and microphone, which can be used to contact the operator directly. This could cause challenges as the operator may receive multiple calls simultaneously. Another challenge is that only people onboard should be able to call the operator. One solution is to have a dynamic changing QR-code placed on the ferry, which changes for each ferry trip.

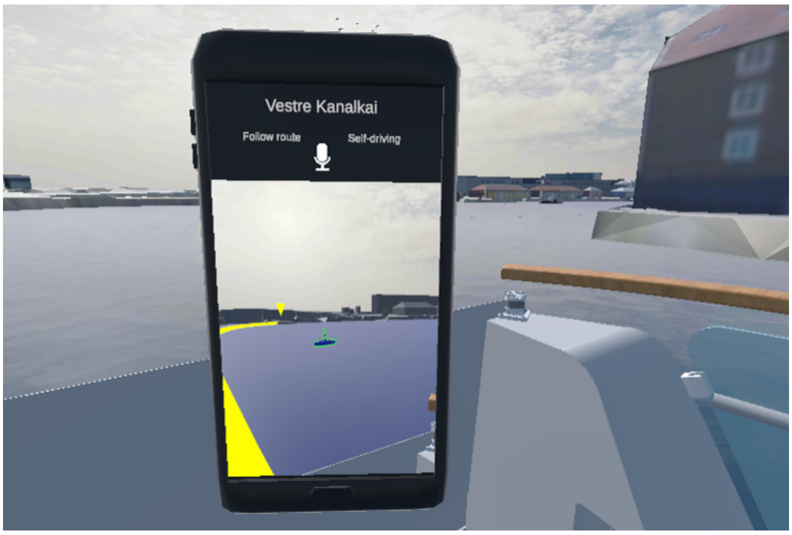

Figure 4.13: AR

The third concept is to further explore the opportunities in smartphones shown in figure 4.13. Newer smartphones can use augmented reality (AR). AR is a technology that merges the physical world with the digital world by displaying a digital layer on top of the physical environment. This gives infinite possibilities for how information can be communicated to the passenger. With the first and second concepts, the passenger has to understand the map's orientation with respect to their own orientation. With AR, the passenger points the camera towards a vessel and immediately can see if the ferry has seen it. Information about the route and the destination's position can be viewed on the screen by pointing the camera in the velocity direction of the ferry. The ability to talk to the operator will also be an option in this concept. Static text is displayed over the "AR-screen" to be available at all times.

The fourth concept is to use lights to communicate information shown in figure 4.14. Specific to case 1, MilliAmpere2 travels only over the canal, which makes

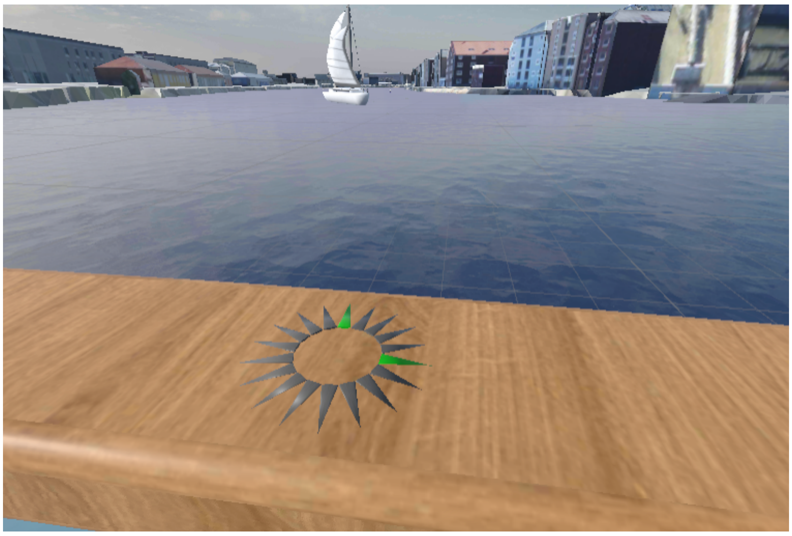

Figure 4.14: Light circle

information about the planned route and the arrival time not interesting as the journey is only 100 meters long. What is of interest is the obstacles the ferry needs to avoid. The lights cover 360 degrees around the ferry. The belonging light will light up when a vessel is within a sensor's sector. These lights will be placed around the railing, where they will be within sight wherever the passenger is positioned. This concept will only communicate if other vessels have been seen, thereby communicating less information than previous concepts. As discussed in section 4.2.2, passengers have different information needs. Some passengers need to know as much as possible, and others will have no information at all. This concept tests if only communicating identified vessels is "just enough" information.

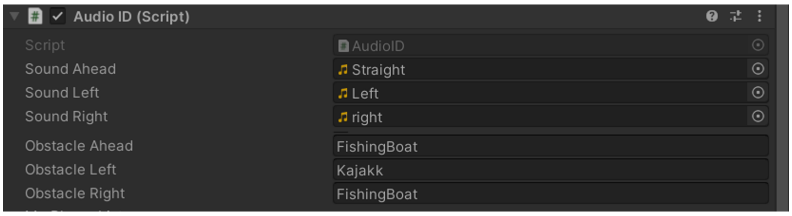

Figure 4.15: Speaker

The final concept is to test the effect of audio, as the previous concepts all have been visual. This concept will be similar to the light circle concept, only broadcasting information about identified vessels, but in a newer version, the speaker can also give information about arrival time, offset from the route, operator actions, etc. The main challenge is to communicate the right amount of information. To frequently updates will be perceived as noise. A screenshot of how this concept is implemented is shown in figure 4.15. The motivation behind this concept is to test if passengers prefer information through audio over visual.

4.6.2 Leisure boat driver

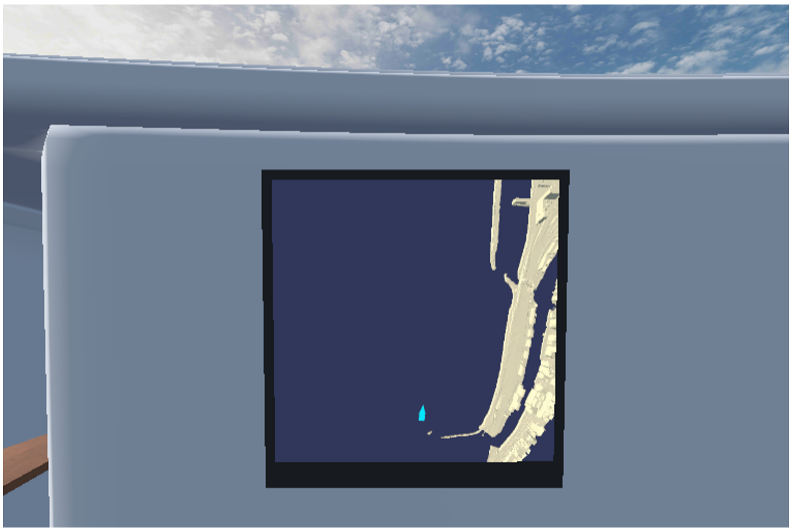

Figure 4.16: GNSS

The first concept is to test how a global navigation satellite system (GNSS) can be used in maritime navigation shown in figure 4.16. This is already available today but is included to be compared with the other navigation concepts. The system shows the vessel's current position with respect to geographical data. The driver can easily see the position on the map and get detailed information about the surroundings, like the sea depth level. Other vessels will not be visual on the map because this requires an AIS system. This concept is motivated by testing if only information about the driver's position is enough to have a decent level of situation awareness. The driver must on their own be able to understand the situation by perceiving the elements in the environment, comprehending and projecting the future states.

The second concept displays the position of vessels with an AIS system installed, shown in figure 4.17. The boat driver will see other vessels at the display in addition to navigation status, speed, position, course, heading, etc. (See a complete overview in (ShineMicro, 2022)). The boat driver can plan ahead and is better prepared to take earlier actions by getting this information. The AIS system will not explicitly tell if a vessel is autonomous as there are no standards for it today.

The third concept is a further development of the AIS display shown in figure 4.18. The change is the additional information about autonomous vessels. From table 4.3, the vast majority wanted to know if the vessel was autonomous. This is implemented by giving the autonomous vessel a distinct color compared to the conventional vessels. Purple color is used because it is rarely used in the maritime domain (Porathe, 2018). Another feature added to the display is the planned route of the autonomous vessel. From the pre-survey (figure 4.3), route information

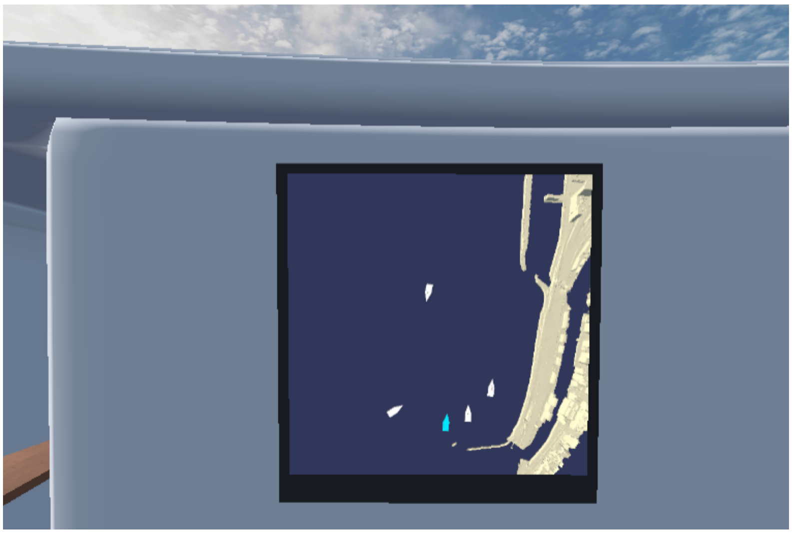

Figure 4.17: AIS

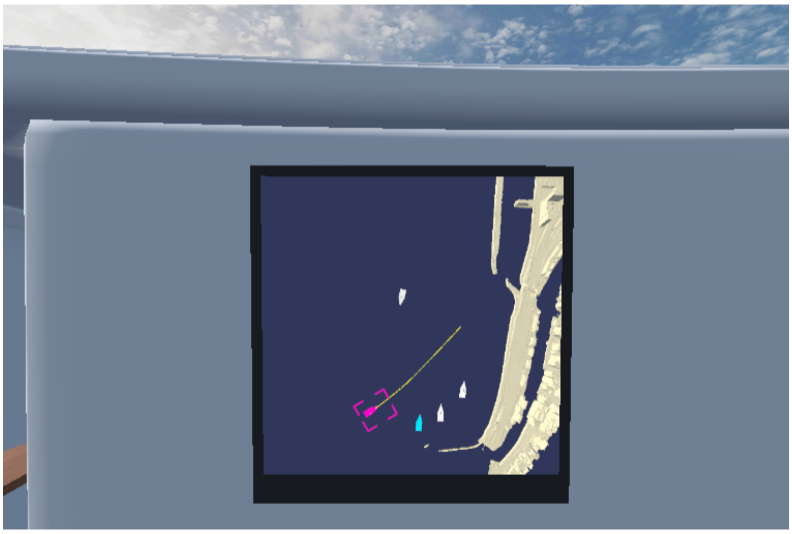

Figure 4.18: AIS+

was by a good margin the most desired information. Because a complete route plan may contain classified information, the available route information is only a few minutes ahead. Additionally is the visualizing tool moving haven added. The moving haven shows the difference between the planned and actual positions. This can work as a safety zone for other mariners.

The fourth concept is to visualize the same information as the third concept but on a phone shown in figure 4.19. Besides the information being displayed on a phone, the perspective is now changed to the autonomous vessel. The motivation behind this concept is that not all leisure vessels have installed an AIS B system

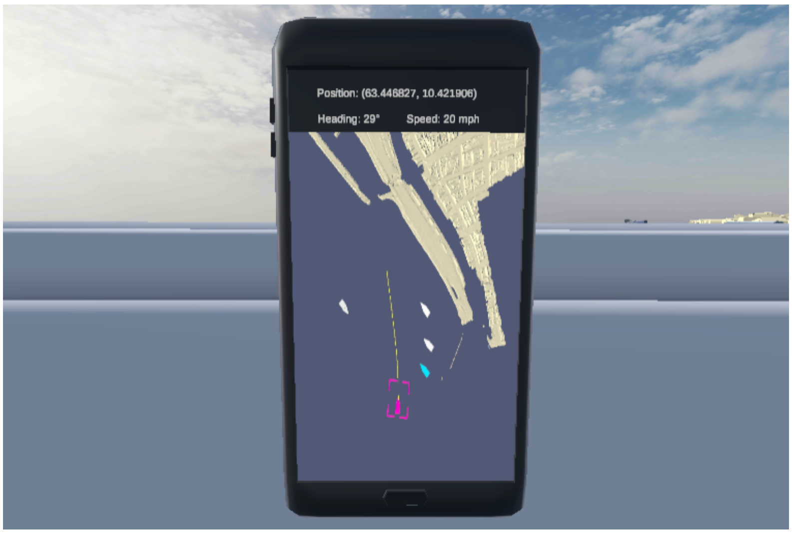

Figure 4.19: Web AIS+

onboard, but most have a smartphone available. Information about the route, identified vessels, and safety zone can be broadcasted to a web portal where it shows the status and intentions of the MASS in real-time. This is especially useful for smaller leisure vessels like kayaks and inexperienced boat drivers. By knowing the MASS's status and intentions, early action can be taken.

Figure 4.20: AR

The fifth concept is again to use the phone as a visualizing tool and take advantage of the opportunity to use AR shown in figure 4.20. The idea is that the boat driver can point the camera toward the autonomous vessel to see the status and intentions. On top of the screen gets the boat driver information about if their vessel has been identified by the MASS. To verify that this is correct, the current position and heading are displayed. In addition, the AR application will show the route and the safety zone when the phone is directed toward the MASS. The camera can also be pointed toward other vessels nearby to see if the MASS has identified them. If identified, the vessel will have a green silhouette around them.

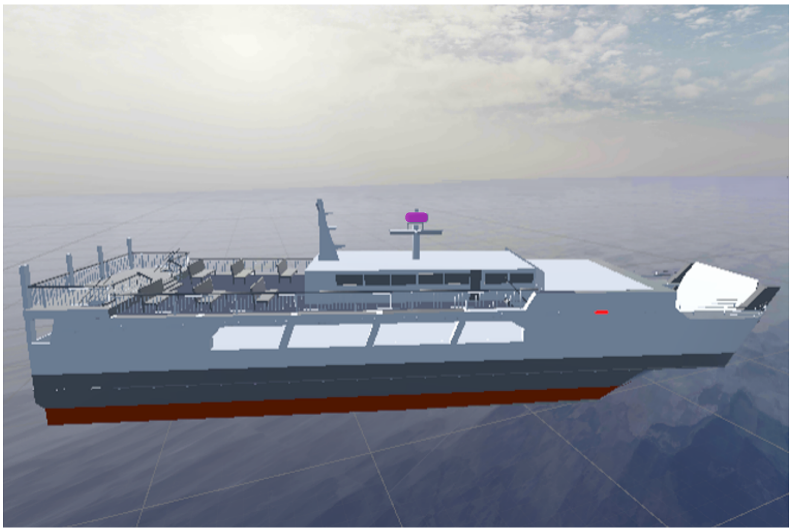

Figure 4.21: Light strip

The final concept is to use light signals to broadcast the planned route from the MASS to vessels nearby, shown in figure 4.21. In the pre-survey, the light signal was the highest-rated boat driver concept (figure 4.4). A purple light will flash periodically every two seconds to signal that the ship is autonomous. There will be multiple lights on each side of the ship to show the planned route. Each light indicates the action taken the next minute into the future. For example, light number ten indicates action ten minutes ahead, and light number two will indicate action two minutes ahead. Depending on the color of the light, the action can be either keep the course, change course to starboard, or change course to port. The colors for showing starboard and port action are green and red, which is standard in the maritime domain. By only broadcasting that the vessel is autonomous and its intentions, one can test if this is enough information for nearby boat drivers.

Chapter 5

Evaluation

Given that the guidelines for designing situation awareness (SA) with respect to human factors are quite general, it is vital to test each concept early in the design process. By testing the concepts, knowledge of what works and the challenges to overcome is important learning outcome for further development. The approach taken in this thesis for testing SA is direct subjective measures. This is completed by participants answering text questions, multiple-choice questions, and grading scale questions. The advantage of subjective measures is the easiness and cost-effective performance, and test results are simple to analyze.

5.1 User test

The goal of the user test was to evaluate the passenger concepts with regards to situation awareness and trust, while the boat driver concepts were tested for situation awareness and decision-making assistance. In addition to testing the eHMI concepts, knowledge about the what kind of information the participants wanted to know about MASS and their general thoughts of automation at sea was researched.

5.1.1 Participants and procedure

21 participants (76.2 % men and 23.8 % women) tested the VR simulator. All participants were between 18 years and 35 years, and 42.9 % had the boat license. The user test took place in a warehouse at Nyhavna (Trondheim, Norway), shown in figure 5.1. The motivation behind this location is that in the warehouse, there is a model of MilliAmpere2 made of wooden boards. The participants could walk around in the wooden model simultaneously using the VR headset. The 3D model in the VR environment (case 1) and the wooden model were of the exact dimensions, which enabled the participants to physically touch the railing with the VR hand controllers while touching the railing in the VR environment. This resulted in a realistic and immersive experience as the haptic and visual senses coincided.

To make the participants walk freely and not be restrained by any wires, a wireless router created a local network that transported data in real-time from the computer to the VR headset.

Figure 5.1: User test set-up

The user test started with a short presentation of the thesis and the motivation for performing the user test. For testing the passenger concepts (case 1), the participants were placed standing over a marked spot (made with tape) inside the wooden model, the same starting position in the VR environment. When the simulation started, the participant could walk around for a little bit to get familiar with the digital environment. When the participant was ready, different concepts would appear for them to interact with before moving over to the next one. The simulation was stopped after all the passenger concepts had been tested. The same procedure was repeated for the boat driver eHMI concepts (case 2), but now the participant sat in a chair and outside the wooden model. After both the VR simulations were completed, the participants answered an online survey (in Norwegian) which is attached in appendix A. The survey had the same set-up as the pre-survey found in section 4.2 and the same tools were used for analyzing the test results.

5.1.2 Results

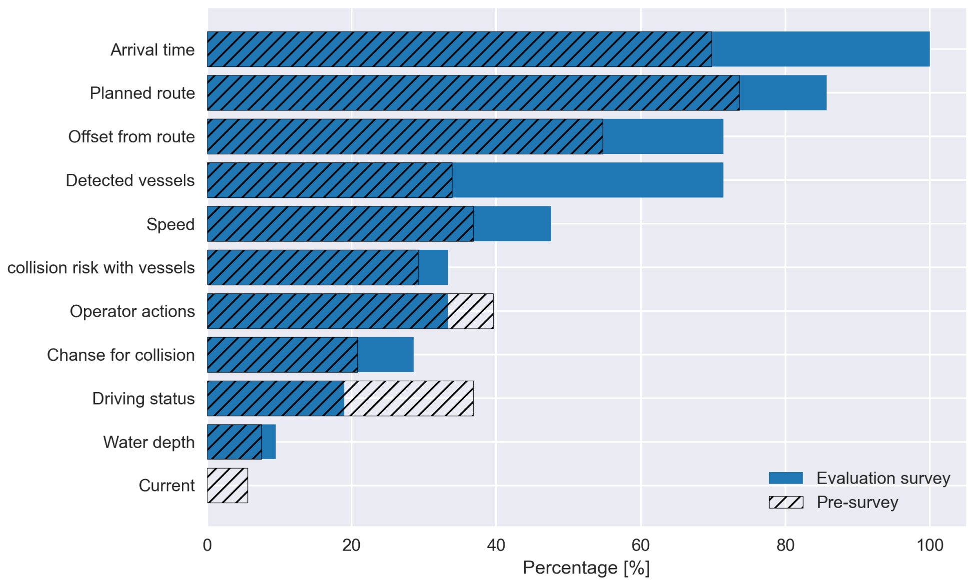

Figure 5.2: Information need for passengers

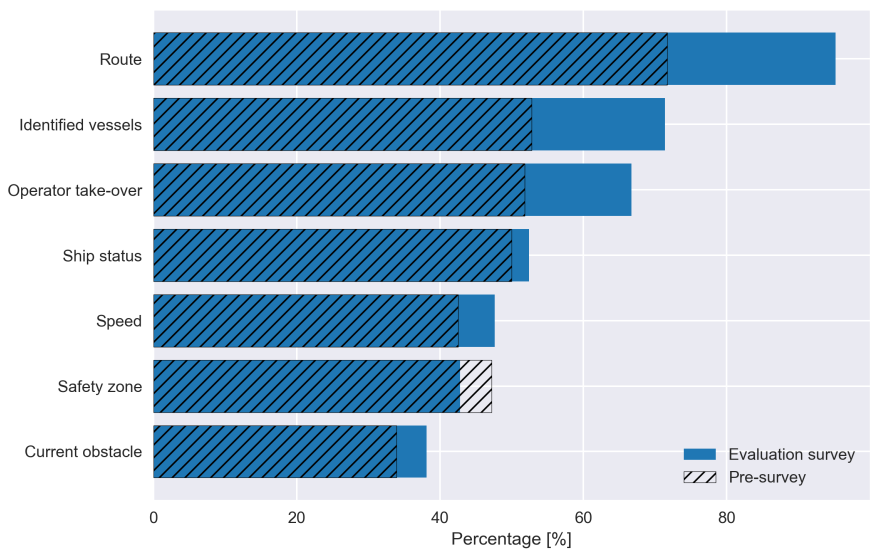

Figure 5.3: Information need for boat drivers

Questions for case 1	Yes	No	Don't know
Will lack of status and intention reduce your usage of the ferry?	23.8%	57.1%	19%
Do you feel unsafe if status and intention are not available?	47.6%	42.9%	9.5%

Table 5.1: Passenger answers

Questions for case 2	Yes	No	Don't know
Would you increase the distance to MASS if no concepts were used?	61.9%	14.3%	23.8%
Want to know if nearby ship is autonomous?	66.7%	19%	14.3%
Safety increases with use of the concepts?	95.2%	0%	4.8%

Table 5.2: Boat driver answers

5.1.3 Usability assessment

Usability is defined with five attributes (Nielsen, 1993):

1. Learnability: The user quickly understands how it works and can start using the system without or with little training.
2. Efficiency: The system provides a high level of productivity.
3. Memorability: When the user comes back to the system after some time, it takes little time to start using it again.
4. Errors: The system should be stable and provide little to no errors.
5. Satisfaction: The user should want to use the system because of its easiness and because they like the system.

The standard procedure for investigating the overall usability is to take the mean value of every attribute. Unfortunately, the five attributes are not too easy to test in the VR simulator. Instead, there are added different attributes which is specific to this thesis. For the passenger eHMI concepts, are situation awareness, trust and satisfaction tested. For the driver eHMI concepts, the attributes are available information, situation awareness, assistance in decision-making, and satisfaction tested. Reliability is essential to understand the usefulness of the user test. The test results should be the same if different participants retook the user test. The data collected from the user test needs to be analyzed. Boxplots are the chosen method for displaying the feedback for the eHMI concepts. This is because boxplots give detailed information about the data set (minimum, first quartile, median, third quartile, maximum, and outliers). A generic example of a boxplot is shown in figure 5.4.

The boxplot for the passenger eHMI concepts is shown in figure 5.5. The participants rated every concept from 1 to 7 based on situation awareness, trust and satisfaction.

- It is clear that the concept *Fixed display* is superior to the other concepts. The median values have the highest scores possible, and the interquartile range is small. Besides from being the concept that is most similar to what

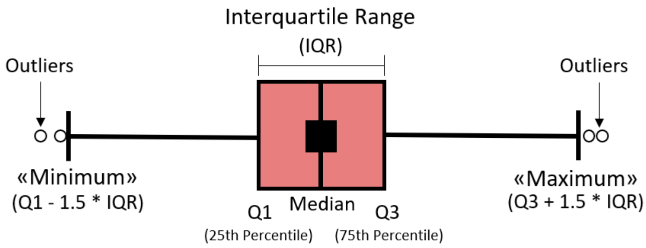

Figure 5.4: Different parts of boxplot

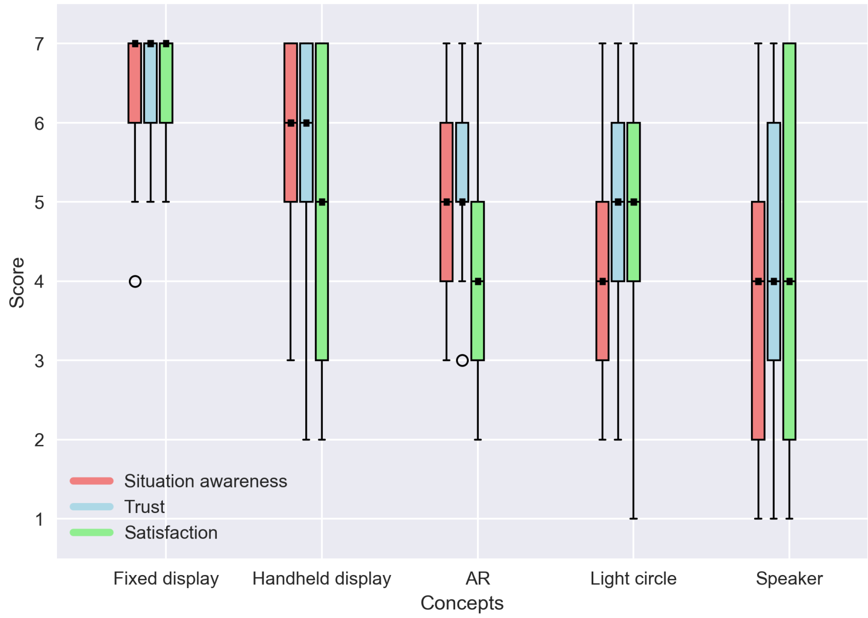

Figure 5.5: Rating of passenger concepts

is already used in other commercial transportation vehicles today, it is the concept that provides the most information to the users. "*The screen gives the feeling of the complete solution*" - participant x.

- The *handheld display* scores relatively high on situation awareness and trust. This is natural, as the information displayed is similar to the previous concept. However, it is worth noting that it scores far lower on satisfaction. Many participants communicated their concern about the extra work of having to download/scan an app or QR code. "*The fixed display and the phone app provide the same information, it will only be a matter of what is most convenient*" - participant x.
- The *AR* display shows the same information as the phone but scores lower on all the attributes. The passenger needs to actively turn around and point the camera toward desired knowledge which could be one reason. The satisfaction scores are low, "*to much effort to point the camera around the boat.*

It is fun the first time, but then the screen and phone are better options" - participant x.

- The *light circle* scores low on situation awareness. This makes sense as the only information provided is which vessels are identified by the ferry. Nevertheless, the rating on trust and satisfaction is on an acceptable level. The simplicity and that the concept provides which obstacles are spotted could be the reason. "*The light display is intuitive, and it is positive that the user does not need any extra equipment*" - participant x.
- The *Audio* concept scores the lowest of all the concepts. It only provides information about the identified vessels, which is only available for a short time. In addition, the speaker plays the audio message only one time for each vessel, which makes the information easy to miss. "*The passenger can get worried if the audio message is not received, can happen when listening to music*" - participant x.

The boxplot for the driver eHMI concepts is shown in figure 5.6. The participants rated every concept from 1 to 7 based on information needs, situation awareness, assistance in decision-making, and satisfaction.

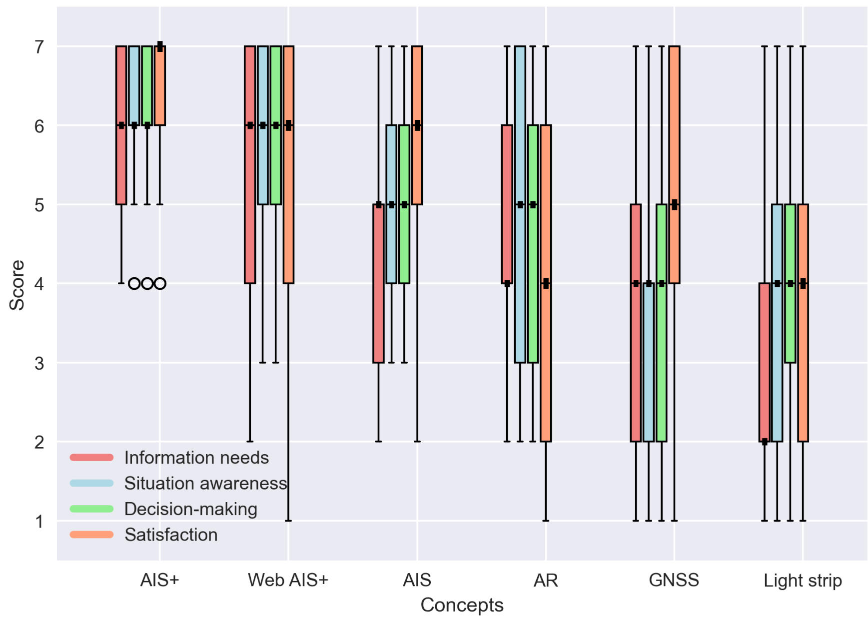

Figure 5.6: Rating of driver concepts

- *AIS+* scores the highest in every attribute. The extensive information available helps the driver understand the situation. More detailed information about the autonomous ferry is of value, and the information is displayed on a permanently mounted screen, making it easy to use. "*AIS+ display information clearly by showing heading, planned route, and other vessels nearby*" - participant x.

- *Web AIS+* displays the same information, but now on a handheld device. The ratings vary more, probably because of the extra effort of holding the phone while driving. "*Hard and irresponsible to use the phone while driving*" - participant x.
- The rating decreases for *AIS*. The information displayed is less detailed, which the participants do not receive positively. Extra information about the autonomous vessel is desired and scores therefore lower on the coverage of information needs. Nevertheless, is it a good aid for decision-making. "*Easy to get information from AIS*" - participant x.
- The *AR* concept received some varying feedback. The participants disagreed with each other on effectiveness and satisfaction. The concept provides as much information as the *AIS+*, but maybe not as clearly. In addition, AR requires that the driver turn around, which can cause a reduction in focus. "*The AR displays much information, but because of the constant turning, it is easy to lose situation awareness*" - participant x.
- The *GNSS* concept only provides the position of the boat. As the boxplot indicates, this is insufficient information to assist the boat driver.
- The *light strip* concept has the lowest rating. It provides only information about the planned route for the MASS. Interestingly enough, is this information rated lower than the *GNSS* concept. This can indicate that information about own vessel is seen as more important than information about others. The lights were not intuitive for the participants, and there was a need to explain the color codes and what the lights indicated. This concept depends on IMO standardizing the colors and the meaning of the lights. "*The light signals can be very good - as long as the meaning of colors is easily understood*" - participant x.

Besides reliability, validity is another crucial factor user tests should fulfill. Validity represents how accurate the measurements are; it shows if the results represent what was intended to be measured. It is not tested statistically, but instead methodological understanding and common sense (Nielsen, 1993). The question of how many participants is enough to get some valid results is not straightforward. According to (Rosenzweig, 2015), 8 people are enough given that they represent different user personas. 21 participants were taking the user test in this thesis. Even though the number is far greater than the suggested quantity, the participants cover only three different user personas (young adults, people with boat licenses, and experts within the maritime autonomous vehicles field). The undersigned guided the participants when using the VR simulator, which may have affected how the participants experienced the eHMI concepts. The guidance included what the participants should pay attention to, how to use the concepts and explained if something was unclear.

Chapter 6

Discussion

The development of the eHMI concepts is based on literature and brainstorming around potential concepts. As stated in section 2.5, the design team should consist of team members with different skills and backgrounds. This is not fulfilled as the undersigned has only been working on the concept development. The concepts from the first iteration of the design process were used in the user test. Ideally, the concepts should have been through multiple iterations (figure 2.5) before being used in the user test. The user test was performed for case 1 and case 2 by running the same simulation repeatedly but with different eHMI concepts available for the participants. The disadvantage of this form of execution is that the participant gets more and more familiar with the scenario for each concept. Instead, the standardized way of testing situation awareness - SAGAT (section 2.1.1) should have been used. More detailed information about the situation awareness could have been found by utilizing SAGAT. The reason to deviate from SAGAT was the extra required time in implementation and the increase in time per participant in the user test.

In addition to designing and testing concepts for how MASS can communicate status and intentions to its surroundings, four research questions were formulated. This section will discuss the research questions given the knowledge established by working with this thesis.

1. What kind of information should be included in automation transparency?

Regardless of what kind of information to be communicated to the passengers, the main question is if there is a need for the passengers to know the status and intention. In the pre-survey 54.7% wanted to know this kind of information. Given the surveys, some information seems to be of particular interest. The pre-survey and evaluation survey indicate that the "big picture" information (the overall view of the situation) is of most interest. As seen in figure 5.2, information about arrival time and planned route scored the highest in both the pre-survey and evaluation survey, which may indicate that type of information are independent of age. According to (Veitch and Alsos, 2021), passengers need only information that confirms the objectives is seen to avoid collisions. So even though information about operator action, detected vessels, and the precision of route following scored relatively high, there still needs further research to decide if this information is necessary to communicate to the passengers. This does not mean this kind of information should automatically be included. The information communicated to the passenger will require fine-tuning as detailed information may work against its purpose.

The boat driver needs to be able to percept, comprehend, and project into the future. As stated in section 2.1, good situation awareness is necessary for the decision process. From the pre-survey (98.1% possess the boat license), 84% reported that they wanted to know if a nearby vessel was autonomous, but 66.7% wanted to know the same information in the pre-survey. This can indicate that younger people are more positive about autonomous vessels, but more research is required. According to (Lyons, 2013), information must be carefully tuned to avoid information overload. Further research is required to determine the information needed for nearby boat drivers, but "big picture" information seems to be of most interest. It is interesting to see that these top three information characteristics are the same in the pre-survey as in the evaluation survey shown in figure 5.3. The route plan was the most desired information about the MASS. Information about which vessels were identified and whether the operator had taken control was also of high interest. This agrees with the findings in (Dey et al., 2020), which states that broadcasted messages should be restricted to the status and intentions of the vehicle. However, as (M. Endsley, 2012) states, the available information needs to be precisely tuned for every individual scenario, which is challenging.

2. How to communicate automation transparency in the maritime domain?

The recipients of automation transparency have been passengers and leisure boats in this thesis. Given the eHMI concepts developed in this thesis, a fixed display seems the most promising option for receiving information. This is coherent with how other public transportation vehicles communicate with their passengers today. The advantage of a fixed display is that the information is available at all times and does not require any extra effort from the passengers. This is supported by the light circle concept, which scored higher in satisfaction than both the handheld display and the AR concept (figure 5.5). Situation awareness seems to be dependent on how information is perceived. The fixed display, handheld display, and AR communicate the same information, but as shown in figure 5.5, the fixed display has much higher scoring in situation awareness than the other concepts. Since there is no standardized way of making the system transparent (Fleischmann and Wallace, 2005), further research is necessary as in this thesis, only a few concepts have been developed and tested.

The way leisure boats receive information about other vessels should cover information needs, increase situation awareness and assist in decision-making. The main challenge with the introduction of autonomous vehicles is the interaction between the agents in the traffic (Tabone et al., 2021). According to figure 5.6, it seems like the participants from the user test want to know as much about the situation as possible. The concepts GNSS (own position), AIS (own position and position of other vessels), and AIS+ (own position, position of other vessels, and extra information of MASS) test how much information is necessary. AIS+ scores higher in information needs than the other concepts and also in situation awareness, decision-making, and satisfaction. However, as stated in section 2.3.2, too much information can cause information overload. The concepts AIS+, web AIS+ and AR display the same information but in different ways. For example, one may argue that using a phone while maneuvering is dangerous, as it takes the attention away from the driving. As with the passenger eHMI concepts, a mounted display is the preferred method. Nevertheless, this needs to be researched further and tested in real-life experiments, not only in VR simulator.

3. Can automation transparency help to build trust for passengers and conventional ships?

One may question how transferable VR simulations are to real-life test experiments. To test for trust, according to section 2.3.3 the situations should consist of both uncertainty and vulnerability, which is not present in the VR-simulator. The participants are in a safe environment where they are never exposed to any form of danger. The participants had to visualize how they would have felt in real life, which can have given unreliable results. According to (Clarke, 2021), there need to be completed more studies on VR to research how close it can replicate real-life experiments.

In this thesis, trust has been researched using subjective testing. In the pre-survey, 59.7% (table 4.2) answered that automation transparency would have a positive impact on trust as them being passengers. In the evaluation survey, 42.9% (table 5.1) said they would feel safer if automation transparency was available. According to (Høklie, 2017), transparency is one of three components that is required to have trust (the others are comfort and control). Therefore, automation transparency on its own is not enough to build trust. In addition, passengers already have high trust in commercial transportation vehicles since they have to pass strict regulations that demand extensive testing. Some participants in the user test communicated that if the ferry behaved strangely or something odd happened, automation transparency would be of high value as it explains why it behaves in a certain way. Given the answers from the evaluation survey, automation transparency could build trust if an odd situation occurs, but in general, status and intentions may serve more as a "nice to have" feature than a necessity as the passenger already has high trust in the ferry because of the high trust in authorities.

In the pre-survey and the evaluation survey, 66.4% and 61.9% respectively, said their information needs are higher for autonomous vessels compared to conventional vessels and in the pre-survey 84% explicitly wanted to know if the ship is autonomous. This may indicate that the participants feel more unsure about autonomous vehicles. According to James Reason's Swiss Cheese Model (section 2.3.4) the boat drivers have the full right to be skeptical of the introduction of new technology. Automation transparency enables nearby vessels to get information about the autonomous ship, covering the extra information needed for autonomous vessels. It is a general belief that eHMI will improve trust in automated vehicles and the sense of security and make it clearer to understand the intentions of automated vehicles (Ortega, 2022), but more research needs to be completed to conclude if this is also true for autonomous maritime vessels.

4. What are the consequences of using automation transparency?

As stated above, for the passengers onboard a MASS, automation transparency may increase trust in a chaotic situation. In the evaluation survey (table 5.1), the participants were asked if lack of status and intention would reduce their usage of the ferry; 23.8% said yes. As one sees the positive aspects of automation transparency, the consequence could increase in acceptance rate (Herlocker et al., 2000). This would probably happen as well to autonomous ferries when they become an integrated part of the public transport system, and as a consequence, the importance of automation transparency may be reduced. However, as stated in (Lee and See, 2004), the degree of trust humans have in automation may influence the usage.

In the evaluation survey, 61.9 % said they would increase the distance to the nearby vessel if they knew the vessel was autonomous (table 5.2). This may indicate that explicit marking of autonomous vehicles will lower the confidence of other boat drivers. One may ask if it is a good idea to classify the vessel as autonomous to others as in the end, the autonomous vessel is just another vessel that shall behave by following COLREGS like everyone else. Nevertheless, it has been shown that decisions based on ship movements are prone to errors and misunderstandings (Veitch and Alsos, 2021). These misunderstandings must be solved by communication, and it is essential that ship-to-ship communication is possible. Automation transparency may increase safety at sea. In the evaluation survey, 95.2% (table 5.2) reported that safety would increase if eHMI boat driver concepts were available. However, since this has only been tested in a VR simulator, the results are hard to verify, and the consequences of eHMI need to be researched further.

Chapter 7

Conclusion

This thesis has researched the importance and effect of automation transparency for MASS. A VR simulator for eHMI concepts in the maritime domain has been developed. In total have 11 concepts, 5 passenger eHMI concepts, and 6 leisure boat eHMI concepts been implemented. The passenger eHMI concepts test situation awareness, trust, and satisfaction. The boat driver eHMI concepts test information needs, situation awareness, decision-making, and satisfaction. The eHMI concepts were tested by conducting an user test with 21 participants.

With the assumption that VR is transferable to real-life test experiments, it is believed that eHMI will improve trust in automated vehicles, sense of security and make it clearer to understand the intentions of automated vessels in the maritime domain. Furthermore, given the eHMI concepts developed in this thesis, a fixed display seems to be the most promising option to receive information where the end-user wants to know as much information about the situation as possible.

Passengers rate general information about the journey the highest. The majority wants to know the status and intentions of the MASS and believes that this will increase the trust and comfort level. The consequence of excluding automation transparency for passengers will to a small degree, affect the usage negatively, but further work needs to be completed before one can conclude.

Information needs are higher for autonomous vessels compared to conventional vessels. Boat drives rate the route plan of the MASS the most important. Information about which vessels were identified and whether the operator had taken control was also of interest. The consequence of knowing the vessel is autonomous could result in an increased distance to the MASS compared to conventional ships. Further investigation is needed to conclude if the eHMI concepts will increase safety, but the results are promising.

The completed work in this thesis has laid the foundations for real-life experiments, where further progression can be obtained to achieve the full potential for autonomous maritime vessels.

Chapter 8

Future work

The future work recommendations are meant to inspire further research.

- Iteration stage number two. Following the user interface design process, the next step after the test and evaluation stage is to go back and re-design the concepts.
- Concepts should be similar to the final design: The developed concepts serve as a good indicator of which concepts have the potential. The next generation of concepts should be closer to the final design to be more realistic.
- The previous user test evaluated every concept individually. Combining different concepts should be tested (for example, the passenger has available the fixed display, handheld display, and speaker at the same time).
- Besides evaluating the boat driver concepts in a motorboat, other vessels should also be included, for example, kayaks.
- Conduct a new user test with the next version of the concepts. The participants should include the recommended eight personas, and ideally, more people should attend the user test. Instead of only using subjective test measurements, objective test measurements should be used as well (observe the test user with numeric scales, frequency of actions, heart rhythm, etc.)
- All concepts have been tested in good weather conditions in VR. Changing the different weather types should be considered.
- Make physical prototypes for the highest-rated concepts and test them in real-life experiments.

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Appendix A

Additional Material

Attachments for evaluating trust between people and automation, the Google form used in the pre-survey and the Google form used in the evaluation survey.

Checklist for Trust between People and Automation

Below is a list of statement for evaluating trust between people and automation. There are several scales for you to rate intensity of your feeling of trust, or your impression of the system while operating a machine. Please mark an "x" on each line at the point which best describes your feeling or your impression.

(Note: not at all=1; extremely=7)

1 The system is deceptive

1 2 3 4 5 6 7

2 The system behaves in an underhanded manner

1 2 3 4 5 6 7

3 I am suspicious of the system's intent, action, or outputs

1 2 3 4 5 6 7

4 I am wary of the system

1 2 3 4 5 6 7

5 The system's actions will have a harmful or injurious outcome

1 2 3 4 5 6 7

6 I am confident in the system

1 2 3 4 5 6 7

7 The system provides security

1 2 3 4 5 6 7

8 The system has integrity

1 2 3 4 5 6 7

9 The system is dependable

1 2 3 4 5 6 7

10 The system is reliable

1 2 3 4 5 6 7

11 I can trust the system

1 2 3 4 5 6 7

12 I am familiar with the system

1 2 3 4 5 6 7

Figure 8. Proposed questionnaire to measure trust between people and automated systems.

Masteroppgave

Hei!

Min masteroppgave handler om å designe og teste løsninger for hvordan en autonom (selvkjørende) båt kan kommunisere sin status, rute og situasjonsforståelse med omverden.

Jeg skal ta utgangspunkt i et forskningsprosjekt som utvikles på NTNU som har som mål å utvikle den første (!) autonome passasjerfergen i verden.

Passasjerfergen er under bygging, så for å teste mange løsninger raskt og billig skal jeg lage et VR (Virtual Reality) program.

*Må fylles ut

Kort om deg

1. Kjønn *

Markér bare én oval.

- Mann
- Dame

2. Alder *

Markér bare én oval.

- Under 18 år
- 18-25 år
- 26-35 år
- 36-45 år
- 46-55 år
- 56-65 år
- 66-75 år
- Eldre enn 76 år

3. Er du båtvant? *

Markér bare én oval.

- Ja
- Nei

4. Anser du deg som en teknologioptimist/entusiast? *

Markér bare én oval.

	1	2	3	4	5	
Liten grad						Stor grad

5. Hvor fortrolig er du med autonome båter? *

Markér bare én oval.

	1	2	3	4	5	
Liten grad						Stor grad

Autonom passasjerfergetur

Passasjerfergen kjører autonomt (helt av seg selv), mens operatøren (kapteinen) er på land og kan overta kontrollen ved behov.

Alle ombord er passasjerer og det er plass til 12 personer. Strekningen er på 100 meter og går fra den ene siden av kaien til den andre.

Se video av prototypen av passasjerfergen (ca 1 minutt)

http://youtube.com/watch?v=L_G_Cemgfgg

Endelig versjon av passasjerfergen

6. Nevn de 3 viktigste faktorene for at du skal føle deg trygg ombord? *

7. Hva slags informasjon bør være tilgjengelig for passasjerene?

Merk av for alt som passer

- Ankomsttid
- Planlagt rute
- Fart
- Havdybde
- Strømhastighet og strømretning
- Kjørestatus (forskjørsrett/vikeplikt)
- Avvik fra planlagt rute
- Hvilke båter som er registeret av fergen
- Hvilke båter som utgjør en kollisjonsrisiko
- Sjanse for kollisjon
- Eventuelle handlinger som operatøren (kapteinen) foretar seg
- Andre:

Designkonsepter

Nedenfor presenteres flere konsepter for å formidle informasjon (status, kjøremodus, situasjonsforståelse og intensjon) til passasjerene.

Disse skal du nå evaluere.

8. Skjerm (viser status, rute, identifiserte båter og planlagte handlinger) *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

9. Nettside/app for mobil (samme informasjon som skjerm) *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

10. AR-app på mobil (bruker kameraet på mobilen til å se markering rundt objekter som båten har identifisert og rute). * AR = Argumented Reality

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

11. Lyssignaler (viser planlagt rute og identifiserte båter) *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

12. Lydsignaler (sier planlagt rute og identifiserte båter) *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

13. Har du forslag til andre konsepter?

14. Som passasjer har du behov for å vite om fergens status, intensjon og situasjonsforståelse? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

15. Hva slags tillit har du til at en autonom passasjerferge transporterer deg trygt frem? *

Markér bare én oval.

	1	2	3	4	5	
Veldig liten						Veldig stor

16. Ville tilliten din økt hvis du kunne sett direktesendt video av operatøren (kapteinen)? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

17. Ville tilliten din økt hvis du visste fergens status, intensjon og situasjonsforståelse? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

18. Eventuelle andre kommentarer kan du skrive her

Deling av situasjonsforståelse og intensjon fra autonom båt til andre skip

Denne delen skal kartlegge hvordan en autonom båt best kan kommunisere sin situasjonsforståelse og intensjon til andre skip. Du er nå sjåfør på en fritidsbåt og er i samme farvann som autonome båter og menneskestyrte båter.

19. Ønsker du å vite om båten i nærheten er autonom? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

20. Ville du manøverert annerledes hvis du visste at båten i nærheten var autonom? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

21. Er informasjonsbehovet ditt større for båter i nærheten som er autonome enn menneskestyrte? *

Markér bare én oval.

	1	2	3	4	5	
Liten grad						Stor grad

22. Hvor trygg ville du følt deg hvis du navigerte i nærheten av en autonom båt? *

Markér bare én oval.

	1	2	3	4	5	
Veldig utrygg						Veldig trygg

23. Hva slags informasjon skulle du ønske var tilgjengelig om den autonome båten? *

Merk av for alt som passer

- Rute
- Båter den har oppdaget
- Kjøremodus (følge planlagt rute, unngå kollisjon)
- Hastighet
- Hvilken hindring (båt) som er hovedfokuset
- Om den menneskelige operatøren (på land) har tatt over styringen
- Trygghetssone
- Andre:

Designkonsepter

Nedenfor presenteres flere konsepter for hvordan informasjon om en autonom båt kan formidles til fritidsbåter i nærheten.

Disse skal du nå evaluere.

24. App/nettside *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

25. AR-app *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

26. Lyssignaler *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

27. Smartspeil *

Markér bare én oval.

	1	2	3	4	5	
Veldig dårlig						Veldig bra

28. Har du forslag til andre konsepter?

29. Eventuelle andre kommentarer kan du skrive her

Evaluering av VR-konsepter

*Må fylles ut

1. Kjønn *

Markér bare én oval.

- ◯ Mann
- ◯ Dame

2. Alder *

Markér bare én oval.

- ◯ Under 18 år
- ◯ 18-25 år
- ◯ 26-35 år
- ◯ 36-45 år
- ◯ 46-55 år
- ◯ 56-65 år
- ◯ 66-75 år
- ◯ Eldre enn 76 år

3. Har du båtsertifikatet? *

Markér bare én oval.

- ◯ Ja
- ◯ Nei

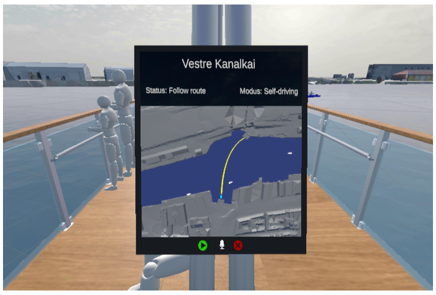
Passasjer

4. Hva slags informasjon bør være tilgjengelig for passasjerene? *

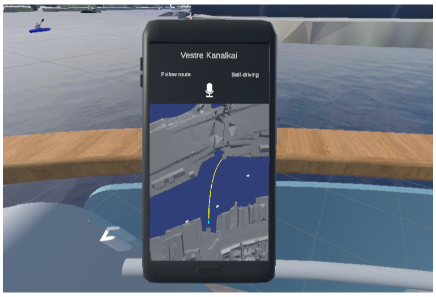
Merk av for alt som passer

- ☐ Ankomsttid
- ☐ Planlagt rute
- ☐ Fart
- ☐ Havdybde
- ☐ Strømhastighet og strømretning
- ☐ Kjørestatus (forskjørsrett/vikeplikt)
- ☐ Avvik fra planlagt rute
- ☐ Hvilke båter som er registeret av fergen
- ☐ Hvilke båter som utgjør en kollisjonsrisiko
- ☐ Sjanse for kollisjon
- ☐ Eventuelle handlinger som operatøren (kapteinen) foretar seg
- ☐ Andre: ________________

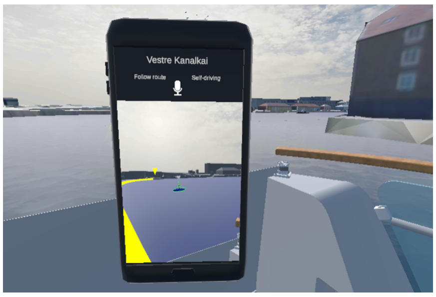
Skjerm



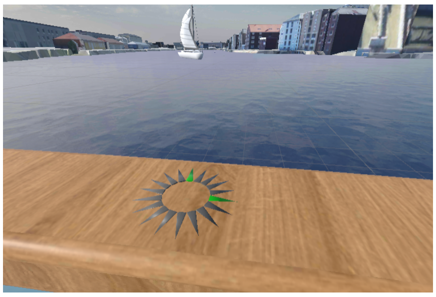
Mobil



AR



Lys-display



5. Konseptet formidler oversikt over situasjonen (situasjonsforståelse)? 1 = dårligst, 7 = best *

Markér bare én oval per rad

	1	2	3	4	5	6	7
Skjerm	◯	◯	◯	◯	◯	◯	◯
Mobil	◯	◯	◯	◯	◯	◯	◯
Ar-app	◯	◯	◯	◯	◯	◯	◯
Lys-display	◯	◯	◯	◯	◯	◯	◯
Høytaler	◯	◯	◯	◯	◯	◯	◯

6. Eventuelle kommentarer til forrige spørsmål

____

7. Konseptet øker tilliten til fergen? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
Skjerm	◯	◯	◯	◯	◯	◯	◯
Mobil	◯	◯	◯	◯	◯	◯	◯
Ar-app	◯	◯	◯	◯	◯	◯	◯
Lys-display	◯	◯	◯	◯	◯	◯	◯
Høytaler	◯	◯	◯	◯	◯	◯	◯

8. Eventuelle kommentarer til forrige spørsmål

____

9. Ville du benyttet deg av konseptet hvis du hadde muligheten? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
Skjerm	◯	◯	◯	◯	◯	◯	◯
Mobil	◯	◯	◯	◯	◯	◯	◯
Ar-app	◯	◯	◯	◯	◯	◯	◯
Lys-display	◯	◯	◯	◯	◯	◯	◯
Høytaler	◯	◯	◯	◯	◯	◯	◯

10. Eventuelle kommentarer til forrige spørsmål

____

11. Hadde du følt deg uttrygg i fergen hvis informasjon om status og itensjon ikke var tilgjengelig? *

Markér bare én oval.

- ◯ Ja
- ◯ Nei
- ◯ Vet ikke

12. Begrunn svaret *

____

13. Er sjansen mindre for at du benytter deg av en autonom ferge i fremtiden hvis informasjon om status og intensjon ikke er tilgjengelig? *

Markér bare én oval.

- ◯ Ja
- ◯ Nei
- ◯ Vet ikke

14. Begrunn svaret *

____
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Båtsjåfør

15. Ønsker du å vite om båten i nærheten er autonom? *

Markér bare én oval.

- ( ) Ja
- ( ) Nei
- ( ) Vet ikke

16. Begrunn svaret *

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17. Hva slags informasjon skulle du ønske var tilgjengelig om den autonome båten? *

Merk av for alt som passer

- [ ] Rute
- [ ] Båter den har oppdaget
- [ ] Kjøremodus (følge planlagt rute/unngå kollisjon)
- [ ] Hastighet
- [ ] Hvilken hindring (båt) som er hovedfokuset
- [ ] Om den menneskelige operatøren (på land) har tatt over styringen
- [ ] Trygghetssone
- [ ] Andre: ______________________

18. Er innformasjonsbehovet ditt større for båter i nærheten som er autonome enn menneskestyrte? *

Markér bare én oval.

	1	2	3	4	5	
Liten grad	( )	( )	( )	( )	( )	Stor grad

19. Eventuelle kommentarer til forrige spørsmål

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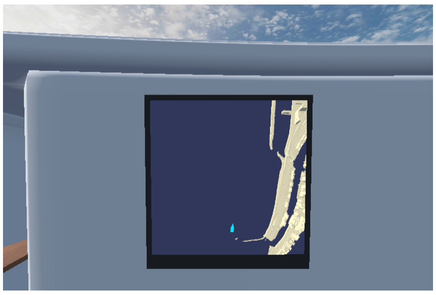
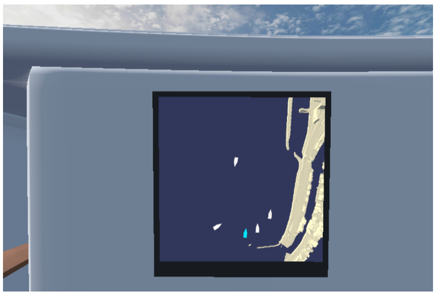
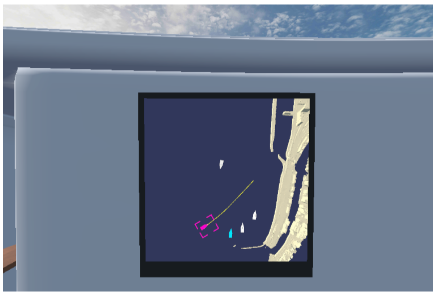
GPS



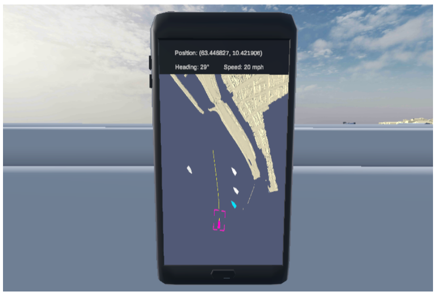
AIS



AIS+

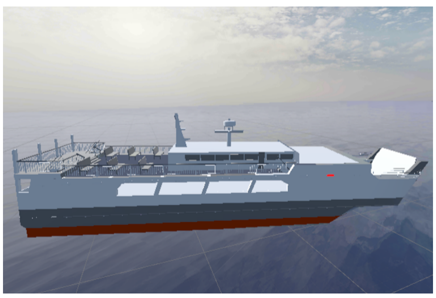


Mobil (AIS+)



AR

Lyssignaler



20. Dekker konseptet informasjonsbehovet ditt? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
GPS	( )	( )	( )	( )	( )	( )	( )
AIS	( )	( )	( )	( )	( )	( )	( )
AIS+	( )	( )	( )	( )	( )	( )	( )
Mobil (AIS+)	( )	( )	( )	( )	( )	( )	( )
AR-app	( )	( )	( )	( )	( )	( )	( )
Lyssignaler	( )	( )	( )	( )	( )	( )	( )

21. Eventuelle kommentarer til forrige spørsmål

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22. Konseptet formidler oversikt over situasjonen (situasjonsforståelse)? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
GPS	( )	( )	( )	( )	( )	( )	( )
AIS	( )	( )	( )	( )	( )	( )	( )
AIS+	( )	( )	( )	( )	( )	( )	( )
Mobil (AIS+)	( )	( )	( )	( )	( )	( )	( )
AR-app	( )	( )	( )	( )	( )	( )	( )
Lyssignaler	( )	( )	( )	( )	( )	( )	( )

23. Eventuelle kommentarer til forrige spørsmål

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24. Konsptet hjelper deg med å ta trygge og gode valg? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
GPS							
AIS							
AIS+							
Mobil (AIS+)							
AR-app							
Lyssignaler							

25. Eventuelle kommentarer til forrige spørsmål

26. Ville du benyttet deg av konseptet hvis du hadde muligheten? *

Markér bare én oval per rad

	1	2	3	4	5	6	7
GPS							
AIS							
AIS+							
Mobil (AIS+)							
AR-app							
Lyssignaler							

27. Eventuelle kommentarer til forrige spørsmål

28. Hadde du hatt større avstand til den autonome båten uten bruk av konseptene? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

29. Begrunn svaret *

30. Øker tryggheten til den autonome båten ved bruk av konseptene? *

Markér bare én oval.

- Ja
- Nei
- Vet ikke

31. Begrunn svaret *

32. Eventuelle andre kommentarer kan du skrive her

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