Exploring the Usage and Potential of Augmented Reality at Sea

Master's thesis in Product Development

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Abstract

This master's thesis explores the potential of augmented reality as a navigational aid in maritime environments. The aim has been to investigate how AR technology can improve safety, user experience, and efficiency for boat users. The project has been carried out in collaboration with Volvo Penta and Chalmers University of Technology and follows an iterative product development process with a strong focus on user needs.

Data to aid the development was collected through surveys, interviews, and a focus group involving both experienced and novice boat users. Based on this input, three conceptual solutions were developed and evaluated using Pugh and Kesselring matrices. The most promising concept, "The All-in-One AR Assistant", was selected for further development. A detailed requirements list was created to define functional needs and guide the development of a minimum viable product. Two prototypes were developed in Figma and Unity for the Magic Leap 2 AR headset and tested in realistic marine environments.

The results indicate that AR can enhance situational awareness, support decision-making, and offer a more intuitive navigation experience, especially in low-visibility or high-stress scenarios. The study also identifies key design challenges, such as information filtering, user customisation, and the potential pitfall of overreliance on technology. The study concludes that AR shows strong potential for marine navigation, although a lot of further development in both hardware and software as well as user testing is needed to make an AR martime product ready for the market.

Keywords: Augmented Reality, Maritime Navigation, Product Development

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Andreas Belle Nylén & Gustaf Lööf, Gothenburg, May 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

AR	Augmented Reality
AIS	Automatic Identification System
HMD	Head Mounted Display
IMU	Inertial Measuring Unit
ML2	Magic Leap 2
OEM	Original Equipment Manufacturer
POI	Point Of Interest
SLAM	Simultaneous Localisation and Mapping
TRL	Technology Readiness Level
UI	User Interface
VR	Virtual Reality
XR	Extended Reality

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1
Introduction

Transportation and technology are at the heart of modern society, enabling connectivity, efficiency, and sustainability. The rise of extended reality technologies, particularly augmented reality, presents a unique opportunity to enhance the marine experience. From improving navigation to simplifying docking operations, AR can provide real-time, intuitive support to both original equipment manufacturers and end users, such as boat owners and operators. [2] This project focuses on exploring and prototyping AR solutions to address real-world challenges in the marine industry.

1.1 Background

There is a fast-paced digital transformation in the maritime industry driven by rapid progress in artificial intelligence and the Internet of Things. These technologies have enabled the development of things such as smart navigation systems that enhance safety and efficiency on board. However, despite these technological developments, navigation and monitoring systems on boats still require a lot of interpretation and process a lot of data from different sources. This can lead to cognitive overload and reduced reaction times [29].

In a collaboration between Chalmers University of Technology and Volvo Penta, a unique subject was proposed: investigate how AR can be used in a maritime environment.

1.1.1 Volvo Penta company

Volvo Penta was founded in 1907 and is now part of the larger Volvo Group, which delivers sustainable transport and infrastructure solutions worldwide [38]. Penta's products are power solutions applied in two different categories, the marine sector and the industrial sector. The marine sector offers products such as engines, propulsion systems and other smaller equipment to enhance the boating experience, i.e., steering options.

Even though the main focus at Volvo Penta are their development of engines and propulsion systems, a rise of innovations in automation and digitalization can be seen, such as their Glass Cockpit System from 2013 or the Volvo Penta Easy Connect from 2018.

Volvo Penta customers are primarily original equipment manufacturers, or OEMs for short, and suppliers globally. Pentas customers are the ones with direct contact with the end-users in both the leisure boat and commercial boating categories.

1.2 Project description

This project explores the use of AR to enhance the experience of boating in commercial and recreational use cases. As AR technologies continue to become more easily accessible and more capable, this project aims to look into how such technologies can contribute to marine navigation, safety, and create value for individuals at sea. The research will identify specific areas of use in which AR can deliver tangible benefits on water and then develop an operative proof of concept demonstrating one or more of such usages.

1.2.1 Purpose

The purpose of this project is to create knowledge and research in the emerging world of augmented reality and human-computer interaction. Research into the use cases of augmented reality at sea can serve to improve and streamline the boating experience, both for commercial and private stakeholders. Then to use a product development methodology to provide a conceptual product for these use cases with a functional prototype for testing and showcasing the potential of the product.

By creating new knowledge and research into how augmented reality can be used at sea, maritime safety and operational efficacy can be increased, together with enhancing boating experiences for both beginners and experienced boat drivers in commercial and leisure applications.

The intent is to make new contributions regarding the possibilities of AR in marine environments and show its practicability via a functional concept specifically designed for implementation onboard boats.

1.2.2 Limitations

The target groups of the project will be both commercial boat users and leisure boat users. However, depending on the quantity of people from the target groups available for the study, people not within the target groups might be used in, e.g. evaluations about how intuitive the solution is. During the project different use cases will be investigated, and these cases will be the base for what the prototype is going to do; however, due to time limitations, not all of the produced use cases will be implemented.

The project will be carried out in Sweden and therefore the testing will be done in Swedish environments, and the investigation into implementing a similar product elsewhere might be limited. This will also entail that the majority of people involved

in studies and evaluations will mostly be Swedish or be located in Sweden. Laws and regulations, e.g. for navigation, will be based on Swedish regulations, and they might be different elsewhere in the world.

Additionally, this thesis is undertaken as a product development thesis, and a product-developing framework and mindset will permeate through the entire process, meaning that the prototype software and accommodating hardware are one piece of the project and not the whole project, as the case might be had this thesis instead been written in a computer science or IT department.

1.2.3 Ethical considerations

Firstly, this thesis is supported by Volvo Penta, who have shared important resources, e.g. hardware that would otherwise not be available to the thesis and would have a significant impact on the results. It is therefore important to be transparent with this fact.

Secondly, when developing navigational aids, there is research suggesting that such aids and tools can trick users into a false sense of security and overreliance on technology [14]. This has the potential of causing harm to humans, animals and the environment and remains an important consideration when developing applications on the combined subject of AR and navigation.

This thesis contains interviews and survey results from potential stakeholders; all of the participants have been given the option to remain anonymous if they choose, and indeed, the identities of individuals beyond their work or hobby in a marine environment are irrelevant for the purposes of the questions that are intended to be answered either way. Further, we are bound by GDPR when conducting the study; this means, among other things, that participating individuals also have the ability to request that their personally identifiable information be removed at their request if we choose to store such information.

1.3 Literature review and similar works

To get a better understanding of the academic and engineering landscape involving augmented reality and its use in maritime environments, a literature study was performed. Searching on Google Scholar, the keywords “augmented reality” and “maritime” yield around 54 000 results at the time of writing; generally, most studies that were tagged with these keywords are about the use of augmented reality for assisting navigation in some regard. A couple handpicked studies will be reviewed in this section, and while most of the papers retrieved are geared towards larger, commercial cargo ships, conclusions that are useful for the purposes of this project are presented.

Firstly, a useful literary review for the Journal of Navigation that details eleven different papers on the use of augmented reality for navigation and estimation of

the TRL for each project was investigated. AR was used both on traditional screens and HMDs. For this thesis, this review paper tells us that there exists quite a bit of research on AR for navigation to consider for this project [16]. Another retrieved paper was about AR for sailing [15]. It explores some differences with AR for navigation with regards to sailing instead of a propeller for propulsion.

In addition, two studies that focus exclusively on AR for use on smartphones were evaluated. The first study evaluated the use of an application that would warn captains of smaller vessels when their boat was about to reach waters where the depth is less than three meters. The phone sounds an alarm, the captain picks the phone up, and an overlay in the phone's camera feed highlights the shallow waters to be avoided [30].

The other study that existed purely on a smartphone evaluated how an AR application could be used to create an interactive guided tour of a shipwreck that was sunk just off the coast of Crete. In the study, users are guided up to a vantage point by the app, where a recreation of the sinking is shown with AR and additionally displays an interactive underwater 3-Dimensional scene of the wreck site [18].

Finally, a paper as part of the conference proceedings 51st Nordic Ergonomics and Human Factors Society Conference 2022 was investigated. The paper explores what maritime problems AR could help or alleviate, and additionally, users attitudes towards devices used to facilitate AR [1].

Additionally, some relevant patents were evaluated to get a better insight into the patent landscape. Two patents that are relevant to this project were investigated further. Firstly, a South Korean patent on how a neural network can detect and track other vessels from a digital camera stream [27]. And secondly, a patent by Flir states that a computer can distinguish what it is looking at in a maritime setting and display relevant content based on camera input [13].

There has already been quite a lot of research on the subject of AR at sea, but the circumstances of this project makes it uniquely positioned to target an area that has fewer studies while still being able to take advantage of ''the broad strokes" from the works and patents in adjacent areas.

2
Theory

In the following sections, a brief explanation of the theory used in the thesis will be carried out.

2.1 Primary Data Collection

According to Denscombe, the choice of primary data collection methods i.e. surveys, interviews, and focus groups, should be based in the researchers understanding of knowledge and the type of data that is wanted [8].

- **Surveys** align with positivist approaches, aiming for objectivity and generalizability. They are suited for collecting standardized and quantifiable data from a large number of people.
- **Interviews** Interviews are used when researchers want to understand people's personal experiences and opinions. Instead of using fixed questions, interviews often have more open conversations so that participants can explain things in their own words, which leads to qualitative data.
- **Focus Groups** Focus groups are used to learn what people think and how they talk about a topic in a group setting. When people share and respond to each other's ideas, it can help researchers see common views, disagreements or new ideas that come up through discussion. This method is helpful for understanding group opinions and social interaction [8].

Denscombe highlights that methodological choice should reflect the research question, theoretical framework, and the type of knowledge being pursued.

2.2 Data analysis

To get a better understanding of stakeholders, the market feasibility and to develop insights further, some tools for data analysis are used.

2.2.1 KJ-analysis

KJ Analysis was developed by Jiro Kawakita and is a method to organize qualitative data into groups [34]. It is often used in product development and design to cluster related ideas (i.e. from interviews and focus groups) into groups to identify patterns and themes. This helps organize complex data such as quotes into requirements and pain points.

2.2.2 Requirement list

To determine what is a must for any product and what is ”nice to have”, it is common to write a requirement list. In the list it is decided if a particular feature of a product is an absolute must or can be optional depending on different trade offs. It is not uncommon to change or update this list during the development process when more knowledge is gathered and available.

2.3 Concept Generation

To aid the product development cycle, a couple of methods to help developers think about what product they are developing and perhaps more importantly, who or what they are developing for will be used.

2.3.1 Personas & Scenarios

Personas and scenarios are often used in design to more easily connect user needs to the product in development [31]. A persona is a fictional character based on user research and it represents a specific group of people in the target group. It includes details such as demographics, goals, behaviors, and pain points. Personas help designers stay user-focused and develop empathy throughout the design process. A scenario is a fictional story that describes how a persona interacts with a system in a specific environment. Scenarios provide insight into user tasks, motivations and constraints. Personas and scenarios together guide design decisions, give context to requirements and ensure solutions are grounded in real-world use.

2.3.2 Brainstorming

Brainstorming is a method to generate a large amount of ideas in a short time, it prioritizes quantity over quality and produces the most ideas possible. A key to brainstorming is to not judge any ideas but instead encourage outside-the-box thinking [28]. Brainstorming has limitations and without proper refinement and evaluation of the ideas, it will mostly lead to insufficient solutions.

2.4 Concept Evaluation

Since the aim is to develop one product, it is useful to try to pick the best parts of different concepts and if possible merge to one final concept, to do this, A Pugh matrix and Kesselring matrix will be used.

2.4.1 Pugh Matrix

The Pugh Matrix is a tool to compare concepts in a methodical way. It bases the scores of the concepts on how they perform against a reference on different requirements [5]. Simple scoring with “+” better than, “-” worse than or “0” the same as the reference for each criterion. This can be iterated with different references

and with the concepts as references to compare all concepts against each other. The Pugh Matrix gives both a simple solution to derive the best concept and to see for each requirement which solution performs the best.

2.4.2 Kesselring

The Kesselring matrix is a method that can give a more accurate result based on requirements since the requirements are weighted against each other [36]. This adds another dimension to the evaluation. Each requirement is assigned a "score" that defines the importance of that specific requirement to the overall goal. This method helps prioritize criteria and gives a more nuanced comparison between the concepts.

2.5 Business Model Canvas

The Business Model Canvas, developed by Osterwalder and Pigneur, is a strategic tool used to describe and analyse the core elements of a business model [26]. The canvas is structured around nine different categories: *customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure.*

2.6 Augmented Reality

Augmented Reality is the technology that utilises a number of digital elements, for example, images, 3D models, or data, and mixes them with the real world in real time. Augmented Reality should be distinguished from Virtual Reality. In VR the user gets immersed in a completely digital world, whereas AR enriches the reality with virtual elements that are relevant to the context and the position of the user. AR can be perceptible with the help of smartphones, tablets, head-mounted displays or smart glasses [3].

General AR systems consist of three main elements: a display device, a set of sensors that are tracking the surroundings and the position of the user, and a computing platform to process and visualise digital content. When it comes to realising mixed reality, the systems rely on positional awareness. The positional awareness can be attained by using IMUs, SLAM and computer vision to align the virtual content and keep it in place relative to the real world [7].

The definition of AR can trace its roots to the article ”A Taxonomy of Mixed Reality Visual Displays” by Milgram and Kishino, where they introduce a single-dimension axle in which the real world and the virtual world are blended along a continuum. While virtual reality is positioned near the edge of this continuum, where the real world is blocked out and all that the user perceives is the digital content, augmented reality in its turn is more in the direction of the real world since it still lets the user see the reality that is around them while just adding a thin layer of digital elements

over it [23].

Moreover, AR has already been tried out in a myriad of applications and uses. Among other areas, augmented reality finds its application in industry. This technology supports a person in their everyday work. Augmented Reality also facilitates the learning process since it can, for instance, visualise the theory in a playful and interactive way [4].

AR presents several challenges, especially in terms of accurate spatial registration, consistently maintaining real-time performance, and the creation of user-friendly interfaces. Furthermore, finding innovative and practical solutions to deal with issues, such as the limited field of view, handling occlusions, and long-term wearability of devices, is still an active research area.

2.7 Figma

Figma is a cloud-based design and prototyping tool used to create user interfaces, wireframes, and interactive mockups. It helps collaboration which makes it especially valuable in team environments where multiple designers or developers work together. With Figma designers can build online prototypes without writing code, which helps early-stage user testing and validating design choices. This makes it an ideal tool in the prototyping and testing phases of the Design Thinking process [9]

2.8 Unity game engine

Unity is a video game engine originally launched in 2005. It has since evolved to support cross-platform development for Windows, macOS, Android and supports multiple AR and VR headsets. [37]
Unity uses a modular system where scripts and attributes can be attached to different game objects and is commonly the first game engine developers learn to use, due to its relative ease of use and large community.
In recent years, Unity has found uses outside of video games as well, for instance, at Volvo Group.

3
Method

The project followed an iterative, user-centered design process inspired by Design Thinking [17]. The process was structured into six main phases: Empathize, Define, Ideate, Prototyping, Testing, and Implementation. Each phase involved specific methods and tools used to understand user needs, generate and evaluate ideas, and develop a functional prototype. An overview of the full process is presented in Figure 3.1.

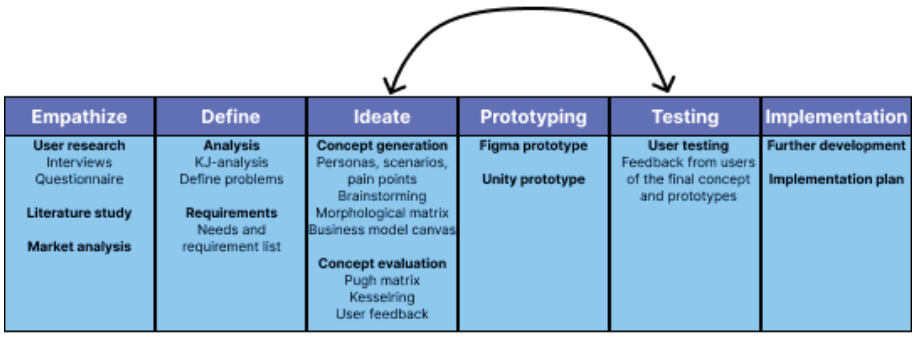

Figure 3.1: Flowchart of the process

3.1 Data collection

To gather more data on the kind of user the product would be developed for, three primary data collection methods: interviews, surveys and focus groups were used.

3.1.1 Survey

To quickly gather quantitative information about people's experiences at sea, a survey was created. The survey was then published in a few Facebook groups related to boating and the Swedish archipelago, which resulted in 52 responses, and the survey was also sent out to a group of boat owners at Volvo Penta, which resulted in 40 responses. The survey aimed to gather information from people within different age groups and with different boating experiences to see what different problems are experienced in connection to boating. The survey was divided into two larger categories, *General* and *Technology On Board,* where the first was about general boating experiences and the second was to see what technology was used

on boats and what problems could be seen in relation to that. Lastly, a question if the respondent would be interested in an in-depth interview, which resulted in 8 interviews. An overview of the survey can be seen in Appendix A and the results will be presented in the results chapter.

3.1.2 Interviews

Eight interviews were used in this project to collect qualitative data from boat users, this is one of the most foundational approaches for qualitative data collection [5]. The interviews were conducted in person or in a Teams-meeting depending on the interviewees preferences. One person conducted the interviews while the other took down notes from the answers given by the interviewees. The interview structure followed a semi-structured approach to get more qualitative data compared with a structured interview [5]. The semi-structured approach gave the interviewees the opportunity to speak freely about open-ended questions and not be dictated to specific answers. The template for the interviews may be revived in Appendix C.

3.1.3 Focus group

To further gather qualitative data on the subject, a focus group was conducted. The focus group was meant to complement the interviews since the interviewees mostly had a lot of boating experience, at least 5 years or more. The focus group consisted of 6 people between 20 and 30 years of age with limited to low boating experience. The aim of the focus group was similar to the aim of the interviews but for a less experienced group and to get them to discuss with each other. A semi-structured interview guide was used, consisting of open-ended questions focused on participants perceptions and experiences of being at sea. Difficulties, feelings of safety or insecurity and suggestions for improvement or support were discussed. The guide was designed to encourage open discussion rather than factual responses.

3.2 Concept development

To gather knowledge from the information gathered, four data analysis strategies were used: KJ-analysis, brainstorming, a Pugh matrix and a Kesselring matrix. The results where then used to help which concepts would be going forward in the product development process.

3.2.1 KJ-analysis

The KJ-analysis was used to cluster the complex data from the interviews to structure it and get a better picture. The answers was grouped into themes and then into smaller groups within that theme. The themes were *Boating & Experience, Challenges, Safety, Technology & Needs and Augmented Reality.*

3.2.2 Brainstorming

A structured brainstorming session was conducted to generate potential features and solve the identified user needs and pain points. The team focused on ideating freely, prioritizing quantity over feasibility in this initial stage. All ideas were later categorized and put into a morphological matrix together with insights from earlier interviews and surveys see Appendix F. This process enabled the creation of concepts and ensured a large range of different solutions were explored before narrowing down to the three main AR concept directions.

3.2.3 Pugh matrix

To evaluate the final three AR concepts a Pugh matrix was conducted as a structured decision-making tool. The matrix gave a systematic comparison of each AR concept against a set of predefined functional requirements derived from the data collection.

In the first iteration, a fully equipped boat outfitted with Garmin marine systems such as chartplotter, sonar, radar, AIS, and other standard navigation tools was used as the reference. This system represents a complete and commonly used navigation solution, which provides a relevant reference for assessing the added value of AR systems. Each AR concept was evaluated relative to this reference across criteria such as for navigation, vessel data, conditions and docking. “+”, “-” or “0” scores were assigned based on the degree to which each concept fell short, met or exceeded the performance of the reference system.

Following the initial assessment, two additional Pugh matrix iterations were conducted. In each of these, one of the previously evaluated AR concepts was used as the new reference. This approach enabled a deeper comparison between concepts themselves, instead of only in the relation to marine electronics commonly used today. By changing the reference, the evaluation showed relative strengths and trade-offs among the AR concepts which provided a more robust basis for selecting the most promising solution.

3.2.4 Kesselring matrix

Following the Pugh matrix evaluations, the three AR concepts were further analyzed using a Kesselring matrix. In this phase each concept was scored from one to five across the same requirement criteria. However the criteria were not weighted equally but a weighting scheme was used based on the relative importance of each requirement. This was determined through the data collection and analysis in Appendix G. The Kesselring matrix gave a weighted scoring process which provided a more quantitative basis for the evaluation. This helped identify the concept with the highest overall performance when taking the user needs into account.

3.3 Unity prototype development

It was decided to develop the prototype using Unity, as the Volvo Group has experience developing applications for smartphones and desktops but also for AR and VR using this engine. In a similar fashion, the decision to develop the prototype for the AR headset Magic Leap 2 [21] was made, as that was the hardware available to the thesis at the time. From the data gathered from interviews and surveys, the first prototype to test should contain only the most basic features to get early feedback from user tests.

During development, a significant portion of the time was spent learning about the Unity engine and how to compile applications for the Magic Leap 2. This endeavour took most of the early weeks of the project, as it took a while to figure out how the environment and build settings should be set up in Unity to generate an application which is installable and runs as expected on the hardware.

Once the appropiate environment had been set up, features to implement and develop could be decided. The features to test were given from the data that had been gathered through the user surveys, interviews and focus group. It was decided early on that the features should only be implemented to a working state and to not spend to much time on each fature in order to test and verify as many features as possible within the given time frame.

Once the requested features were implemented to a satisfactory degree, a visit to Volvo Penta's test site at Krossholmen was scheduled. Here, feedback and additional feature requests were collected while performing usage tests. This strategy was used multiple times, giving valuable feedback and pushing the prototype development forward.

4
Data Collection

To better understand the intended users we are developing for, a user study was performed both to get quantitative data with surveys and also more in-depth qualitative data with interviews and focus groups.

Additionally, a market analysis and literature study was performed to help set up a requirements list for the product.

4.1 User survey

Reviewing the answers from both the survey sent out on social media and the survey sent out internally to Volvo Penta, some conclusions can be drawn. Firstly, the results from the public survey will be reviewed.

4.1.1 Public survey

The public survey (see appendix A) sent out to boat-interested groups on social media received 52 responses. The average respondent is an experienced boater and is middle- to retirement-aged. 4/5 ths of respondents own a boat. A large majority drive motorboats, with roughly 1/3 rd sailing sailboats. A couple of respondents sailed with both a sailboat and a motorboat. While most respondents use their boat for shorter leisure journeys, many users highlighted that they also use their boats in their daily lives to travel between islands in the southern Gothenburg archipelago, blurring the line between leisure and commercial traffic.

Generally, respondents did not find it difficult to find different nautical points of interest when selecting from a premade list of eight items (see question 8 in Appendix A). Respondents were the most interested in taking part in the following pieces of information (presented in descending order):

1. Real time weather (Wind strength, waveheight, temprature, e.t.c.)
2. Navigation
3. Water depth
4. Harbour information
5. Local warnings (Information about other boats or items in the water)
6. Speed and remaining fuel
7. Communication (From other boats and/or coastguard)

Respondents felt that they generally were not distracted by navigation equipment onboard, with traditional sea-charts being slightly more distracting than other equipment. Respondents felt the most uncomfortable while sailing with limited vision and in poor weather. The most common problem the respondents highlighted when prompted to write freely about their great challenges at sea was that there are many other captains of smaller vessels that drive often drive too fast and do not follow maritime traffic rules and that estimating distance can be tricky.

Respondents generally find it important to receive real-time updates while onboard and were very positive about installing new technologies in their boat. Respondents found it annoying to use virtual buttons on touchscreens above regular, physical buttons; most respondents also highlighted that cost and technical issues are their biggest concerns with onboard technology.

Conclusively, the survey tells us that in general, experienced leisure boaters are able to find the services and landmarks they are looking for without too much issue and are the most interested in real-time data about weather, navigation data, information about local harbours, local warnings, boat state, and communication with other vessels. Fast boats with captains that do not follow traffic rules, poor vision, and bad weather are the main scenarios that make respondents uncomfortable, and they are very positive about trying out new technologies.

4.1.2 Internal Penta survey

The responses from the Internal Volvo Penta survey yielded similar results, despite the slight changes made to the survey. One additional feature that was requested when asked about what kind of information one would like to receive was the ability to find friends, free docking spots in guest harbours and coastal restaurants was requested multiple times. One additional insight is that boat owners generally want to be given some assurance that the technology platform or brand they invest in will be supported for the foreseeable future so that the equipment will keep on working, considering the usually high up-front cost.

4.2 Interviews

To gather user data in a qualitative way interviews were conducted with six leisure boat users, one commercial driver and one from the coastguard. The interviews were semi-structured (see Appendix C) to allow the interviewees to speak freely, to not steer them in any direction and to cover all the important topics. The aim of the interviews was to gain insight into what difficulties may be encountered at sea, how the technology on the boat is used today and what trends can be observed in the industry since this is a product for the future. Three of the interviewees were directly connected to Volvo Penta and may therefore have some bias.

4.2.1 Interviews with boat users

The interviewees were selected to be a diverse group of people to involve a broad group of end-users. There were different experiences with boating, where some had grown up with it and others had started later in life. The ages ranged from 30s to 70s and there were two women and four men interviewed in this part. However, everyone was a boat owner to not go outside of our scope and get information relevant to people who actually use boats regularly. One of the interviewees also volunteered for the sea rescue service. These answers were separated, where the person answered the questions from both a personal boating perspective and a professional perspective.

The interviewees, who are leisure boat users, describe their boating in a similar way where the closeness to nature and feeling of freedom are the main reasons why they love boating. The use is similar as well, where shorter trips or daytrips are the most common except for one interviewee who got a larger sailboat and goes out for weeks at a time during summer. The interviewees use the boat during the summer months mostly, but some use it during the fall and spring as well, and the reasons that they don't go out at sea are dependent on the weather conditions. The weather conditions are also the main reason for discomfort on board, together with inexperienced people on board where the responsibilities for others come into play. The interviewees has not had many emergency situations at sea and the two out of six that have needed help have gotten it from other boats rather than having to call the sea rescue service.

All of the interviewees got a plotter on the boat, and this is also the most used technology and the most important information that the plotter gives is the location. Two of the interviewees describe the information boxes that are present on the plotter for islands or landmarks as redundant and that these boxes are more annoying than what they contribute. Other technology varied from only plotter to things such as AIS, sonar and radar. The interviewees discussed different technology that would be desired on the boat, this included radar during twilight since it can be hard to see all the boats, especially the ones without lights when it darkens. This also included cameras when docking to assist with the precision needed and one interviewee that wanted a sonar scanning forward to see what is coming, not only what is straight below.

4.2.2 Focus group

Participants in the focus group expressed uncertainty regarding navigation, understanding maritime signs, and interpreting information from technical devices in the real world. Many found nautical charts and digital navigation tools overwhelming or confusing. Several also described docking as particularly stressful, especially when other people were watching and a lot of other boats around.

Feelings of insecurity were common among the group, especially when participants imagined being alone at sea or facing changing weather conditions. Trust in others, such as more experienced passengers, was often key to participants feeling safe at

sea. The reliance on digital tools also caused concern in the case of technical failure.

Participants expressed a strong interest in more beginner-friendly resources. Suggestions included simplified navigation apps, clear signs at sea, and short instructional videos (i.e. in an app). Several participants said they felt current technology was too complex and aimed at experienced boaters, leaving them unsure where to start.

Despite the concerns, most participants associated boating with positive emotions such as freedom, relaxation, and adventure. Especially when the conditions were good and someone else was in charge. Participants generally expressed a desire to gain more experience and confidence, provided that they had easier access to this.

4.3 Literature study

According to multiple studies, difficulties with navigation are one of the most reported problems among leisure boat users at sea. A lot of boaters have limited experience of interpreting sea charts and understanding the technology equipment on boats [20]. Limited vision and new territories can lead to misjudgments and accidents. Lacking knowledge of natural harbors, shoals and safe docking places is a common problem; more often than not, there is a lack of real-time information about where it is safe to dock, especially when emergencies occur [22].

Sudden changes in weather conditions is one of the most common reasons for accidents at sea, according to Trafikverket [35]. Research shows that people don't manage to react in time when sudden weather changes occur. Limited sight, high waves and strong winds create dangerous situations where the access to visual information can be very important. Insufficient information on sea charts and misinterpreting information from instruments are also common mistakes at sea [33].

4.4 Market Analysis

To assess what kind of onboard navigation technology that is used today, a market analysis was conducted comparing leading marine electronics manufacturers, including Garmin, Simrad, Raymarine, Lowrance, Humminbird, JRC, Transas and Hatteland, see figure 4.1.

	Garmin	Simrad	Raymarine	Lowrance	Humminbird	JRC, bigger vessels	Transas, bigger vessels	Hatteland
Real-time sonar	Yes	Yes	No	Yes	Yes	No	No	No
Autopilot	Yes	Yes	Yes	No	No	No	No	No
Depth warnings	Yes	Yes	Yes	Yes	Yes	No	No	No
Collision warnings	Yes	Yes	Yes	No	No	Yes	Yes	No
Voice control	Yes	No	Yes	No	No	No	No	No
Head-up display	Yes, not for boat	Yes, with camera and screen	No	No	No	No	No	No
Engine integration	Yes	Yes	Yes	Yes	Yes	No	No	Yes
AR	No	No	Yes	No	No	No	No	No
Create/update maps in real-time	Yes	No	No	Yes	Yes	No	No	No

Figure 4.1: Market analysis

The findings show that most manufacturers offer well-established core functions such as real-time sonar, depth warnings, autopilot integration, and collision alerts. Garmin, Simrad, and Raymarine stand out with more advanced systems, including features like voice control, motor integration, especially Raymarine who got an early form of augmented reality. Raymarine's ClearCruise AR is currently the only commercially available system with AR functionality. It uses onboard cameras to project a video feed onto a dashboard screen, where AIS-connected vessels and landmarks are overlaid with distance markers.

Only Raymarine and Simrad offer partial head-up display solutions and Simrad is not available for boats. Across the industry, no system currently supports immersive AR glasses, contextual overlays in the user's field of view. This analysis highlights a significant market gap, while traditional marine navigation systems are mature and reliable, they have not embraced the full potential of augmented reality. This leaves a clear opportunity for a next-generation solution that integrates these advanced capabilities directly into the user's visual field, reshaping the on-board experience.

4.5 Requirement List

To ensure that the AR-assistant system meets the needs of users and delivers meaningful value, a comprehensive set of requirements has been established from the data collection. These requirements were categorized based on their priority and impact on core functionality, with each marked as either a **Demand (D)** features that are essential for the product's viability or a **Wish (W)** features that are desirable but not critical for the initial implementation.

The requirements cover several key categories, including:

- **Navigation:** Fundamentals at sea such as show position, obstacles and intended route.
- **Vessel data:** Information related to the boat's operational status, such as speed, system activity, and fuel consumption.
- **Conditions:** Inputs like weather and wind data that influence navigational decisions.
- **Docking:** Features assisting in both guest and natural harbor docking scenarios.
- **Hardware:** Requirements ensuring robustness, visibility and compatibility for the AR hardware with maritime conditions.
- **Software:** Interface design, feedback mechanisms and user customization options.

These requirements served as a foundation for defining the minimum viable product (MVP) and developing the personas, scenarios and pain points. A detailed version of the requirement list, including the full categorization and priority level of each feature, is available in Appendix E.

5
Concept Development

Before a product is developed, a couple of concepts were generated. This is so that different ideas can be weighed against each other with respect to the intended users (persona) but also between the different concepts.

5.1 Persona & Scenario

From the data collection and analysis sections, three personas together with scenario and pain points were created, see below:

5.1.1 Persona one

Patrik, 27, has just bought his first motorboat and is excited to start his boating life. He has a basic knowledge of boating, but he thinks that it can be hard to navigate, and he feels a bit unsure about the rules at sea.

Scenario

Patrik and his friend are going out for a day trip on the boat. They soon enter a heavily trafficked area and here he starts feeling unsure about where he should position himself and what the actual navigation rules are. Later on, when they get to a less busy area, he finds it hard to estimate distances, which makes it hard to judge how far away islands, landmarks and other boats are. They finally get to Fjällbacka guest harbor, where they are going for lunch, and since it's a nice day outside, there are a lot of boats in movement. They find a docking spot, but because of the lack of experience and stressful environment, they have to try multiple times before they get the boat correctly into the docking spot.

Pain points

- Hard to understand the rules and how to position himself at sea
- Hard to connecting information from the chartplotter to the real world
- Difficult to estimate distances
- Difficult to dock in busy harbours

5.1.2 Persona two

Matilda, 42, is an experienced boater who enjoys taking her family on adventures. While she is confident in navigation, distractions on board and unexpected challenges make some aspects of boating more stressful.

Scenario

Matilda takes her family on a summer boating trip. With kids playing, her partner asking questions, and general noise on board, she sometimes misses speed limits or important navigation rules. As they travel in open waters, wind and swell make it easy to drift off course and she constantly needs to make steering adjustments. When searching for a natural harbor, she struggles to find reliable depth information near islands and isn't sure how to dock safely for an overnight stay due to changing wind conditions. Later, when they arrive at a guest harbor, it's already full, forcing them to spend extra time searching for another spot.

Pain points

- Easy to drift off course, especially in windy conditions or if there is swell
- Difficulties finding natural harbors, reliable depth information close to islands and knowing how to dock because of changing wind conditions
- Frustrated when getting to full guest harbors and difficulty finding spots
- Distractions on board makes it easy to miss speed limits, rules and other boats

5.1.3 Persona three

Per, 55, is an experienced sailor who enjoys long trips and often navigates at night or in poor weather. However, technical issues, information overload, and bad visibility make his trips more stressful

Scenario

Per sets off on a journey for a few days, planning to sail overnight. As he moves into the open sea, navigating in the dark becomes increasingly difficult. The lack of clear markers and the limited visibility make it hard to stay on course, and he has trouble distinguishing navigation buoys from other lights. His chartplotter and radar are useful, but he finds it difficult to rely on them completely without being able to match the sea chart to real-world surroundings. The darkness makes it harder to judge distances, and his radar only picks up larger vessels, leaving smaller boats or unlit obstacles harder to detect. He feels uncertain about his position, especially as there's no clear way to check his distance to key locations. When checking for updates on weather, sea conditions and positioning, Per is overwhelmed by too much information. Multiple apps, alerts and features are shown on his screen, and he struggles to filter out what is immediately relevant to his situation. The next day, his boat's battery starts struggeling, and he struggles to locate a nearby service stop.

Pain points

- Navigation is difficult in low visibility and bad weather, especially with poor markers and no clear way to match sea charts to surroundings
- Information overload makes it hard to quickly find the most relevant information
- Difficulties navigating at night: radar helps with large objects, but smaller boats, unlit obstacles and distance estimation is still challenging
- Struggles to find service stops when dealing with technical issues

5.2 Concept Generation

Ideas for the product were collected throughout the data collection phase, these were both ideas from participants in the studies and ideas thought of by the team during the project. The ideas were also complemented with a more structured brainstorming session where ideas on how AR could solve the different pain points of the personas were generated. All the ideas for the different pain points were put into a morphological matrix together with the earlier ideas to generate rough concepts; see Appendix F. However, this generated a vast amount of different solutions, and even with restrictions and requirements to reduce the number of different concepts, they were still too large. A lot of ideas were also incompatible with each other, and some ideas were deemed unrealistic or outside of the scope for the product developed in this project.

Therefore three concepts were generated through different themes, *The integrated AR assistant*, *The hybrid solution* and *The all-in-one AR assistant*, where the ideas from the morphological matrix were carefully put together to create these concepts. All the three solutions had a different approach, where the all-in-one solution were the most independent from other technology equipment on the boat and the integrated the least independent.

5.2.1 Concept 1: The Integrated AR-Assistant

This concept enhances existing onboard technology by integrating it with AR (Augmented Reality). It is ideal for fully-equipped boats seeking to modernize without replacing current systems.

- **AIS integration:** Highlights and tracks nearby vessels.
- **Safety alerts:** Red markers indicate potential collision risks.
- **Autopilot visualization:** Displays optimal paths over waves.
- **GPS-linked overlays:** Shows distances to objects in real time.
- **Night vision:** Streams camera feeds directly to AR glasses.
- **Docking assistance:** Uses onboard cameras for maneuver guidance.
- **Chartplotter data:** Displays landmarks and routes in AR.
- **Pre-departure checklist:** Visual guide for safety checks.
- **Custom information display:** Choose what data to view in AR.
- **Drone integration:** Scans guest harbours for free docking spots.
- **Speed and limits display:** Live speed and signs shown in view.

- **Wind warnings:** Alerts from integrated wind sensors.

5.2.2 Concept 2: The Hybrid Solution

A flexible AR system that connects with commonly available boating technology. This solution suits users looking to modernize while still using core traditional tools.

- **AIS-based tracking:** Identifies vessels and suggests safe routes.
- **Rule Mode:** Beginner-friendly navigation guidance.
- **Distance estimation:** Gaze-based object distance display.
- **Route overlays:** Visual course displayed in field of view.
- **Speed memory:** Maintains speed limit info until it updates.
- **Night vision mode:** Dark-vision setting on AR glasses.
- **Custom highlights:** Select which data is shown in AR.
- **Radar overlays:** AR marks radar-detected objects.
- **Docking assist:** Visual guides for docking procedures.
- **Seachart integration:** Plan routes and mark positions in AR.
- **Mode selection:** Switch between various information modes.
- **Weather-guided docking:** AI suggests best overnight locations.

5.2.3 Concept 3: The All-in-One AR-Assistant

A complete, standalone AR system designed for high-tech minimalists. It replaces traditional navigational tools with a full AR interface.

- **AR chart overlays:** Complete digital charts in the headset.
- **Follow the dots navigation:** Clear route visualization.
- **Rule-breaking alerts:** Warnings for restricted areas and speeding.
- **AI assistant:** Real-time info on landmarks and islands.
- **Distance estimation:** Based on gaze at target points.
- **Low-visibility overlays:** Highlights invisible hazards.
- **Transparent HUD:** Assists natural harbour docking.
- **Live weather updates:** Real-time environmental data.
- **AI docking suggestions:** Based on wind and forecast data.
- **QR-code docking:** Assigns and guides to guest harbour spots.
- **Parking assist:** AR visualization of boat movement.
- **Trip editing:** Modify routes directly in AR.
- **Smart filtering:** Context-aware data presentation.

5.3 Concept evaluation

All three concept were then put through two different evaluations, the Pugh matrix and the Kesselring method.

5.3.1 Pugh matrix

In the first matrix, the All-in-One AR Assistant came out on top with the highest number of positive scores (+15), indicating better functionality and advanced

features. The Hybrid and Integrated assistants also performed well, scoring +13 and +12 respectively, but lacked some of the independence and automation that the All-in-One solution got. All concepts had an equal number of negative scores (3), suggesting that none had major flaws, but the All-in-One concept offered more value overall, see figure 5.1.

Requirements/Solutions:	Current	The integrated AR assistant	The Hybrid AR assistant	The all-in-one AR assistant
Navigation				
Show position at sea	0	+	+	0
Show obstacles at sea	0	0	+	+
Show/identify other boats	0	+	+	0
Show intended routes	0	+	+	+
Show speed limits	0	-	-	+
Show depth	0	0	0	+
Minimise distractions at sea	0	0	0	+
Assist driving in low visibility conditions	0	+	+	+
Vessel data				
Disp. Fuel consumption	0	0	0	0
Active radio frequency	0	+	+	+
Disp. active warnings	0	+	+	+
Disp. active systems (active headlights e.t.c.)	0	0	0	0
Disp. current speed	0	0	0	0
Conditions				
Show weather forecast	0	+	+	+
Show wind (direction and strength)	0	0	0	+
Assist on how to drive in different conditions	0	+	+	+
Docking				
Assist docking guest harbours	0	+	+	+
Assist docking natural harbours	0	+	+	+
Show free spots	0	+	0	0
Technical				
Integration with existing sensor suite				
Hardware				
Salt water proof				
Water glare suppression				
Lens that allows night-time operation				
Full day battery life				
Ability to use a physical interface to control headset (keyboard e.t.c.)				
Software				
Tactile feedback	0	-	-	-
Select information to display	0	0	+	-
Automatic contextual information (automatic selection of information to display)	0	0	0	+
Sum +		12	13	15
Sum -		3	3	3
Sum all		9	10	12

Figure 5.1: The first Pugh Matrix

In the second matrix the Integrated AR Assistant were used as reference, the Hybrid Assistant scored +5 and -3, while the All-in-One gained +10 but also got -5, indicating that although it displays more advanced features and real-time information, they may come at the cost of distractions and feedback for the user, see figure 5.2.

Requirements/Solutions:	The integrated AR assistant	The Hybrid AR assistant	The all-in-one AR assistant
Navigation			
Show position at sea	0	0	0
Show obstacles at sea	0	+	+
Show/identify other boats	0	+	+
Show intended routes	0	0	0
Show speed limits	0	0	+
Show depth	0	0	+
Minimise distractions at sea	0	0	+
Assist driving in low visibility conditions	0	0	-
Vessel data			
Disp. Fuel consumption	0	0	0
Active radio frequency	0	0	0
Disp. active warnings	0	0	0
Disp. active systems (active headlights e.t.c.)	0	0	+
Disp. current speed	0	0	0
Conditions			
Show weather forecast	0	0	0
Show wind (direction and strength)	0	0	+
Assist on how to drive in different conditions	0	+	0
Docking			
Assist docking guest harbours	0	0	0
Assist docking natural harbours	0	0	+
Show free spots	0	-	-
Technical			
Integration with existing sensor suite			
Hardware			
Salt water proof			
Water glare suppression			
Lens that allows night-time operation			
Full day battery life			
Ability to use a physical interface to control headset (keyboard e.t.c.)			
Software			
Tactile feedback	0	-	-
Select information to display	0	+	-
Automatic contextual information (automatic selection of information to display)	0	0	+
Sum +	0	5	10
Sum -	0	3	5
Sum all	0	2	5

Figure 5.2: The second Pugh Matrix

The third matrix, where the All-in-One Assistant was the reference, both Hybrid and Integrated assistants received negative scores (-7 and -5 respectively). This further reinforces the All-in-One concept's superiorness towards the other two concepts, outperforming them in most areas of the navigation category, see figure 5.3.

Requirements/Solutions:	The integrated AR assistant	The Hybrid AR assistant	The all-in-one AR assistant
Navigation			
Show position at sea	0	0	0
Show obstacles at sea	-	0	0
Show/identify other boats	-	-	0
Show intended routes	0	0	0
Show speed limits	-	-	0
Show depth	-	-	0
Minimise distractions at sea	-	-	0
Assist driving in low visibility conditions	+	+	0
Vessel data			
Disp. Fuel consumption	0	0	0
Active radio frequency	0	0	0
Disp. active warnings	0	0	0
Disp. active systems (active headlights e.t. c.)	-	-	0
Disp. current speed	0	0	0
Conditions			
Show weather forecast	0	0	0
Show wind (direction and strength)	-	-	0
Assist on how to drive in different conditions	0	+	0
Docking			
Assist docking guest harbours	0	-	0
Assist docking natural harbours	-	-	0
Show free spots	+	-	0
Technical			
Integration with existing sensor suite			
Hardware			
Salt water proof			
Water glare suppression			
Lens that allows night-time operation			
Full day battery life			
Ability to use a physical interface to control headset (keyboard e.t.c.)			
Software			
Tactile feedback	+	-	0
Select information to display	+	+	0
Automatic contextual information (automatic selection of information to display)	-	0	0
Sum +	5	4	0
Sum -	10	11	0
Sum all	−5	−7	0

Figure 5.3: The third Pugh Matrix

Across all three matrices, the All-in-One AR Assistant scored the best. However, the Integrated Assistant showed strengths in compatibility with existing onboard systems, making it more valuable for already well-equipped vessels. The Hybrid Assistant offered something in the middle, as expected, balancing stand alone features with good integration potential. The results shows that while the All-in-One concept got the most features and is most futuristic, there are still valuable features

from the other two concepts, especially system integration, simplified interfaces, and user customization, that should be considered in a final solution.

5.3.2 Kesselring

To further investigate the features and assess their relative importance, a Kesselring matrix was conducted. With this method, all requirements were compared to each other to calculate a weight that reflects their overall importance; see Appendix G. These weights were then used to score how well each of the three AR navigation concepts, The Integrated AR Assistant, The Hybrid AR Assistant, and The All-in-One AR Assistant, fulfils the most critical needs of users at sea.

The results clearly showed that the All-in-One AR Assistant outperformed the others, with a total weighted score of 39.57, compared to 37.57 for the Integrated Assistant and 35.09 for the Hybrid Assistant, see Figure 5.4. This confirms that it is the most comprehensive solution, particularly in scenarios where awareness and navigational support are most important. The All-in-One concept scored highest in the most important navigation-related features, such as: Showing speed limits and depth, where it was the only concept to receive high scores. It also showed strong performance in minimizing distractions, assisting in low visibility and showing intended routes.

Requirements/ Solutions:		Weightning	The integrated AR assistant		The Hybrid AR assistant		The all-in-one AR assistant			
Navigation										
Show position at sea		0,886	5	4,43	5	4,43	4	3,544	1	Bad
Show obstacles at sea		0,886	4	3,544	4	3,544	5	4,43	2	OK
Show/identify other boats		0,705	3	2,115	3	2,115	5	3,525	3	Good
Show intended routes		0,682	5	3,41	5	3,41	5	3,41	4	Very good
Show speed limits		0,545	3	1,635	4	2,18	2	1,09	5	Excellent
Show depth		0,818	2	1,636	2	1,636	4	3,272		
Minimise distractions at sea		0,841	4	3,364	3	2,523	4	3,364		
Assist driving in low visibility conditions		0,631	4	2,524	4	2,524	3	1,893		
Vessel data										
Disp. Fuel consumption		0,273	3	0,819	3	0,819	3	0,819		
Active radio frequency		0,068	3	0,204	3	0,204	3	0,204		
Disp. active warnings		0,386	2	0,772	2	0,772	5	1,93		
Disp. active systems (active headlights e.t. c.)		0,045	2	0,09	2	0,09	2	0,09		
Disp. current speed		0,523	3	1,569	4	2,092	1	0,523		
Conditions										
Show weather forecast		0,364	2	0,728	3	1,092	4	1,456		
Show wind (direction and strength)		0,295	5	1,475	2	0,59	3	0,885		
Assist on how to drive in different conditions		0,318	3	0,954	5	1,59	4	1,272		
Docking										
Assist docking guest harbours		0,455	4	1,82	3	1,365	4	1,82		
Assist docking natural harbours		0,455	3	1,365	3	1,365	4	1,82		
Show free spots		0,318	4	1,272	1	0,318	5	1,59		
Software										
Tactile feedback		0,045	2	0,09	2	0,09	2	0,09		
Select information to display		0,705	5	3,525	3	2,115	2	1,41		
Automatic contextual information (automatic selection of information to display)		0,227	1	0,227	1	0,227	5	1,135		
Sum			72	37,568	67	35,091	79	39,572		

Figure 5.4: The Kesselring Matrix scores

While all concepts performed similarly on basic data such as fuel consumption and radio frequency, the All-in-One stood out in its ability to display active warnings and provide status of onboard systems like active lights or radar. All three concepts addressed environment conditions in some way, but the All-in-One Assistant was again the best, especially in visualizing wind direction and strength, suggesting how to drive in varying sea conditions based on data and combining forecast data with AR overlays.

The solutions offered strong docking assistance, but the All-in-One concept offered the best performance across both guest and natural harbors. It also performed well in assisting with finding free docking spots, although the Integrated Assistant included a drone-based feature for looking for free spots. However, the All-in-One concept scored lower in manual information selection and tactile feedback, which shows a trade-off between automation and user control.

5.4 Business model canvas

In order to better understand the structure and feasibility of our Augmented Reality navigation and boating assistance system, a Business Model Canvas was created. This framework helps to identify the key components required to deliver value to both Volvo Penta and end users, while also addressing the operational, financial, and strategic aspects of the solution. The business model canvas can be seen in figure 5.5 below and is explained in detail in the following sections.

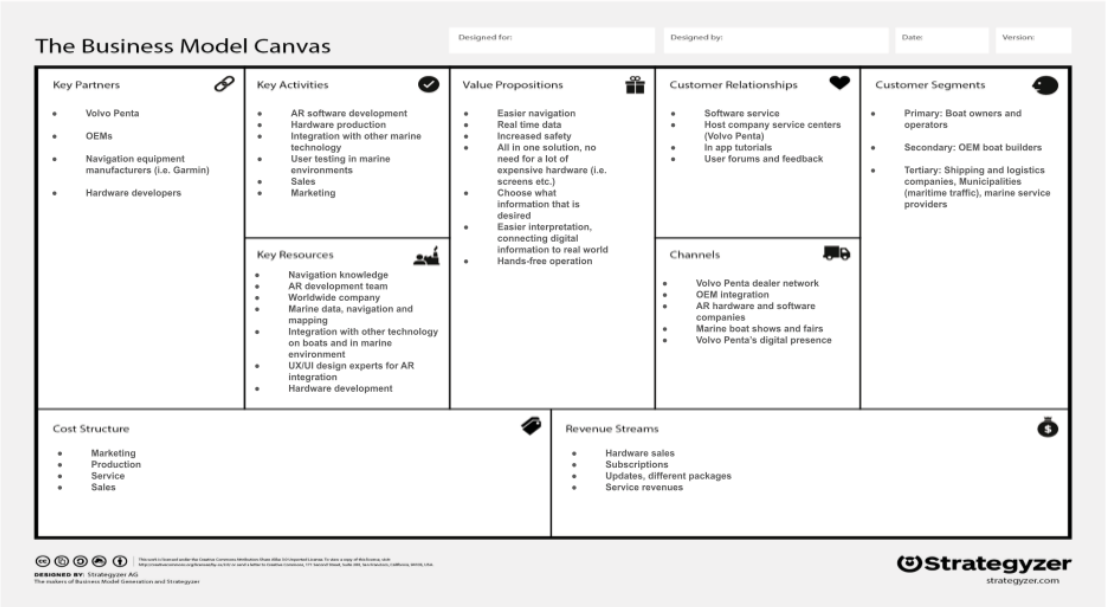

Figure 5.5: Business model canvas

Customer Segments
Our solution primarily targets boat owners and operators, mainly leisure but also commercial users. OEM boat manufacturers that integrate technologies are considered key customers, as well as municipalities with marine public transport, logistics and shipping companies and marine service providers. These segments would benefit from improved navigation and safety.

Value Proposition
The AR navigation and boating assistance system enhances the user experience by making navigation easier, safer and more intuitive. With the real-time data displayed directly in the user's field of view, boaters get better situational awareness and quicker access to the most important information. Safety is increased with features like obstacle alerts, shallow water warnings and warnings when driving in a collision course.

The system replaces the need for multiple physical screens, offering an all-in-one solution that reduces hardware costs. Users can customize the display to show only the information they need, allowing a more personal experience and optimized for specific situations. By connecting digital data to the real world, the system makes complex information easier to understand, and with hands-free operation, users can stay fully engaged in controlling the vessel.

This solution supports Volvo Penta's position as a leader in marine innovation and meets the growing demand for smarter boating technology.

Channels
The system will reach end users through several channels. These include Volvo Penta's global dealer network, which provides access to end users and support services all over the world. Other exposure will come through partnerships with AR hardware and software companies. Marketing efforts will also leverage Volvo Penta's digital platforms and presence at marine industry events such as boat shows and fairs, helping to showcase the technology to both end users and industry leaders.

Customer Relationships
Customer relationships will be maintained through a combination of software-based services and direct support from Volvo Penta. The system will include in-app tutorials to help users get started and understand key features. Assistance will also be available through Volvo Penta's existing service centers. To foster engagement and continuous improvement, user forums and feedback channels should be incorporated, allowing users to share experiences and ask questions. These will be key customer relationships when the new technology is introduced to the market and assist with future development.

Revenue Streams
Revenue for the system can be generated through multiple streams. These include hardware sales, either directly or indirectly. A subscription model can provide access

to premium features such as live updates, advanced navigation data and cloud-based services. Different software packages or updates may be offered at various pricing levels, making it possible for users to choose based on their needs. Service revenues can come from support, customization, and integration services offered through Volvo Penta's network.

Key Resources
The development and delivery of the AR navigation system rely on several key resources. These include specialized knowledge in marine navigation and access to accurate marine data and mapping services. A skilled AR development team is essential for building and maintaining the software and UX/UI design experts ensure the interface is intuitive and effective. Integration with existing boat technologies and systems is supported by Volvo Penta's global network and established infrastructure in the marine industry. An important resource is also the development of AR hardware that is robust, weather-resistant, and made for use in marine environments.

Key Activities
The key activities involved in delivering the AR navigation system include the development of the AR software and the production and development of suitable hardware for marine use. One focus should also be the integration of the system with existing marine technologies, such as navigation equipment and onboard sensors. A lot of user testing in real marine environments is essential to ensure functionality, safety and the fulfillment of user needs. Activities related to sales and marketing are very important to reach both end users and industry partners, helping to position the product within the marine technology market.

Key Partners
The success of the AR navigation system depends on collaboration with various strategic partners. Volvo Penta plays a decisive role in making marine systems, information, and distribution channels accessible. OEM boat manufacturers play a key role as partners for integrating the solution in new boats. Collaboration with navigation equipment producers, such as Garmin, allows compatibility and data transfer between devices. And working with AR hardware developers is also essential so that the technology will be able to function as intended and withstand the marine environment.

Cost Structure
The main cost areas for the AR navigation system include marketing efforts to promote the product to both consumers and industry partners, as well as the production of both software and hardware components. Other costs are providing customer service and technical support and finally sales, including personnel, distribution and partner coordination.

5.5 Final Concept

The final concept, the All-in-One AR-Assistant, is a fully integrated navigational solution designed to replace traditional onboard systems. It targets users who prefer a streamlined experience where all information is accessible through AR glasses. This assistant overlays a digital navigation chart directly in the field of view, creating an all-in-one hands-free interface for navigating at sea.

Core navigation is managed through a “follow the line” visual system, guiding the user along a chosen route with intuitive path markers. Real-time rule enforcement is also included, with the system issuing alerts when the boat is speeding, entering restricted areas or violating maritime rules. Users can access information by simply looking at an island or landmark, with the AR headset displaying relevant data in information pop-ups.

Distance to objects can be estimated by looking at them, while a dark or low-visibility mode helps the user see obstacles that might otherwise go unnoticed. This mode projects hazards as AR overlays with distances, improving safety during nighttime or foggy conditions.

The system also integrates real-time weather and wind updates directly into the AR display. When connected to a wind forecast service, it can suggest optimal overnight docking locations based on upcoming weather patterns. Users can scan a QR code when entering a guest harbor to get assigned a docking spot, with the system then guiding the user to the spot through AR.

Docking is simplified by a parking assist mode, which shows how the boat will move based on current steering settings. Route planning is always available and easy to update when the plans change by users being able to edit and adjust trips directly in the AR interface.

In addition to its core features, the final concept incorporates several high-performing elements from the evaluations from earlier concepts. These include a speed limit “memory” mode, which remembers and displays the last seen speed limit until a new one is detected. A "Rule Mode" for beginners is integrated as well, helping new users understand local navigation rules with on-screen pop-ups connected to the chartplotter. The system also uses wind speed indicators from existing boat equipment to issue high wind warnings. Lastly, users can select the information they wish to display from their onboard technology, providing more control than automatic smart filtering. All features included in this final concept are summarized in Figure 5.6, which shows an overview of the system’s all features.

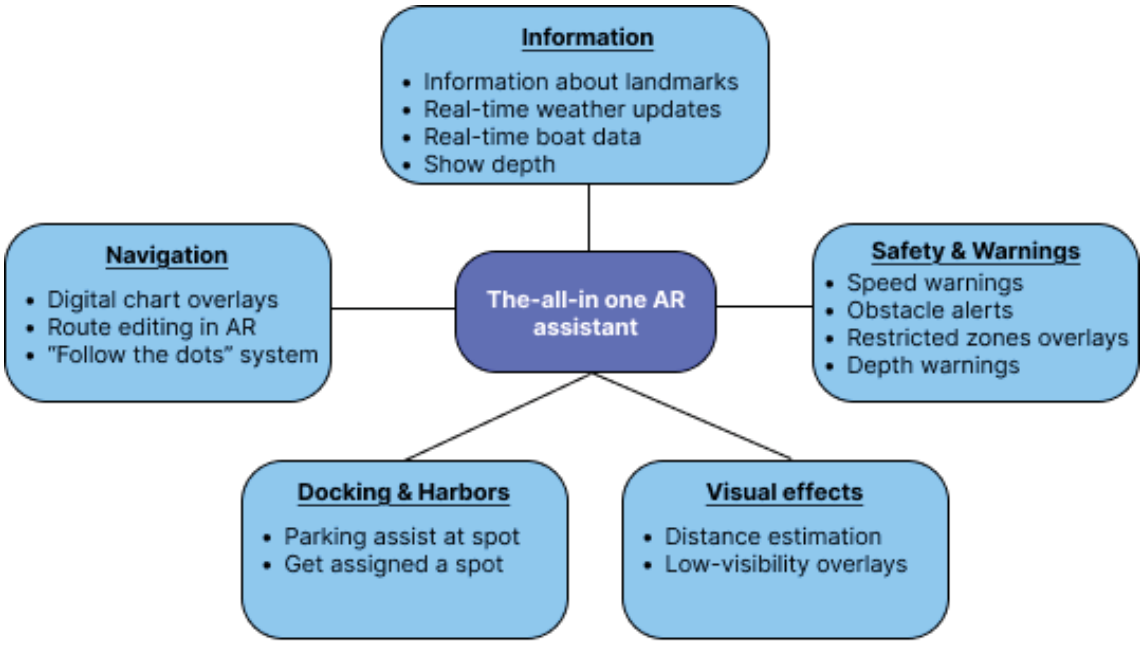

Figure 5.6: The All-in-one AR Assistant concept features

5.5.1 Minimum Viable Product

The **Minimum Viable Product (MVP)** for the all-in-one AR-assistant is defined by a group of features that addresses the most essential navigational needs while establishing a solid foundation for future development. The MVP is created to fulfill only the most critical user and system requirements, as shown below.

Requirements the MVP must fulfill:
These features form the essential foundation of the MVP and ensure baseline operational capability.

- **Show position at sea**
- **Show obstacles at sea**
- **Show/Identify other boats**
- **Minimise distractions at sea**
- **Show depth**

Requirements the prototype should fulfill:
These additional features enhance usability and user control but are not critical for the MVP. They should be prioritized in future development.

- User-customisable interface (select displayed data)
- Show future route
- Show and remember speed limits
- Assist in low-visibility conditions
- Display current vessel speed

Requirements the prototype could fulfill:
These are considered secondary or advanced features. They offer value-added functionality and will be considered as future enhancements.

- Assist docking in guest and natural harbours
- Show weather forecast
- Display active notices
- Show free docking-spots
- Assist on how to drive in different conditions
- Display active systems (light mode, etc.)
- Tactile feedback
- Show wind (direction and strength)
- Active radio frequency

Requirements the prototype will not fulfill:
The following requirement has been excluded from the MVP and prototype due to complexity and scope.

- Automatic contextual information display

The MVP is focused and intentionally limited to ensure a reliable and user-friendly experience at sea. It delivers only the most crucial features necessary for safe navigation. This clear scope allows for effective testing, evaluation and user feedback, which will guide the development of additional features in the future.

6
Prototypes

To get a better feel for the product being developed, two prototypes have been created and will be presented in this chapter. These prototypes rely on the philosophy that "quick and dirty" can show what works and what doesn't early on in the development process.

6.1 Figma prototype

The first two views of the prototype show the user's first interaction with the system. The first screen, see Figure 6.1, is the home view which shows a brief introduction to the program together with several functions. It includes a start button to go to the mode selection screen, an SOS button for emergency situations and a "How it works" button that provides instructions on how to use the AR system. The settings menu gives the option to adjust preferences and select which types of information they want to be displayed in different situations. There is also a help button offering instructions on common situations at sea, such as right-of-way rules and other tips.

Once the user presses the start button, the user goes to the mode view, see Figure 6.2. Here the user can select between modes. Three different modes are available, depending on the current driving situation, Day Cruising Mode for regular daytime navigation, Docking Mode to assist with harbor driving and docking and lastly Night Vision Mode which is designed for low-visibility or nighttime conditions. The purpose of these modes is to give the user an easy way to choose what information is needed in the AR interface in specific driving conditions.

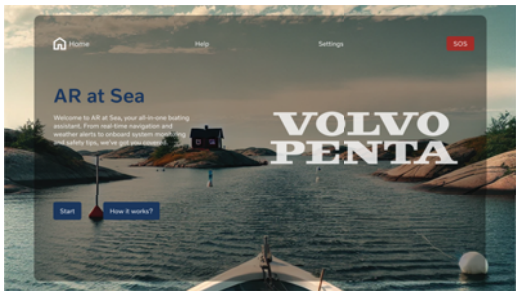

Figure 6.1: Figma prototype: Home page. Background picture generated by ChatGPT

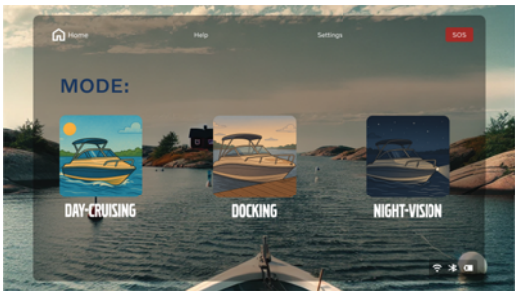

Figure 6.2: Figma prototype: Mode page. Background picture generated by ChatGPT

The following four figures demonstrate the user interface during Day-Cruising Mode. In Figure 6.3, the AR interface highlights areas of shallow water that are too shallow for the vessel by overlaying red markers on the sea surface and it also displays the distance to the island when looking directly at it. The bar positioned at the top of the field of view is providing quick access back to the home screen, a weather forecast for the next three hours and an SOS button on the right. The lower left corner displays the current wind speed and direction. The right side of the interface presents real-time data which in this case includes the current speed limit, the vessel's current speed, the status of the trim tabs, the current depth and there is also a mini chartplotter. All the information in the field of view is customizable and if other information is desirable it is possible to change what is showing in the settings.

When the user press the mini chartplotter, the interface shows Figure 6.4, where the chartplotter is enlarged. In this view the user can select a destination directly by clicking on the destination on the map. When doing so the system shows Figure 6.5, where the interface is the same layout as Figure 6.3 but now includes a clear route in green. This route is displayed as a guiding line from the current location to the selected destination, which helps the user navigate effectively and safely.

Figure 6.6 demonstrates the program's warning system. When the user drives too fast, a warning sign appears in the center of the field of view, telling them to slow down.

The next two figures shows the interface in Docking Mode which is designed to assist the user when entering a guest harbor. In Figure 6.7 the vessel is driving into the harbor after being assigned a specific docking spot. A guidance line is projected onto the sea surface, showing the user the route to their assigned docking spot. The remaining distance to the docking spot is also displayed, which helps the user know how much maneuvering remains and when to prepare different things for docking (i.e. ropes and fenders).

In Figure 6.8, the vessel has reached the assigned spot and the system activates the docking assist function. This feature provides guidance on how to position the boat, helping the user align the boat correctly and assisting a smooth and safe docking. Similar to a parking assist in a car the lines show how the boat will move with the current steering settings. The assist interface is intended to reduce stress and uncertainty during docking situations, especially in tight or crowded conditions.

Figure 6.9 shows the interface in Night-Vision Mode which is designed for use during nighttime or in foggy conditions. In this view, the program does not only highlight the shallow areas and underwater obstacles but it also marks objects above sea level by using AR overlays. Obstacles below the water surface are highlighted in red and those above are marked in green, this help users to quickly identify obstacles below and above the waterline. Based on user feedback, traditional chart symbols for rocks and shallows have also been integrated into this view to increase familiarity and help the user to interpret the infomation. These nautical symbols are the same

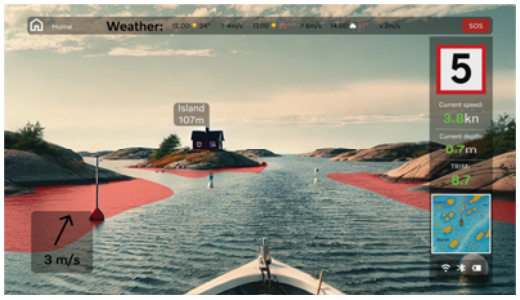

Figure 6.3: (1) Figma prototype: Day cruising mode. Background picture generated by ChatGPT

Figure 6.4: (2) Figma prototype: Chart plotter to choose intented destination. Background picture generated by ChatGPT

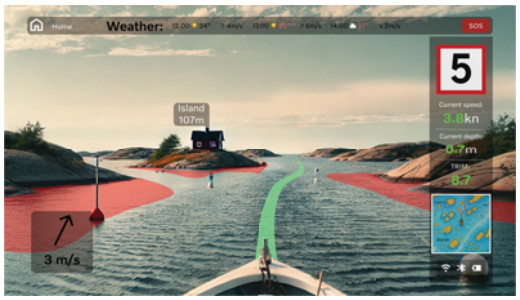

Figure 6.5: (3) Figma prototype: Route to selected destination. Background picture generated by ChatGPT

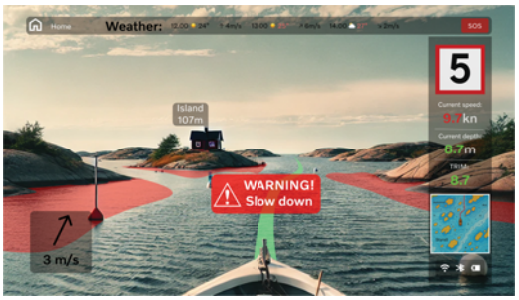

Figure 6.6: (4) Figma prototype: Warning alert for speeding. Background picture generated by ChatGPT

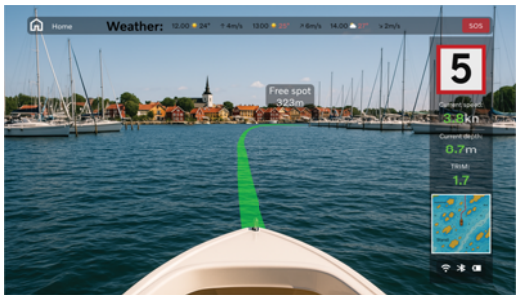

Figure 6.7: 1. Figma prototype: Entering harbor with assigned docking spot. Background picture generated by ChatGPT

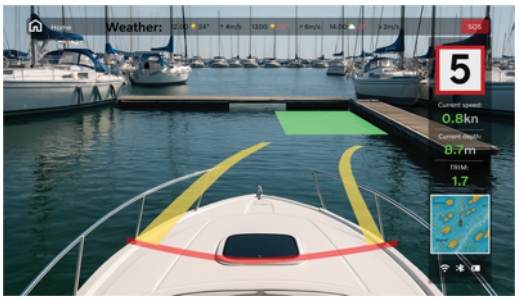

Figure 6.8: 2. Figma prototype: Docking assistance. Background picture generated by ChatGPT

as in existing marine charts which enhances user confidence and understanding. Finally, the distance to each identified obstacle is clearly displayed.

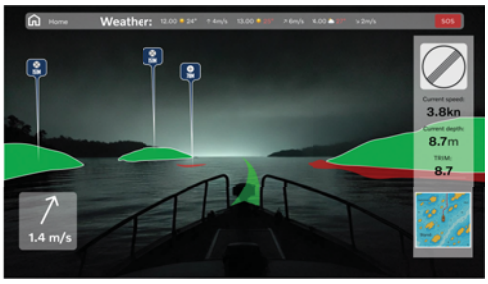

Figure 6.9: Figma prototype. Night vision mode. Background picture generated by ChatGPT

6.2 Unity prototype

To evaluate the concepts, a prototype with the game engine Unity [37] was developed for the AR headset Magic Leap 2 [21]. This prototype contains implementations of some basic features, namely:

- External GPS input
- Coastlines
- limited seachart icons
- limited 3- and 6-meter depth lines
- Depth gauge and depth lines
- Real time weather data
- Real time AIS data [12]

In the virtual world that the Magic Leap 2 displays, data useful for navigating a boat is presented; markers, depthlines, AIS markers and stationary information are geolocated in the virtual world to their real-life counterparts, while information that does not need to be permanently visible is confined to Vuforia image targets [32], and the user may view information hidden by an image target by directly inspecting the target in the real world, in the same manner as one would inspect a newspaper, for instance.

Figure 6.10: Two screenshots of the test footage recorded at Krossholmen

In addition, a companion Android [10] application was developed to use the built in gps provided by a phone running on Android. This data is then sent as a JSON [6] over the local network to the Magic Leap 2 AR headset. The geographic position is then used on board the headset to move the virtual world to the corresponding location in the real world.

6.2.1 External GPS input

The GPS input module opens port 8888 on the local network the ML2 is connected to. On this port, a gps device (in the testing case, a mobile phone) can communicate position data as a JSON [6] as latitude and longitude using the decimal degree system [11], In addition, the optional parameter "hO" (for height override) can override the camera height as meters above the WGS84 ellipsoid [24]. Control over these parameters allows movement of the camera in the virtual world along all axes.

```
{"latitude":<float>,"longitude":<float>,"hO":<float>}
```

Listing 6.1: Overview of JSON gps message

6.2.2 Feedback from Unity prototype testing

During the first test, an interesting piece of feedback was that coastlines should be hidden by default, as they mostly are in the way during daytime operations; the coast is visible to the naked eye anyway, and instead, coastlines could become useful when navigating in low-light situations; therefore, that feature was put under a toggle switch.

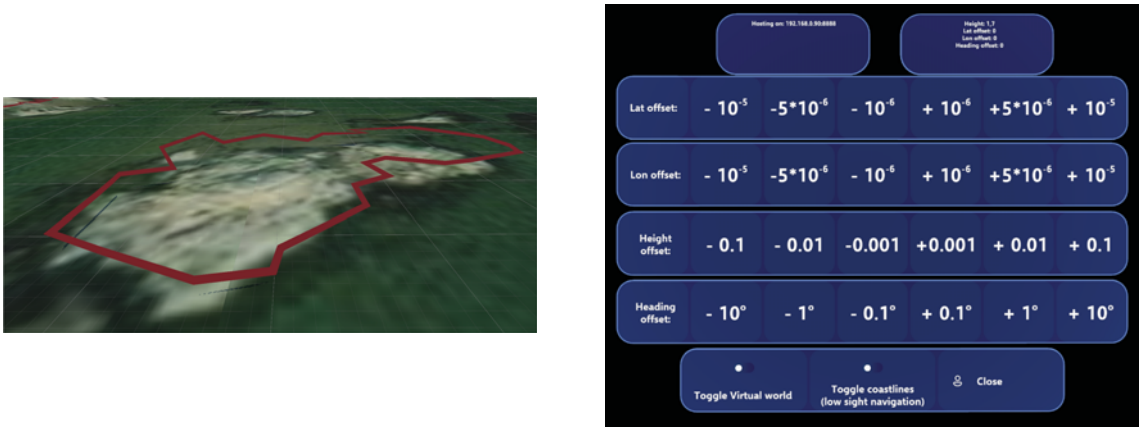

Figure 6.11: A picture of the coastline, in addition to the menu where it can be turned off.

An additional piece of feedback from the same session was that markers should be smaller, to make it more obvious where the marker is actually pointing. It was also suggested that a "demo area" should be created, to better show off the markers up-close and allow a user to familiarise themself with them.

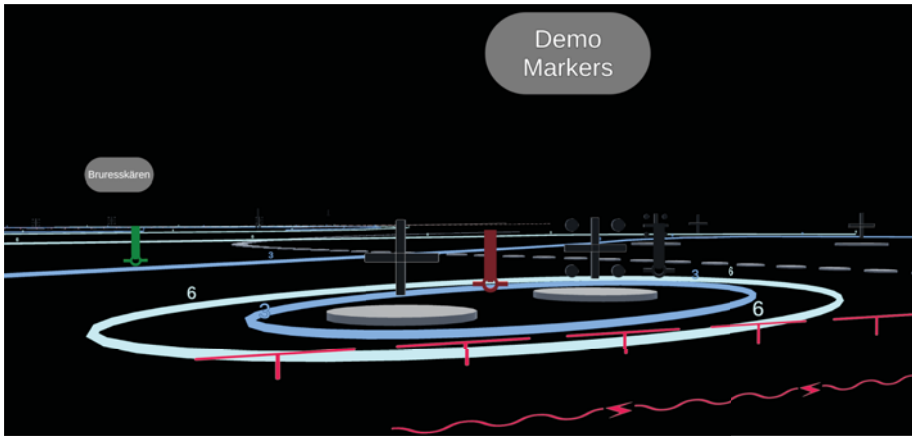

Figure 6.12: A screenshot of the demo markers ”playground”

7

Discussion

In this chapter, the authors will discuss the results and findings of this thesis.

7.1 Surveys

Both surveys got a greater turnout than expected, which turned out to be a good way to get quantifiable information in bulk. It did, however, turn out that most who responded to the survey were, or at least claimed to be, experienced sailors. This is fine in itself, but it would have been interesting to get more data from individuals who have more intermediate knowledge of boating, as one of the identified use cases is AR for use in training scenarios.

7.2 Prototype development

Considering that this thesis is undertaken for the master's programme in product development, it is indeed a little bit perplexing that so much of the prototype development has taken place in a programming and software engineering context. What is important to remember is not to get completely lost in the world of software development and engineering, lest this thesis be more appropriate for a master's thesis in information technology or data science, but to approach the task from a product development angle. This means that prototype development is only a part of the project, and software that perhaps is not as polished as a student with a more computer-geared background might develop is acceptable, and to remember to only test and evaluate the core concepts and functions that were identified in a product-developing manner.

On the subject of developing the prototype, we identified that while many individuals were generally positive to using AR in some capacity on their boat, it was a little unclear as to how. This scenario can be somewhat likened to when Steve Jobs said, "It's not the customer's job to know what they want." Meaning that we as developers must think of exciting things to present to the end user, while still taking their voice into consideration as well.

7.3 Future work

In this thesis only basic navigational features were explored, but many other things could be added to create even more value and knowledge in this field; for instance, one interviewee mentioned that being able to see under their boat while driving to observe marine life and the seabed would have been interesting. This could be a really interesting thing to explore, as tools to discover more about sea life and biology are often limited to literature and the occasional information board.

During the research phase, a company called Lookout was discovered [19]; they sell a 360 degree camera that is supported by an AI module to map out hazards, markers, ships and other POIs in addition to a low-light camera for assistance when navigating in the dark. Although the information is intended to be displayed on a regular 2D screen, their product works in a very similar way to the prototype. Although there is a high up-front cost (14000$ at the time of writing), a merge of the information generated by Lookout's AI module and camera combo displayed on an AR headset would indeed be one interesting combination to explore.

Additionally, ways to integrate the headset even further with onboard systems could be really useful; the ability to connect sensors and instruments from different brands through, for example, NMEA2000, is absolutely essential in making a practically viable product [25].

It also became apparent during testing that moving waves and especially waves that reflect sunlight create some real problems for the ML2 positional tracking. Rather comically, elements that are supposed to be stationary would on occasion float away, as if almost surfing the wave. This creates a problem when the entire project is dependent on high-precision local and global tracking. The problem also permeates throughout the entire operating system, making it very hard to use the ML2 in general. This can be alleviated by looking at and standing in an environment with stationary objects and features.

Another thing that can be improved with the prototype is real and virtual world alignment. During testing, the virtual world will always start with the camera facing north, which might not be the case when the AR at Sea application started, as even the slight deviation from a straight north heading can make markers and objects severely misaligned, especially for distant objects.

7.4 Suggestions for tailored hardware

During the thesis it quickly became apparent that the ML2, although a fine piece of hardware, leaves a couple of things to be desired if it is to be used aboard a boat, an environment that most often is not protected from the elements. Some features that would be absolutely essential are:

- Waterproofing
- Proofing against salt deposition
- All day battery
- NMEA2000 compatibility [25]

The global dimming feature on the ML2 did, however, turn out to be an absolute game changer when testing in sunny environments; the headset dynamically dims the lenses so that virtual elements do not become overlit by even the brightest of sun rays. This feature could, in addition to being able to see what is displayed, also reduce blinding by light on sunny days.

Furthermore, the ”moving floor” headset tracking issue as described in section 7.3 should also be fixed, as the software quickly becomes unusable if the headset is unable to keep virtual elements fixed in place. If the ML2 is to be used, there needs to be a way to override the floor-tracking algorithm used currently.

8

Conclusion

It is the author's belief that the technologies and their interactions explored in this project are a preview of how existing and emerging technologies can be used. As explored in the literature review section, efforts to fuse AR technology and marine experiences are happening, and this thesis proves that AR technology is getting to the point where the outlines of a commercially feasible product can begin to be seen.

Individuals that were reached out to through surveys, interviews and also regular conversation have generally been very excited to learn more about the project and positive about implementing AR in their boating journeys. This leads us to believe that while users are generally open to the idea of using AR, we as product developers need to continue listening to users and come up with new, interesting and useful ways to demonstrate how AR can be used at sea.

There are still some major challenges to overcome: long-lasting batteries, world geometry tracking not thrown off by waves, sensor and system interoperability are just a portion of what needs to be further investigated. There is also a whole lot to do on creating a user-friendly design, especially when considering AR and VR applications, as there is not really an established UI convention in the same manner as for desktop or phone applications, for instance.

Bibliography

[1] Henrik Aasgaard and Steven Cater Mallam. "Human Factors and the Implementation of Smart Bridge Technology". In: *Proceedings of the 51st NES Conference: Work Well – Ergonomics in an Unpredictable World*. Ed. by Jessica Lindblom and Cecilia Österman. Second edition published on October 28, 2022. Uppsala University and EHSS, Oct. 2022, pp. 212–219. URL: https://www.researchgate.net/publication/364647449_NES2022_WORK_WELL_Conference_Proceedings.

[2] Avikus. *Avikus to Unveil NeuBoat at the 2023 Miami International Boat Show*. Avikus. 2023. URL: https://www.avikus.ai/post/avikus-to-unveil-neuboat-at-the-2023-miami-international-boat-show.

[3] Ronald T Azuma. "A survey of augmented reality". In: *Presence: Teleoperators & Virtual Environments* 6.4 (1997), pp. 355–385.

[4] Mark Billinghurst, Adrian Clark, and Gun Lee. "A survey of augmented reality". In: *Foundations and Trends® in Human–Computer Interaction* 8.2-3 (2015), pp. 73–272.

[5] Lars-Olov Bligård. *ACD3, utvecklingsprocessen ur ett människa-maskinperspektiv*. Institutionen för produkt och produktionsutveckling, Chalmers Tekniska Högskola, 2015.

[6] T. Bray. *The JavaScript Object Notation (JSON) Data Interchange Format*. https://www.rfc-editor.org/rfc/rfc8259. RFC 8259. 2017.

[7] Alan B Craig. *Understanding Augmented Reality: Concepts and Applications*. Waltham, MA: Morgan Kaufmann, 2013. ISBN: 978-0-240-82110-4.

[8] Martyn Denscombe. *The Good Research Guide: For Small-Scale Social Research Projects*. 5th ed. Maidenhead: McGraw-Hill Education, 2014. ISBN: 9780335264704.

[9] Figma. *The collaborative interface design tool*. https://www.figma.com. Accessed: 2025-06-04. n.d.

[10] Google Inc. *Android Operating System*. https://www.android.com/. 2008.

[11] International Organization for Standardization. *ISO 6709:2008: Standard representation of geographic point location by coordinates*. https://www.iso.org/standard/39242.html. 2008.

[12] International Telecommunication Union. *Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile band (Recommendation ITU-R M.1371)*. https://www.itu.int/rec/R-REC-M.1371. ITU-R M.1371-6. 2023.

[13] Mark Johnson et al. "Video Sensor Fusion and Model Based Virtual and Augmented Reality Systems and Methods". Patent US10942028B2. Filed August

6, 2019; Priority date November 13, 2015. Mar. 2021. URL: https://patents.google.com/patent/US10942028B2/en.

[14] Radha Kumaran et al. "The impact of navigation aids on search performance and object recall in wide-area augmented reality". In: *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 2023, pp. 1–17.

[15] Francesco Laera. "Augmented Reality for Easy Sailing". In: *2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 2020, pp. 312–313. DOI: 10.1109/ISMAR-Adjunct51615.2020.00088.

[16] Francesco Laera et al. "Augmented reality for maritime navigation data visualisation: a systematic review, issues and perspectives". In: *Journal of Navigation* 74.5 (2021), pp. 1073–1090. DOI: 10.1017/S0373463321000412.

[17] Jeanne Liedtka. "Perspective: Linking Design Thinking with Innovation Outcomes through Cognitive Bias Reduction". In: *Journal of Product Innovation Management* 32.6 (2015), pp. 925–938. DOI: 10.1111/jpim.12163.

[18] Gunnar Liestøl, Michael Bendon, and Elpida Hadjidaki-Marder. "Augmented Reality Storytelling Submerged. Dry Diving to a World War II Wreck at Ancient Phalasarna, Crete". In: *Heritage* 4.4 (2021), pp. 4647–4664. ISSN: 2571-9408. DOI: 10.3390/heritage4040256. URL: https://www.mdpi.com/2571-9408/4/4/256.

[19] Lookout. *Lookout: AI Camera for Safe Boating*. https://www.getalookout.com. Founded in 2021, Lookout is a Boston-based company developing AI-powered camera systems for marine safety. 2021. URL: https://www.getalookout.com.

[20] Margareta Lützhoft, James Nyce, and Erik Petersen. "Maritime technology and human integration: The challenge of automation in shipping". In: *Human Factors* (2010).

[21] Magic Leap, Inc. *Magic Leap 2*. https://www.magicleap.com/magic-leap-2. 2022.

[22] Lars Mårtensson and Anders Wästberg. *Användning av elektronisk navigation i fritidsbåtar*. https://www.sjofartsverket.se. Sjöfartsverket. 2017.

[23] Paul Milgram and Fumio Kishino. "A taxonomy of mixed reality visual displays". In: *IEICE Transactions on Information and Systems* E77-D.12 (1994), pp. 1321–1329.

[24] National Geospatial-Intelligence Agency. *Department of Defense World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems*. Tech. rep. TR8350.2. U.S. Department of Defense, 2014. URL: https://earth-info.nga.mil/php/download.php?file=coord-wgs84.

[25] National Marine Electronics Association. *NMEA 2000 Standard*. https://www.nmea.org/nmea-2000.html. Access to full specification requires membership or purchase. 2024.

[26] Alexander Osterwalder and Yves Pigneur. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, NJ: John Wiley & Sons, 2010. ISBN: 9780470876411.

[27] Se-Gil Park, Jae-Yong Oh, and Hye-Jin Kim. "System and Method for Automatic Tracking of Marine Objects". Patent KR101941521B1. Filed December

7, 2016; Priority date December 7, 2016. Jan. 2019. URL: https://patents.google.com/patent/KR101941521B1/en.

[28] Paul B. Paulus and Bernard A. Nijstad, eds. *Group Creativity: Innovation Through Collaboration*. New York: Oxford University Press, 2003. ISBN: 9780195147308.

[29] Marta Plaza-Hernández et al. "Integration of IoT Technologies in the Maritime Industry". In: *Distributed Computing and Artificial Intelligence, Special Sessions, 17th International Conference*. Ed. by Sara Rodríguez González et al. Cham: Springer International Publishing, 2021, pp. 107–115. ISBN: 978-3-030-53829-3.

[30] Thomas Porathe and Jonas Ekskog. "Egocentric Leisure Boat Navigation in a Smartphone-based Augmented Reality Application". In: *Journal of Navigation* 71.6 (2018), pp. 1299–1311. DOI: 10.1017/S0373463318000371.

[31] John Pruitt and Tamara Adlin. *The Persona Lifecycle: Keeping People in Mind Throughout Product Design*. San Francisco, CA: Morgan Kaufmann, 2006. ISBN: 9780125662512.

[32] PTC Inc. *Vuforia Engine for Unity: Image Targets*. 2025. URL: https://library.vuforia.com/features/images/image-targets.

[33] Kevin Radford, James Pilcher, and Robert Loeb. "Cognitive load and decision making in marine operations". In: *Journal of Marine Operations* 12.3 (2018), pp. 112–124.

[34] Raymond Scupin. "The KJ Method: A Technique for Analyzing Data Derived from Japanese Ethnology". In: *Human Organization* 56.2 (1997), pp. 233–237. DOI: 10.17730/humo.56.2.x335923511444334.

[35] Transportstyrelsen. *Sjöfartsstatistik och olycksdata*. https://www.transportstyrelsen.se. Sverige. 2022.

[36] Karl T. Ulrich and Steven D. Eppinger. *Product Design and Development*. 6th ed. New York: McGraw-Hill Education, 2016. ISBN: 9780078029066.

[37] Unity Technologies. *Unity Real-Time Development Platform*. https://unity.com. Version 2022.3 LTS. 2025.

[38] Volvo Penta. *Industrial and marine engine innovation – History & innovation*. https://www.volvopenta.com/about-us/history-innovation/. Hämtad 4 juni 2025. 2025.

A

Public survey

A.1 Survey questionaire

Questions were available in both Swedish and English, but only the English translation is presented here to conserve document space. Answer alternatives marked with ☐ *means multiple answers are allowed per question, while* ○ *means only one answer is allowed per question or only one answer per row in the case of matrix questions.*

1. How old are you?
   - ○ <20
   - ○ 20 - 29
   - ○ 30 - 39
   - ○ 40 - 49
   - ○ 50 - 59
   - ○ >60
   - ○ Prefer not to say
2. Do you own a boat?
   - ○ Yes
   - ○ No
3. If yes, what kind of boat?
   - ○ Sailboat
   - ○ Motorboat
   - ○ Other *(Free text answer)*
4. How much do you use a boat during a year?
   - ○ Less than a week
   - ○ 1-2 weeks
   - ○ 3-6 weeks
   - ○ Multiple months
   - ○ Whole year
5. How long is your boat journey on average?
   - ○ 0-15 min
   - ○ 15-30 min
   - ○ 30-60 min
   - ○ 1-2 h
   - ○ 2 h+
6. What user segment describes your boating the best?
   - ○ Leisure
   - ○ Commercial

- ○ Other *(Free text answer)*

7. How easy do you think it is to find these locations when you are out to sea?

	1 (Easy)	2	3	4	5 (Hard)	Don't know
Natural harbours	○	○	○	○	○	○
Places to fish	○	○	○	○	○	○
Guest harbours	○	○	○	○	○	○
Service stations	○	○	○	○	○	○
Fuel stations	○	○	○	○	○	○
Coastal bathing area	○	○	○	○	○	○
Landmarks	○	○	○	○	○	○
Other vessels	○	○	○	○	○	○

8. What information would you like to receive when you are out at sea?
   - ☐ Navigation
   - ☐ Warnings (e.g. about other boats or objects in the water)
   - ☐ Real-time weather (e.g. wind strength, wave height, temperature)
   - ☐ Water depth
   - ☐ Harbor information (free docking spots, distance to jetty)
   - ☐ Speed and fuel levels
   - ☐ Communication (e.g. from other boats or the coast guard)
   - ☐ Instructions of maintenance or repairs
   - ☐ Experiences (Fact charts, quiz walk etc.)
   - ☐ Other *(Free text answer)*
9. What kind of navigation equipment do you have on your boat?
   - ☐ GPS
   - ☐ Sonar
   - ☐ Radar
   - ☐ Traditional charts
   - ☐ Other *(Free text answer)*
10. How much do you experience that technology on board, such as the navigation systems, distracts from the surroundings?

	1 (Little)	2	3	4	5 (A lot)	Don't know
GPS	○	○	○	○	○	○
Sonar	○	○	○	○	○	○
Radar	○	○	○	○	○	○
Traditional charts	○	○	○	○	○	○

11. How comfortable do you feel navigating in the following situations?

	1 (Uncomfortable)	2	3	4	5 (Confident)	Don't know
Limited vision (fog or darkness)	○	○	○	○	○	○
Tight waterways	○	○	○	○	○	○
Open sea	○	○	○	○	○	○
Bad weather	○	○	○	○	○	○
Heavily trafficked waters	○	○	○	○	○	○

12. What do you think the biggest challenges are when navigating at sea?
    Free text answer
13. How important is it for you to have access to real-time information on the boat? (For example, weather, obstacles or waterways)

    1 2 3 4 5
    ○ ○ ○ ○ ○
14. Is there some kind of technological equipment you find difficult to use onboard?
    Free text answer
15. How open would you be to implementing new technology on your boat?

    1 2 3 4 5
    ○ ○ ○ ○ ○
16. What are your biggest concerns regarding technology on your boat?
    - ☐ That it is too complicated
    - ☐ That it is distracting
    - ☐ Risk of technological failure
    - ☐ That it is too expensive
    - ☐ Other *(Free text answer)*
17. Would you like to add something? Feel free to comment below!
    Free text answer
18. If you want to know more about what we are doing and are up for an in-depth interview, please write your email below and we will be in touch!
    Free text answer

A.2 Survey results

Questions were available in both Swedish and English, but only the English translation is presented here to conserve document space. Swedish free-text answers have been translated.

Total responses: 52

1. How old are you?
   - <20 : 1
   - 20-29 : 7
   - 30-39 : 7
   - 40-49 : 11
   - 50-59 : 9
   - >60 : 17
   - Prefer not to say : 0

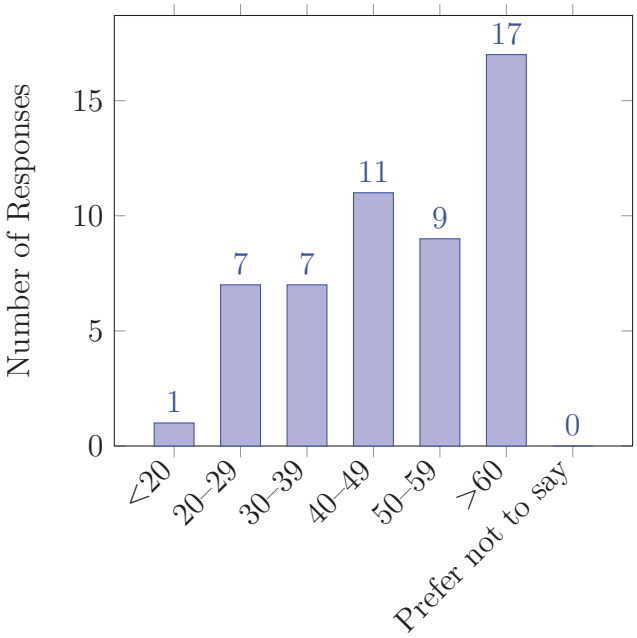

Figure A.1: Age distribution of survey respondents

2. Do you own a boat?
   - Yes : 43
   - No : 9

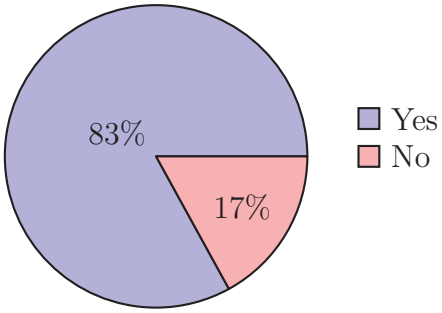

Figure A.2: Percentage that owns a boat

3. If yes, what kind of boat?
   - Sailboat : 9
   - Motorboat : 31
   - Other *(Free text answer)* : 3

   Free text answers:

Rowing boat
Both sailboat and motorboat
Both sail and motorboat

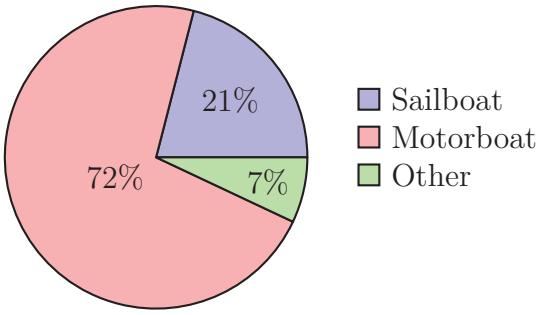

Figure A.3: Percentage of what kind of boat respondents owns

4. How much do you use a boat during a year?
   - Less than a week : 0
   - 1-2 weeks : 9
   - 3-6 weeks : 14
   - Multiple months : 20
   - Whole year : 9

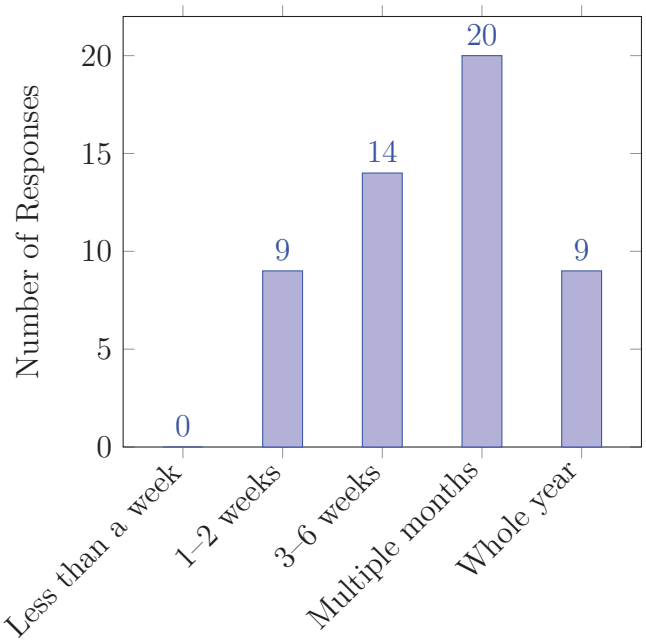

Figure A.4: Distribution of boat use per year

5. How long is your boat journey on average?
   - 0-15 min : 3
   - 15-30 min : 20
   - 30-60 min : 8
   - 1-2 h : 8
   - 2 h+ : 13

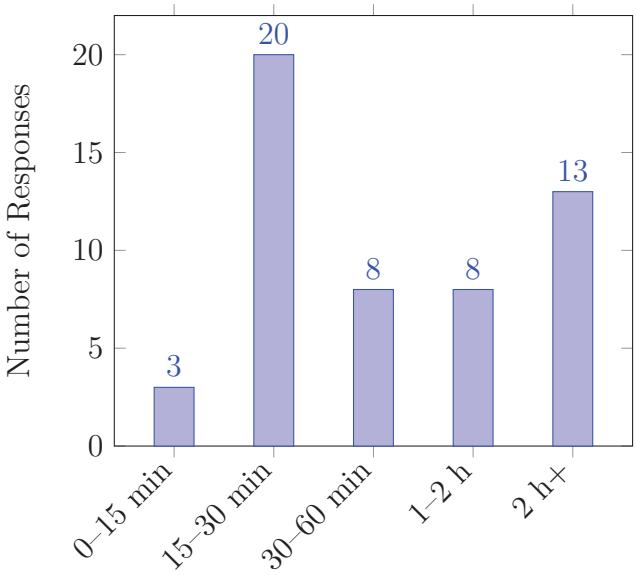

Figure A.5: Distribution of boat journey time

6. What user segment describes your boating the best?
   - Leisure : 42
   - Commercial : 2
   - Other *(Free text answer)* : 8

   Free text answers:

Shopping
Leisure and commercial
As an islander year-round, you need to get to other islands and the mainland when the archipelago boat is not suitable.
From Saltholmen to summer house
Transport (I live on an Island)
As transport from island to mainland
Commuting and entertainment
Commuting for work

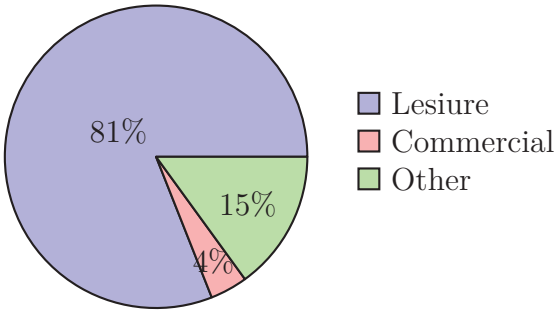

Figure A.6: Percentage of primary activity boat(s) is used for

7. How easy do you think it is to find these locations when you are out to sea?

	1 (Easy)	2	3	4	5 (Hard)	Don't know
Natural harbours	22	12	8	2	1	7
Places to fish	17	9	9	1	4	12
Guest harbours	26	9	8	1	4	6
Service stations	16	5	11	7	4	9
Fuel stations	21	8	8	6	3	6
Coastal bathing area	24	12	7	3	0	6
Landmarks	24	11	6	3	0	10
Other vessels	28	6	7	1	0	10

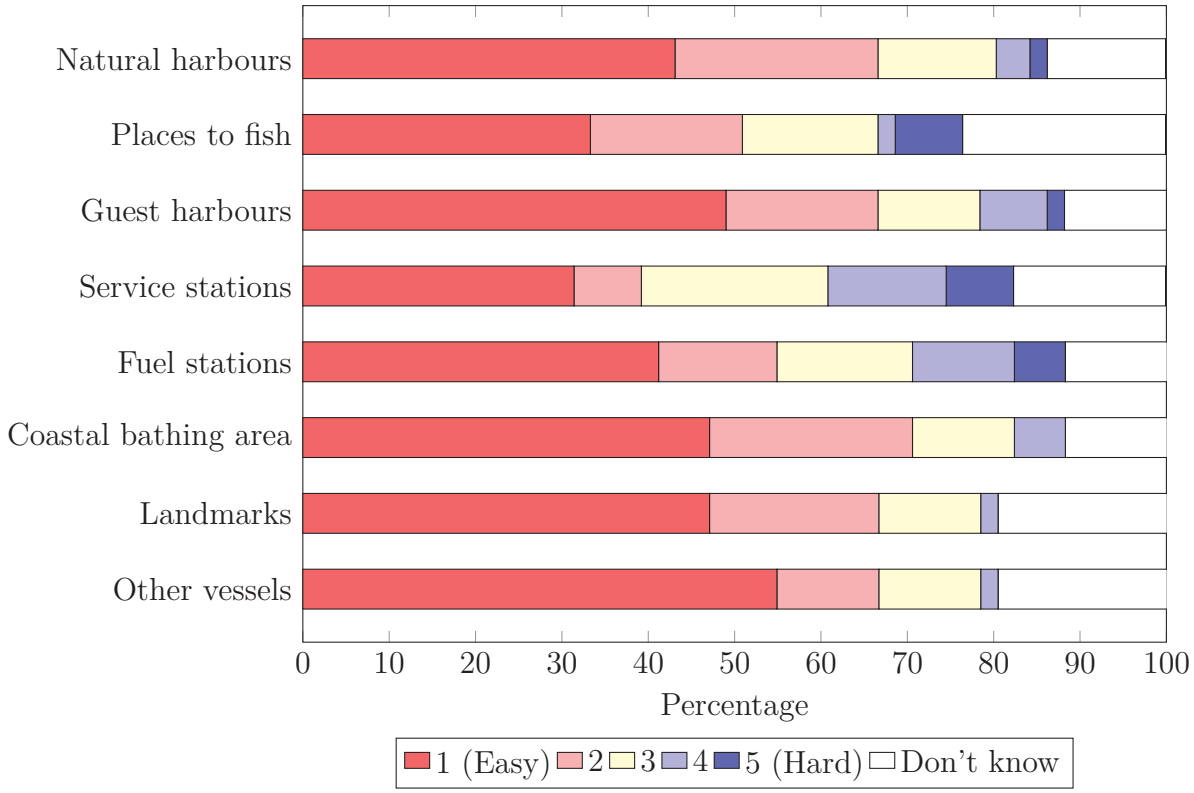

Figure A.7: Stacked bar chart of ease or difficulty finding maritime objects

8. What information would you like to receive when you are out at sea?
   - ☐ Navigation : 37
   - ☐ Warnings (e.g. about other boats or objects in the water) : 32
   - ☐ Real-time weather (e.g. wind strength, wave height, temperature) : 38
   - ☐ Water depth : 36
   - ☐ Harbor information (free docking spots, distance to jetty) : 35
   - ☐ Speed and fuel levels : 29
   - ☐ Communication (e.g. from other boats or the coast guard) : 26
   - ☐ Instructions of maintenance or repairs : 4
   - ☐ Experiences (Fact charts, quiz walk etc.) : 3
   - ☐ Other *(Free text answer)* : 3

   Free text answers:

Battery levels are a critical factor
Where I sailed last time, I use that a lot
Almost everything that is listed here is displayed on a modern plotter and on a VHF (If you have a VHF certificate)

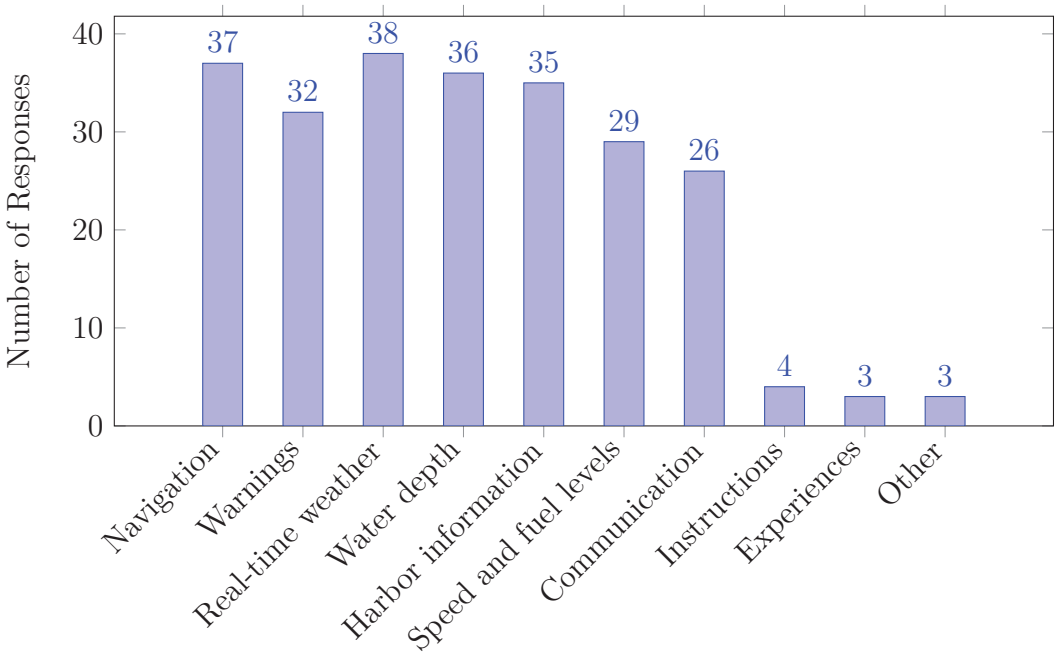

Figure A.8: Distribution of the kind of information respondents would find interesting at sea

9. What kind of navigation equipment do you have on your boat?
   - ☐ GPS : 45
   - ☐ Sonar : 28
   - ☐ Radar : 8
   - ☐ Traditional charts : 31
   - ☐ Other *(Free text answer)* : 4

   Free text answers:

Memory
None
VHF
Phone

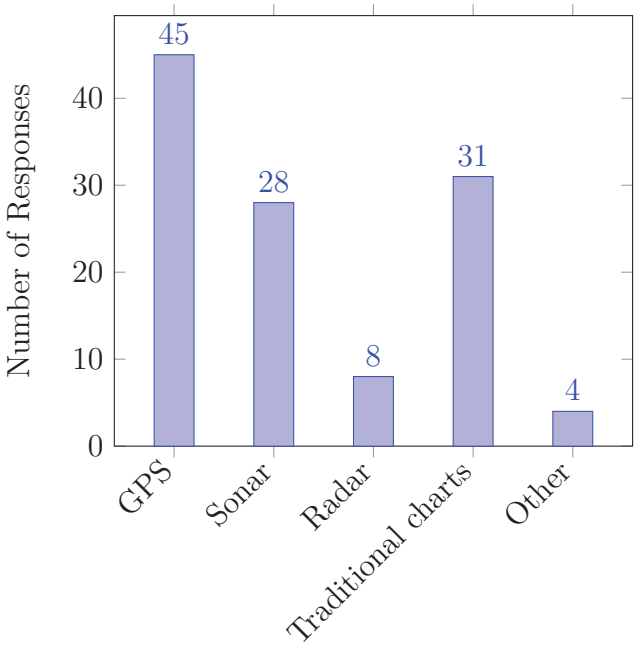

Figure A.9: Distribution of the kind of equipment respondents have at their disposal

10. How much do you experience that technology on board, such as the navigation systems, distracts from the surroundings?

	1 (Little)	2	3	4	5 (A lot)	Don't know
GPS	24	16	6	3	0	3
Sonar	27	5	4	0	0	16
Radar	11	3	4	2	1	35
Traditional charts	16	7	9	4	4	12

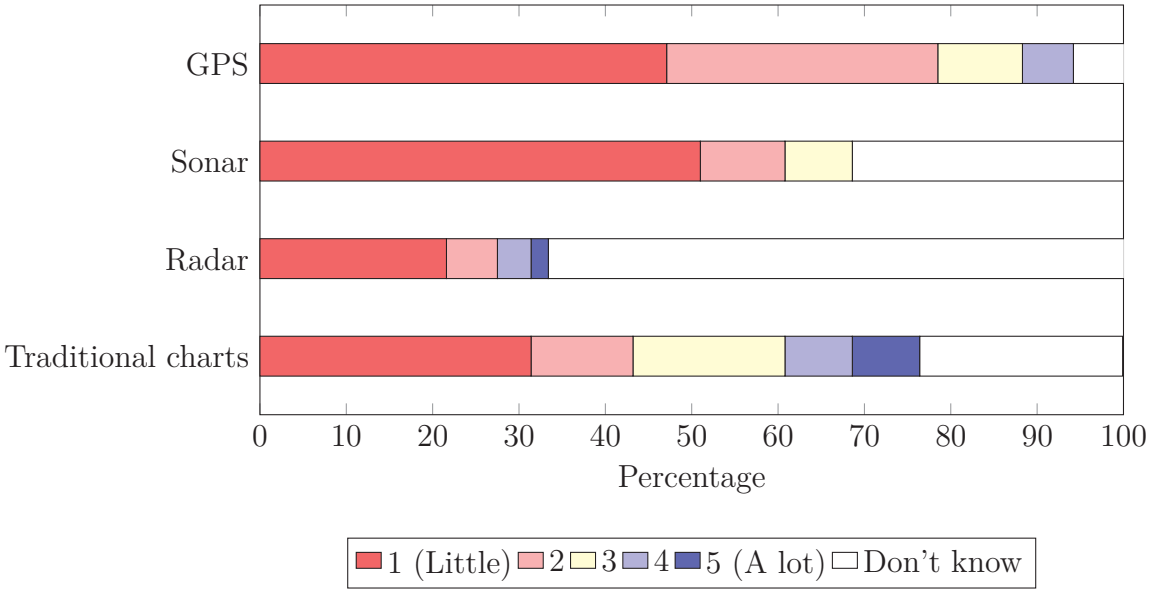

Figure A.10: Stacked bar chart of ease or difficulty navigating with differing techonologies

11. How comfortable do you feel navigating in the following situations?

	1 (Little)	2	3	4	5 (A lot)	Don't know
Limited vision (fog or darkness)	8	12	20	6	5	1
Tight waterways	5	2	21	11	12	1
Open sea	6	6	9	9	22	0
Bad weather	8	12	14	10	7	1
Heavily trafficked waters	6	7	13	9	15	2

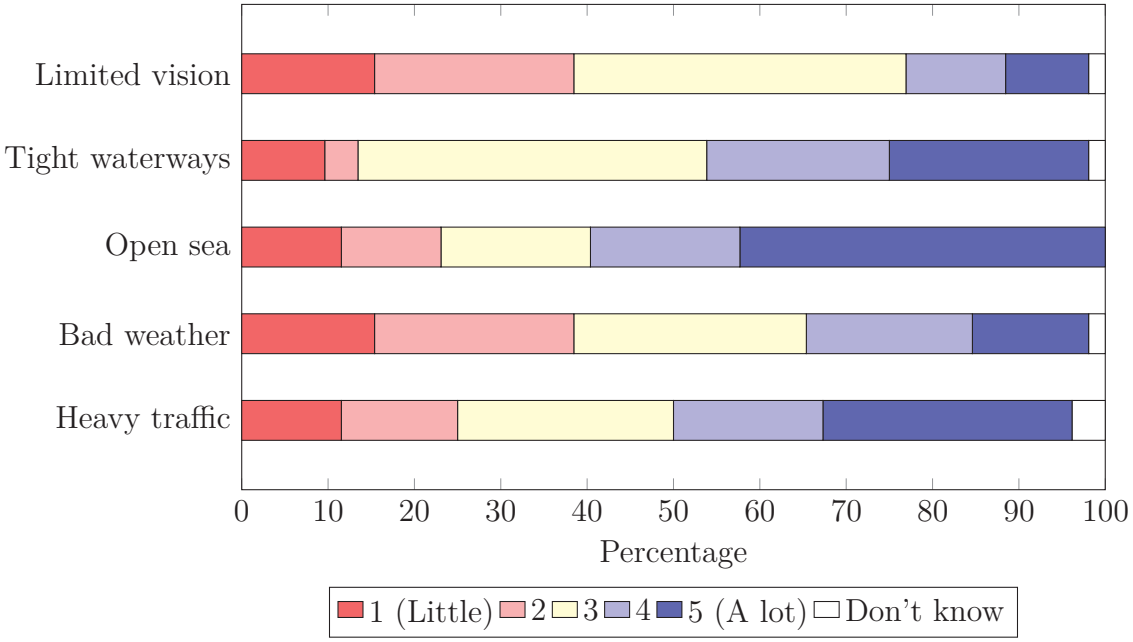

Figure A.11: Stacked bar chart of ease or difficulty navigating in differing scenarios

12. What do you think the biggest challenges are when navigating at sea?
Free text answers:

If it gets foggy
Seeing debris in the waves.
Poor visibility and darkness
Water depth
Small boat, big waves. Or that those who drive boats in the summer don't always have much control.
Seeing the difference on islands that are close to each other
Meeting people in other boats who don't know the rules of the road and general seamanship
Fast motorboats with poor visibility and no control over the rules of the road. Very unpleasant.
Poor visibility
That the machine doesn't start
Canoes and objects that don't use lanterns or similar objects that are not visible
Distance assessment
Residual swell.
You have to be careful despite the open sea.
All people who don't know what the rules of the sea are
All others who are out driving fast and don't have control, like jet skis
Poor visibility and rapid weather changes
Reading currents so the drift doesn't get too big
Distance assessment
Fog
Find a guest spot during July.
Shallow/enough depth
Weather
The plotter becomes plotty
Easy no challenges
Perceiving things in time at high speeds
The weather
Fog
Too many "gooseberries"
Others who do not follow boating etiquette.
Dark with dense fog
Stormy weather and darkness
to judge distances correctly
Fog

13. How important is it for you to have access to real-time information on the boat? (For example, weather, obstacles or waterways)

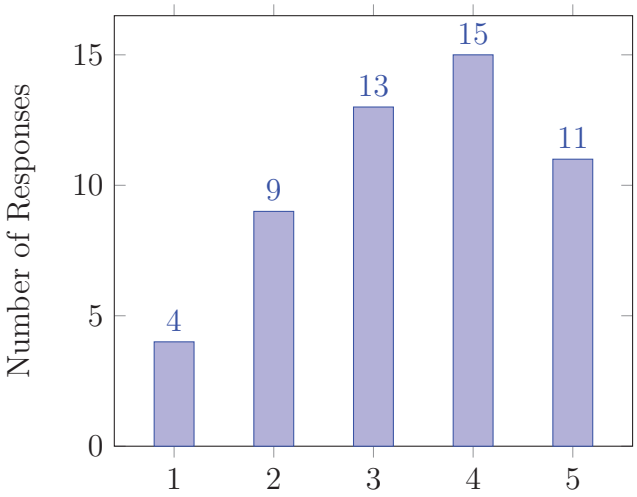

Figure A.12: Distribution of respondents' ratings of the perceived importance of real-time information. Average: 3.38

14. Is there some kind of technological equipment you find difficult to use onboard? *Free text answers:*

Touch screens, better with traditional buttons
Reading radar is not easy.
Screens with touch "buttons" are often distracting and difficult to use
All equipment is difficult before you get used to it. Do it before you set out.
Don't know
Don't have any technological equipment
Currently using my phone for navigation. Small screen and difficult to see the direction of the boat at low speed in, for example, fog.
Does not use any technical equipment
Radar *This answer appeared 4 times and has been shortened to one row.*
No *This answer appeared 11 times and has been shortened to one row.*

15. How open would you be to implementing new technology on your boat?

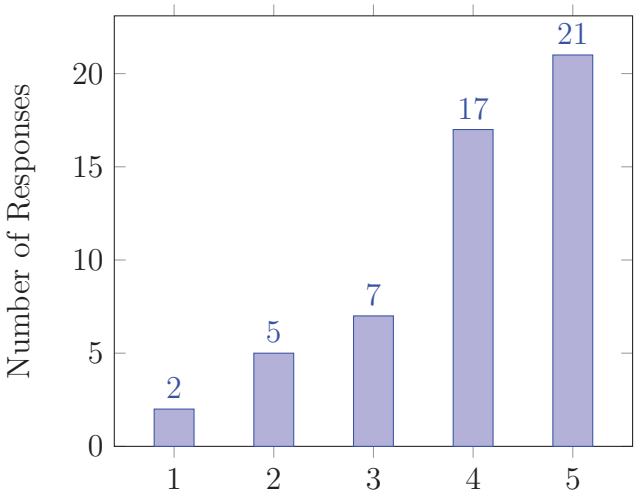

Figure A.13: Distribution of respondents' ratings of interest in trying out new technologies. Average: 3.96

16. What are your biggest concerns regarding technology on your boat?
    - ☐ That it is too complicated : 13
    - ☐ That it is distracting : 4
    - ☐ Risk of technological failure : 29
    - ☐ That it is too expensive : 36
    - ☐ Other *(Free text answer)* : 4

    Free text answers:

No need
Not enough charging stations
Theft risk. Must be able to start up quickly. Today I can drive away, loosen all the straps, start the engine and be off in about 2-3 minutes. If it is difficult to pick up the equipment, it will not be used. I also drive in the middle of winter, so it must work even then.
Nothing.

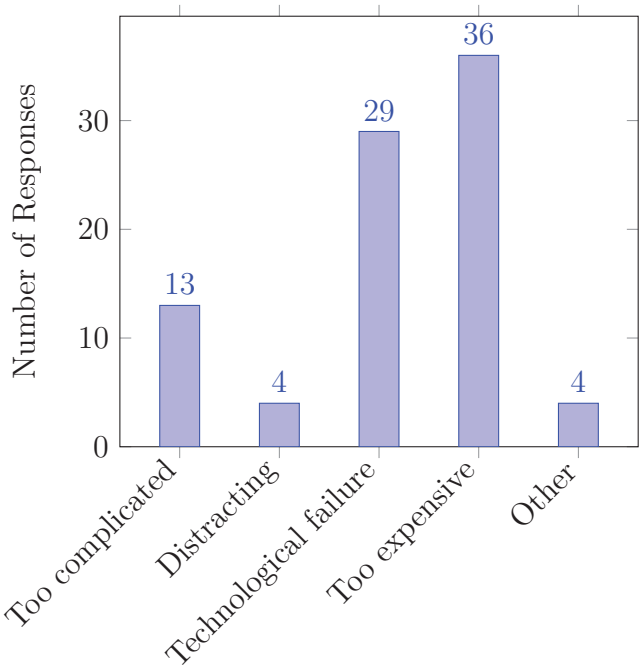

Figure A.14: Distribution of the kind of problems respondents could experience relating to the implementations of new technology

17. Would you like to add something? Feel free to comment below!

    Free text answers:

When you write Fuel, keep in mind that larger electric motors should come in strong. Charging stations will be needed.
I drive an electric boat but I missed questions about it
It would have been good to have a simple emergency button to contact the marine rescue service. I've never had to contact them, but if something goes really crazy, it can be difficult to get the phone out and call.
Nothing.

B

Internal survey

B.1 Survey questionaire

Questions were available in both Swedish and English, but only the English translation is presented here to conserve document space. Answer alternatives marked with ☐ *means multiple answers are allowed per question, while* ○ *means only one answer is allowed per question or only one answer per row in the case of matrix questions.*

1. How old are you?
   - ○ <20
   - ○ 20 - 29
   - ○ 30 - 39
   - ○ 40 - 49
   - ○ 50 - 59
   - ○ >60
   - ○ Prefer not to say
2. Do you own a boat?
   - ○ Yes
   - ○ No
3. If yes, what kind of boat?
   - ○ Sailboat
   - ○ Motorboat
   - ○ Other *(Free text answer)*
4. What is your boating experience?
   - ○ No experience
   - ○ Little experience
   - ○ Some experience
   - ○ Extensive experience
   - ○ Expert
5. How much do you use a boat during a year?
   - ○ Less than a week
   - ○ 1-2 weeks
   - ○ 3-6 weeks
   - ○ Multiple months
   - ○ Whole year
6. How long is your boat journey on average?
   - ○ 0-15 min
   - ○ 15-30 min

- ○ 30-60 min
- ○ 1-2 h
- ○ 2 h+

7. What user segment describes your boating the best?
   - ○ Leisure
   - ○ Commercial
8. How easy do you think it is to find these locations when you are out to sea?

	1 (Easy)	2	3	4	5 (Hard)	Don't know
Natural harbours	○	○	○	○	○	○
Places to fish	○	○	○	○	○	○
Guest harbours	○	○	○	○	○	○
Other vessels	○	○	○	○	○	○
Fuel stations	○	○	○	○	○	○
Coastal bathing area	○	○	○	○	○	○
Landmarks	○	○	○	○	○	○
Service stations (for repairs)	○	○	○	○	○	○
Service stations (E.g. to buy food)	○	○	○	○	○	○

9. What information would you like to receive when you are out at sea?
   Free text answer
10. What kind of navigation equipment do you have on your boat?
    - ☐ Chartplotter
    - ☐ Sonar
    - ☐ Radar
    - ☐ Traditional charts
    - ☐ Other *(Free text answer)*
11. How much do you experience that technology on board, such as the navigation systems, distracts from the surroundings?

	1 (Little)	2	3	4	5 (A lot)	Don't know
Chartplotter	○	○	○	○	○	○
Sonar	○	○	○	○	○	○
Radar	○	○	○	○	○	○
Traditional charts	○	○	○	○	○	○

12. Which situations/conditions at sea do you find difficult to navigate in?
    Free text answer
13. What do you think the biggest challenges are when navigating at sea?
    Free text answer
14. How important is it for you to have access to real-time information on the boat? (For example, weather, obstacles or waterways)

1	2	3	4	5
○	○	○	○	○

15. Is there some kind of technological equipment you find difficult to use onboard?
    Free text answer
16. How open would you be to implementing new technology on your boat?

1	2	3	4	5
○	○	○	○	○

17. What are your biggest concerns regarding technology on your boat?
    - ☐ That it is too complicated
    - ☐ That it is distracting
    - ☐ Risk of technological failure
    - ☐ That it is too expensive
    - ☐ Other *(Free text answer)*
18. Would you like to add something? Feel free to comment below!
    Free text answer
19. If you want to know more about what we are doing and are up for an in-depth interview, please write your email below and we will be in touch!
    Free text answer

B.2 Survey results

Questions were available in both Swedish and English, but only the English translation is presented here to conserve document space. Swedish free-text answers have been translated.

Total responses: 40

1. How old are you?
   - <20 : 0
   - 20-29 : 2
   - 30-39 : 5
   - 40-49 : 10
   - 50-59 : 18
   - >60 : 5
   - Prefer not to say : 0

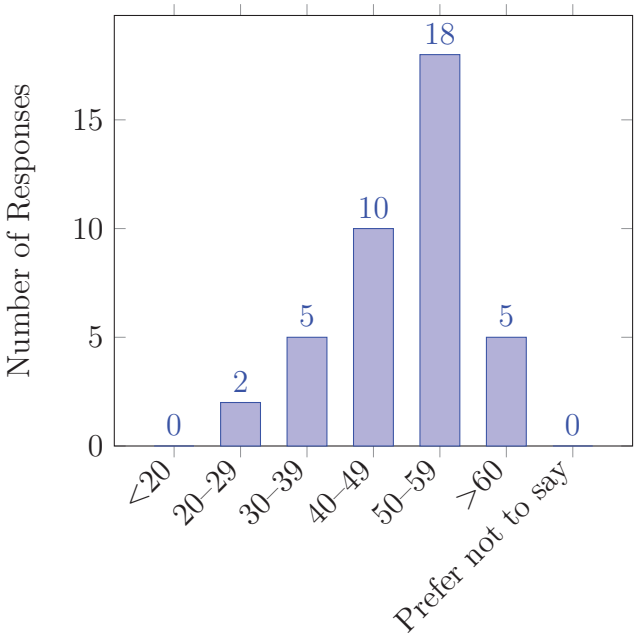

Figure B.1: Age distribution of survey respondents

2. Do you own a boat?
   - Yes : 36
   - No : 4

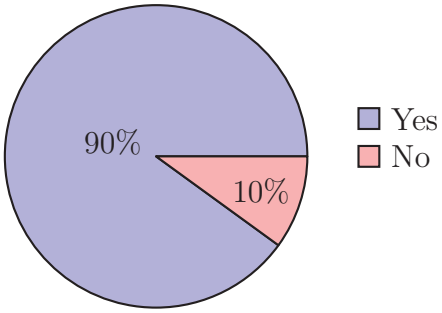

Figure B.2: Percentage that owns a boat

3. If yes, what kind of boat?
   - Sailboat : 8
   - Motorboat : 25
   - Other *(Free text answer)* : 2

   Free text answers:

Both sail and motorboat and I drive professionally
Sailboat and motorboat

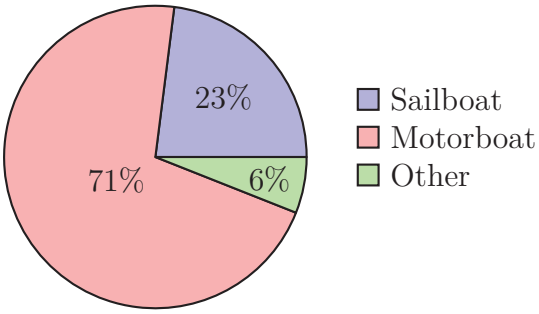

Figure B.3: Percentage of what kind of boat respondents owns

4. What is your boating experience?
   - No experience : 0
   - Little experience : 1
   - Some experience : 7
   - Extensive experience : 23
   - Expert : 5

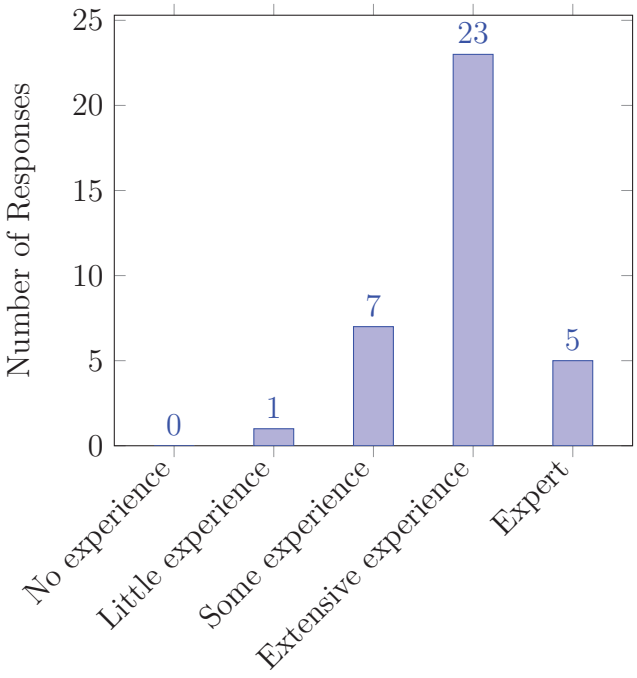

Figure B.4: Experience distribution of survey respondents

5. How much do you use a boat during a year?
   - Less than a week : 2
   - 1-2 weeks : 6
   - 3-6 weeks : 14
   - Multiple months : 15
   - Whole year : 3

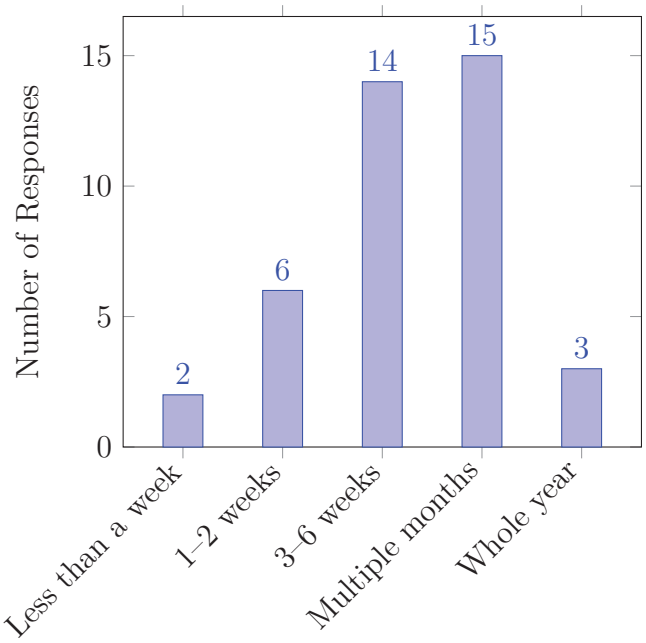

Figure B.5: Distribution of boat use per year

6. How long is your boat journey on average?
   - 0-15 min : 0
   - 15-30 min : 7
   - 30-60 min : 11
   - 1-2 h : 5
   - 2 h+ : 17

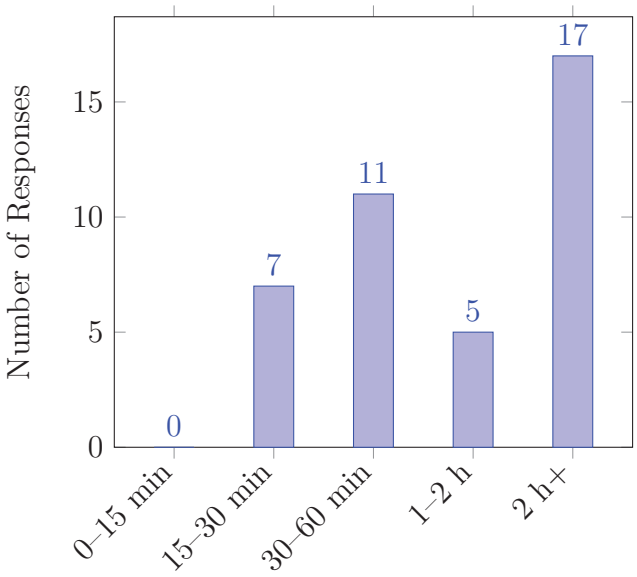

Figure B.6: Distribution of boat journey time

7. How easy do you think it is to find these locations when you are out to sea?

	1 (Easy)	2	3	4	5 (Hard)	Don't know
Natural harbours	12	14	7	6	1	0
Places to fish	5	4	8	4	4	15
Guest harbours	19	14	4	1	1	1
Other vessels	10	14	5	4	1	6
Fuel stations	8	15	10	6	0	1
Coastal bathing area	9	6	9	9	2	5
Landmarks	16	7	9	5	1	2
Service stations (for repairs)	3	8	12	5	2	10
Service stations (E.g. to buy food)	8	16	10	2	1	2

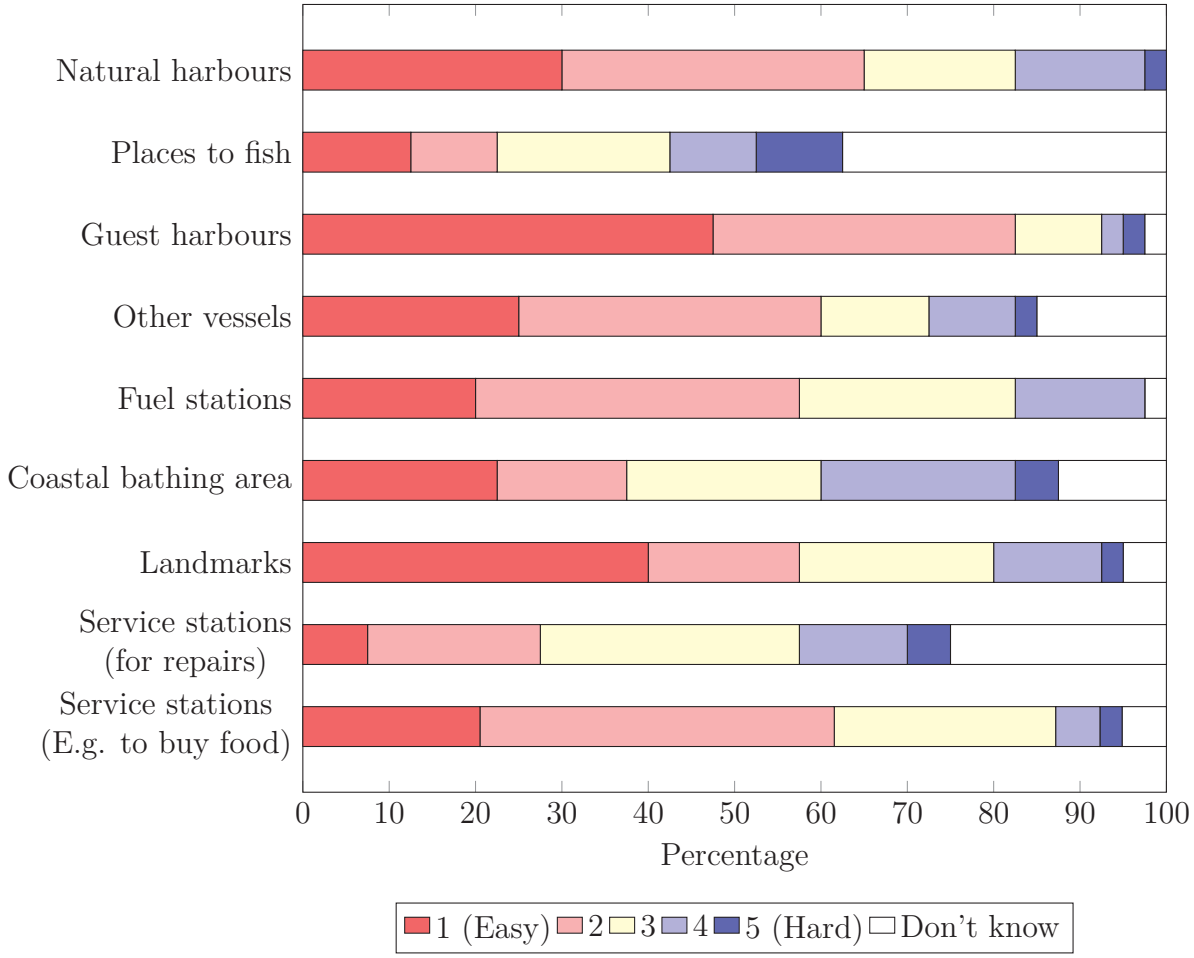

Figure B.7: Stacked bar chart of ease or difficulty finding different maritime objects

8. What information would you like to receive when you are out at sea?
   Free text answers:

How full it is in the guest harbor in real time. Dockspot can only be seen the next day if you want to book
Would like to find natural harbors easier but currently uses skippo.
Weather, navigation warnings
Easier way to meet others by boat for a more social experience. For next season we will try seapeople which also seems to facilitate the above points.
How many boats are already in the guest harbor or natural harbor.
I am not really looking for any information. But perhaps would appreciate all the above information if it was easily accessible.
I think I already have what I need...
Easy access to what services can be found in different harbors - e.g. electricity/water/shower. Is there a gas station? Is there a possibility of repairs, is there a shop for spare parts? In a natural harbor - are there toilets, bollards, clearer depth indication?

Occupancy in harbors and what services are available and in detail where in the harbor they are located. E.g. Septic suction, fuel, food, guest space.
If there is space in guest ports. It is boring to travel far and arrive and realize that it is full.
Would like to see if there was space in guest ports or if it was full.
Weather information
Weather.
Weather and other traffic
Weather conditions and accessibility in port
Position at gas station, number of available spaces in guest ports,
I already have what I need
Better depth information next to islands, restaurants and eateries, grocery stores and other services
Weather, wind, wave height along the intended route. Example: How big are the waves and how much wind is there at the mouth of Gullmarsfjorden. That can decide whether I go to Lysekil or Ljungskile from Henån, for example.
Real-time occupancy in ports and bays. Remaining range given speed profile and remaining fuel Alarms about course and speed indicate grounding Tips on the best way to maneuver for docking (also evaluating afterwards versus what you actually did is interesting)
If there is space in guest harbors, both day and night. I would like to be able to easily save nice places we docked at or where we see others docked, to remember at a later time Service points for repair or service and what their occupancy looks like.
Where my friends are and if there is space where I am heading. Where I can refuel HVO100. Good places to stop for lunch.
Is it full in a harbor, natural harbor, different rules for fishing harbors, takes time to read about all natural harbors where there are rocks, grounds and what to think about - can be a bit difficult if 3 intended places are full. Where is the best place to dock for the next 24 hours based on weather and wind. Are the waves too high to pass certain places, often requires local knowledge.
Nothing beyond navigation, the planning is done before departure
Guest berths
Available berths in a guest harbour. That is, how many non-bookable berths are currently available?
Weather
None, but the entire sea chart should be integrated into the navigation equipment (plotter). Specifically the speed limits I think most of the information is there, you just have to find out. Service berths
Where are open restaurants, menus, bathing areas with ratings, how full it is in a guest harbour.
Above all, navigation, clear/simple interfaces for other boats, sea marks, ground, speed, possible errors, etc.
Weather, wind, events, acquaintances
Obstacles, sea weather, where friends are, coastal events.

A trusted site to locate dealers and ability to determine if fuel stations are open with an up to date operating hours

9. What kind of navigation equipment do you have on your boat?
   - ☐ Chartplotter : 34
   - ☐ Sonar : 22
   - ☐ Radar : 12
   - ☐ Traditional charts : 26
   - ☐ Other *(Free text answer)* : 10

   Free text answers:

AIS
Skippo
Seachart on mobile phone
Compass, log with speed and distance through the water, GPS
Eniro for sea, on a mobile phone
Tablet with Skippo
Skippo on mobile phone
Custom-made system for various sensors
Mobile phone
Skippo

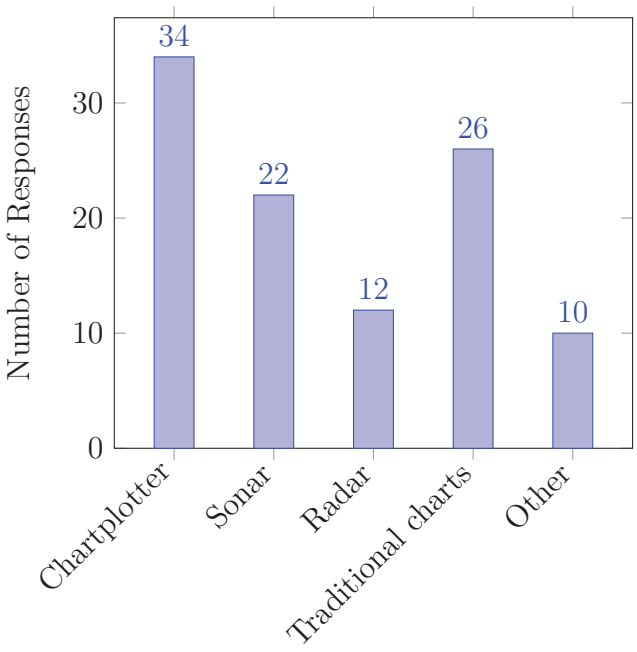

Figure B.8: Distribution of the kind of equipment respondents have at their disposal

10. How much do you experience that technology on board, such as the navigation systems, distracts from the surroundings?

	1 (Little)	2	3	4	5 (A lot)	Don't know
Chartplotter	22	6	9	2	1	0
Sonar	24	8	1	0	1	6
Radar	11	9	4	1	0	15
Traditional charts	1	11	12	8	4	0

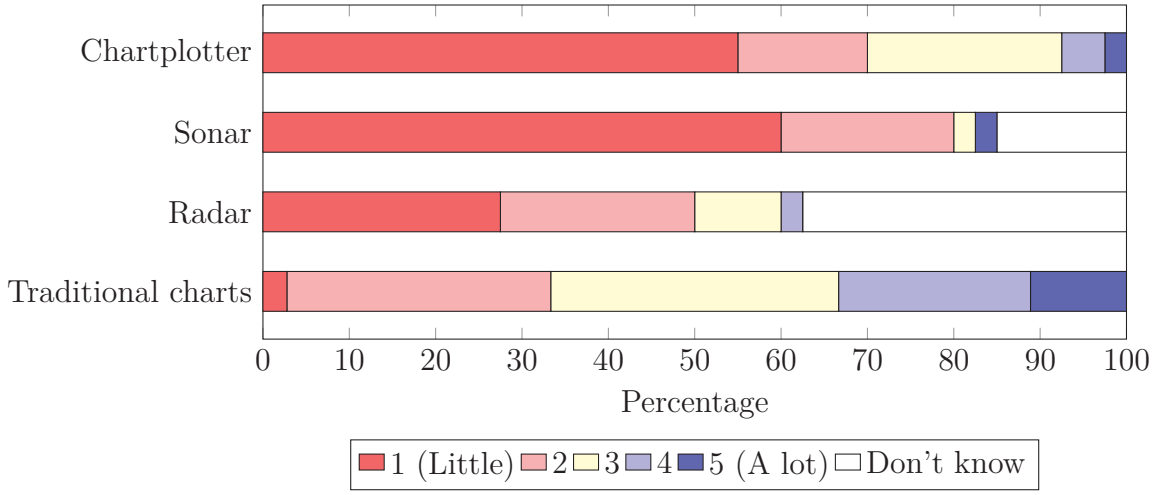

Figure B.9: Stacked bar chart of ease or difficulty navigating with different techonologies

11. Which situations/conditions at sea do you find difficult to navigate in?
Free text answers:

Fog
When you feel unsure about depth curves, they are not accurate
Fog, darkness
Rain and darkness that makes it impossible to use the screen on your mobile/pad.
Traffic with other vessels
Darkness
At speeds over 25 knots. Fog and Darkness
Night, or if technical equipment is not working (which in practice means electrical failure).
Bad weather and darkness.
Darkness, inland with poor visibility.
Lots of traffic and reduced visibility. Sailing boats sailing in narrow passages can be difficult to predict what they will do and require extra supervision.
The combination of fog and rain with rough seas.
New places with a lot of shallows
Proper fog. Especially if you have a substandard radar.
Poor visibility
Fog and bad weather
Rain, Fog; Wind
fog and darkness
Open sea/outskirts
Cramped shallow places with a lot of shipping
A lot of wind High waves Poor visibility
Bad weather with a lot of wind
When you are in new places. When someone on the boat is hungry or seasick. When the weather is worse
Poor visibility.
Harsh weather, poor visibility, high seas. Shallow water, unclear about what the water depth is, if it is not clear on the plotter, or other objects (stones, etc.) around the berth.
In ports
A lot of traffic, wind, waves, what kind of crew is on board, low blood sugar - because the port is full. Fog and darkness
Cramped channels and shallow areas, e.g. Albrektsunds Kanal if you are alone in the boat and do not know that you are meeting a larger ship
Night and poor visibility
A lot of rain. Poor visibility. Strong winds.
Darkness, reduced visibility, rough weather
Windy weather, crowded harbor
Fog. When there is a lot of traffic.
Archipelago and places with reefs

Open sea but very shallow.
Narrow passages with a lot of traffic, and high speed.
Darkness
Heavily trafficked narrow waters. Dusk in the archipelago.
Harsh weather to include fog and rough sea state

12. What do you think the biggest challenges are when navigating at sea?
Free text answers:

Strong water or strong wind
Traffic with other vessels
Ships around
Other boat owners. Poor seamanship or seamanship of others.
Distance assessment - connecting charts/plotters to reality.
I don't see any major challenges with today's technology. Plotters, GPS, AIS, weather forecasts.
Staying focused. The times I've been on the verge of running aground or going wrong are the times when the weather has been good and visibility is good. I sit and drive while drinking coffee, eating a bun and talking to my passengers. Suddenly I realize that I'm heading into shallow water. When navigation conditions are difficult, I don't sit and drink coffee and slave with the navigation and then I haven't been on the verge of going wrong either.
Other boats' actions.
Screaming children :)
When you don't have a proper chart for an overview
Such visibility. Other boats with unclear intentions.
Sea conditions wind/sea
To have access to Position
to avoid shallows
When you are going really fast and there are narrow, hidden passages. If you slow down, it usually works out.
Places where it is crowded or shallow
To balance all aspects - where am I, what does the chart show ahead, where is everyone else, how do I move, how do others move, and how are the waves coming. Especially when you are in areas with shallows etc. (On questions 14 and 16 you forgot to write the scale, i.e. whether 1 is most important or 5 is most important. I put 5 = very important/open. There is a risk that people will interpret the scale differently...)
High speed and in poor visibility.
to know where you want to go next.
Fairway relatively navigable water
To be on water where I don't know how the wind behaves - when it is windy and how long it will remain in the old sea and when the wind is from which direction.

Finding the fastest and most comfortable route considering wind, waves and currents
Keeping the correct course in slightly more open water and longer distances.
Knowing which way to go. To me, everything looks the same at sea.
Taking into account larger ships in the fairways, it would have been good if you could see them directly on the plotter
Distance assessment and exact position in relation to the ground.
Geographically locating yourself between the plotter and reality, makes it easier with a large plotter, but expensive...
Weather and light conditions.
Other boaters and not fully knowing the depth in certain tributaries

13. How important is it for you to have access to real-time information on the boat? (For example, weather, obstacles or waterways)

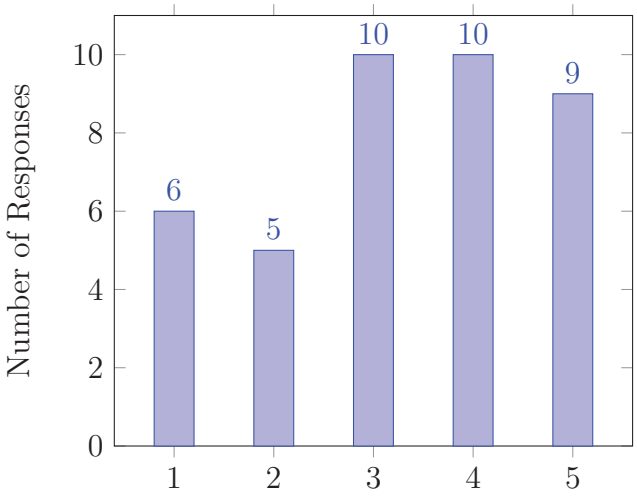

Figure B.10: Distribution of respondents' ratings of the perceived importance of real-time information. Average: 3.03

14. Is there some kind of technological equipment you find difficult to use onboard?
Free text answers:

Engine
The sonar
I think it is difficult to connect reality and charts (digital or paper) in terms of distance.
VHF
In my opinion, touch screens are one of the biggest dangers. When the boat is moving, it becomes very difficult to handle the screens, simple things like zooming in/out can be very difficult and require you to focus excessively on the screen instead of what is happening around the boat.
Correct setting of the radar in combination with heavy rain and rough seas.
Radar requires training and experience but can be crucial in the dark and poor visibility.
It is about electricity, batteries, solar cells, consumption, knowing the battery and charge status when you are stationary.
We develop modern things, most people use old equipment. There you have to get to know your boat and its equipment
Radar
Configuration and compatibility between manufacturers, NMEA2000 is a way to standardize.
It is mainly problems when you shift focus between technical equipment and visual supervision that problems arise.
A touch screen can be difficult to use when operating at speed or in a rough sea state

15. How open would you be to implementing new technology on your boat?

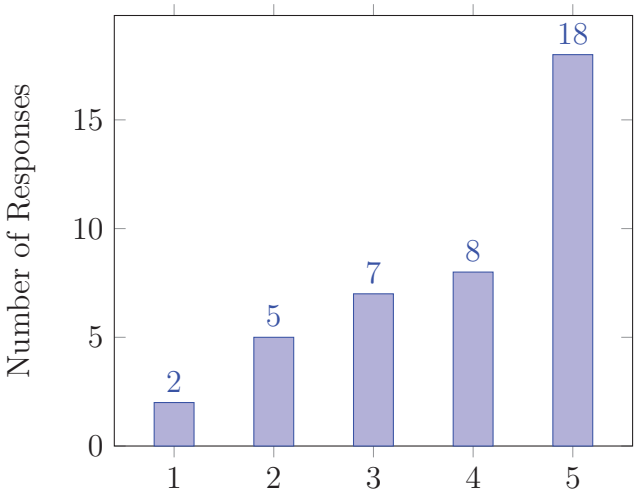

Figure B.11: Distribution of respondents' ratings of interest in trying out new technologies. Average: 3.88

16. What are your biggest concerns regarding technology on your boat?
    - ☐ That it is too complicated : 5
    - ☐ That it is distracting : 6
    - ☐ Risk of technological failure : 18
    - ☐ That it is too expensive : 34
    - ☐ Other *(Free text answer)* : 6

    Free text answers:

Takes up space, potentially reduces the boat's performance, potentially reduces the boat's aesthetics
Becoming dependent on it if things go wrong
That it does not age with dignity, it is dependent on services/external systems
Difficult to know what to buy/invest in
Time-consuming
That it doesn't add anything for me

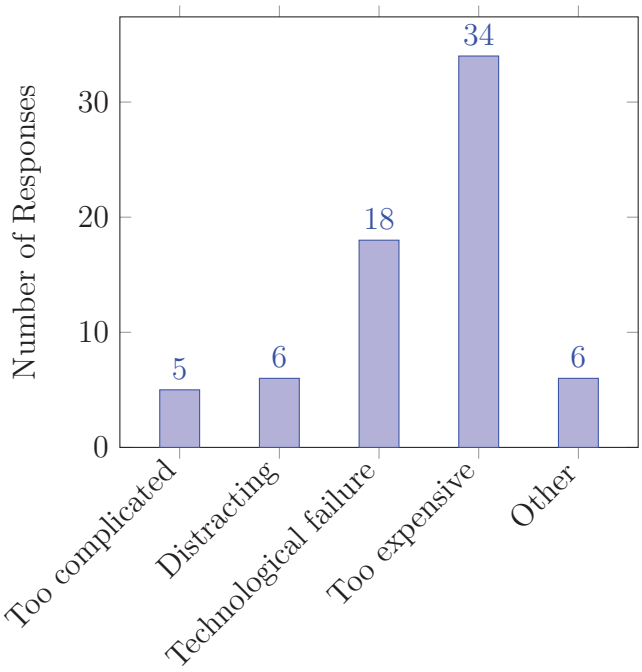

Figure B.12: Distribution of the kind of problems respondents could experience relating to the implementations of new technology

17. Would you like to add something? Feel free to comment below!
Free text answers:

You MUST be able to navigate with just a paper map and compass, everything else breaks sooner or later.
I'm a bit torn about how well natural harbors should be marked. There is a certain advantage in not even finding random spots marked.
I sail a lot and often race, that's when most of the challenges arise.
Adjusting your navigation systems so that they show exactly the information you want to see is extremely important. Being able to do this well in advance of departure is also important because it becomes extremely distracting to do this while underway. Filter out all information on the chart that is not relevant, e.g. if your boat has a draft of 1 m, it is completely irrelevant to include 6- and 10-m curves on the chart. If you don't drive in the dark, the lighthouses are uninteresting. It is very easy to overload the driver with information, which means that the relevant information is easily missed. Simple functions such as e.g. zooming out/in should be possible with physical buttons so that it can be done with minimal distraction from the surroundings.
you want it to be easy to handle the boat. everyone, even those who do not have much experience, should be able to do it without needing much training or experience
experience that all technology for boats is unnecessarily expensive, and half as good as for smart homes etc. difficult to link different technologies/brands. difficult to know what to buy, one company does one thing well, another something else. There is a high focus on pulling wires etc. it is difficult in a boat, little focus on solving the small everyday problems you have.
More women should start driving their own boat - investigating why could be interesting - why they do not drive their own boat today.
Today I mostly take day trips so my answers may not have that much weight. However, I have extensive experience both as a racing sailor but perhaps above all by having worked with Electric drivelines for recreational boats for 20 years. During that time I had an extremely large amount of customer contact and became familiar with customers' concerns and difficulties. I also believe a lot in bringing in technology that monitors the boat and that is rather used when you are not in the boat.
I drive both a sea rescue boat and a sailboat so I tried to answer based on my accumulated experience
I'm probably not the right target group for this because my boating life is quite simple. I manage well with a simple plotter and charts as a back-up

C

Interview template

Presentation about the project

Instructions: *Keep it short; don't lead them into ideas about AR at sea just yet. Only say that we are looking into ways to enhance the boating experience at sea on behalf of Volvo Penta and Chalmers.*

General

How old are you?

What kind(s) of boat do you use?

What do you use your boat for? activities, traveling to destinations, how long are the travels in time and/or distance?

When do you use your boat, which time of the year, all weathers, night/day?

How often do you use your boat?

What is your background in boating? (Just started, a lot of experience, etc.)

On which occasions do you feel uncomfortable on the boat? If any

Have you encountered any problems with your boat, specifically when you are out at sea or docking? If yes, what were they? (For example, run aground)

When you are on a journey and see something interesting, how do you go about retrieving information about what you are seeing? (For example, landmarks or islands)

What are your favorite things about being out at sea and going boating? What are some of your favorite memories from being out at sea?

What are your favorite destinations? What makes them special?

Technology on the boat

What kind of technology do you have on the boat?

What is the most important technology, according to you?

What technology do you use the most?

Do you encounter any problems with the technology on the boat or something you find difficult/frustrating in regards to the technology on the boat? If yes, what are they?

Is there some kind of technology that you miss on the boat?

If something breaks on the boat, how would you go about solving the problem?

What is the most important information you need/want to receive when you are out at sea?

Safety

Have you ever been in a situation at sea where you needed assistance?

How did you go about getting this assistance or solving the problem?

End and wrap-up

Finally, is there something you would like to add?

Say thanks and goodbye

D

Gantt Schedule

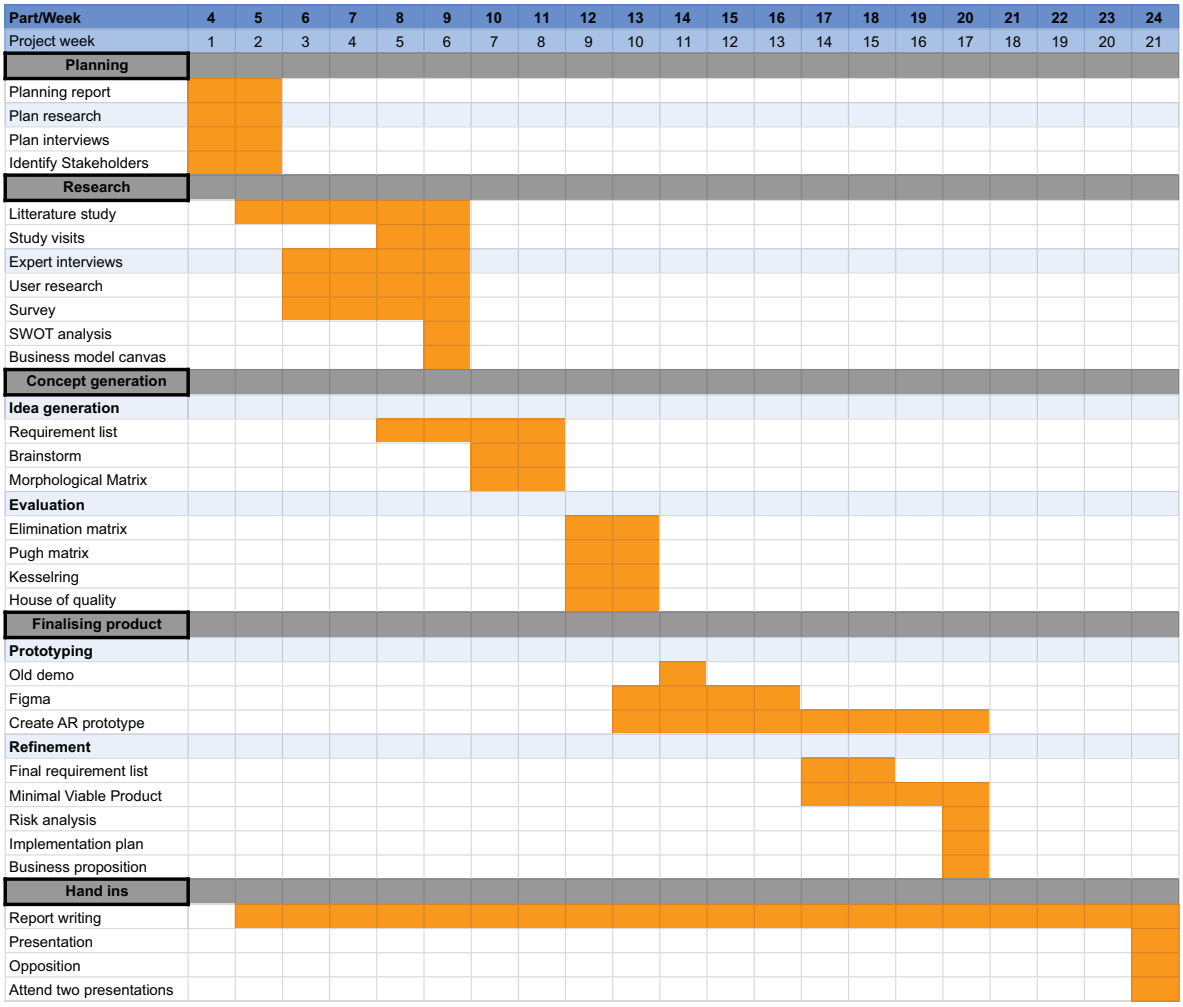

Figure D.1: The Gantt schedule for the thesis

E

Requirement List

Requirement	D/W
Navigation	
Show position at sea	D
Show obstacles at sea	D
Show/identify other boats	D
Show intended routes	D
Show speed limits	D
Show depth	D
Minimise distractions at sea	W
Assist driving in low visibility conditions	D
Vessel Data	
Display fuel consumption	D
Active radio frequency	W
Display active warnings	W
Display active systems (light mode etc.)	W
Display current speed	D
Conditions	
Show weather forecast	D
Show wind (direction and strength)	W
Assist on how to drive in different conditions	W
Docking	
Assist docking guest harbours	D
Assist docking natural harbours	W
Show free spots	D
Technical	
Integration with existing sensor suite	W

Requirement	**D/W**
Hardware	
Salt water proof	D
Water glare suppression	D
Lens that allows night-time operation	D
Full day battery life	D
Ability to use a physical interface to control headset (keyboard etc.)	W
Software	
Tactile feedback	D
Select information to display	D
Automatic contextual information (automatic selection of information to display)	W

Table E.1: A table with requirements and their respective Demand(D) and Wish(W) for the final product.

F

Morphological matrix

Navigation:												
Understand navigation rules	Egocentric map view	AR identification of other vessels then showing how to position/drive in relation to that	Information boxes of how to drive in different situations	Rules mode for beginners	Follow the line or dots live on water	Warnings for crossing trajectories	Play scenarios in VR top practise rules	Quiz questions to make it more fun	Rule breaker warnings	Red dots on boat you have to steer clear from	Create digital manual for beginners to understand rules and regulations as well as safety predictions to take while boating	See other boats on the physical sea chart
Comfortable navigation	Settings in autopilot for comfortable trip	AR shows what the best "angle of attack" when driving in wavy conditions	Information boxes on how to best "attack" waves									
Connect information from the chartplotter to the real world	Show specific landmarks point them out on the plotter and in the AR view	Say “what about” to get information about a specific target	Put the symbols (e.g. from plotter) onto the real world	Use AR glasses to estimate distance between islands or destinations by using GPS	Sea chart on paper get position overlaid							
Estimate distances	“Range finder”, show distances to different objects at sea, either automatically or by picking different objects	Look for some time at a point and the distance appear	Say distance and it appears	Collissiion course warnings, calculate with speed and direction, use of "fartkamera"								
Drift off course	Get live information about currents, example moving arrows over the surface	See the line where the boat will go on correct steering settings	Use of glasses to warn driver if she goes off course by following dots or lines									
Speed limits	Auto speed warning	Speed limit “memory” mode: Remember relevant information until it changes	Live speed limit and speed of the boat in the field of view in the ar headset, qr code on the speed signs or sensors when you drive past one	Speedometer with warning								
Low visibility (Darkness)	Low light mode: use headset cameras to amplify dark areas, obstacles, also try to supplement known obstacles	Dark vision camera										
Low visibility (Fog, rain etc)	Enter a low visibility mode and when you can't see things the AR will present it instead	Choose what the AR headset should show (Islands, landmarks, other vessels)	Show a path that is safe, then obstacles are not a problem (same for dark vision)									
Information overload	Information filtering mode/context aware information: Select info to view or only present information relevant to context	Game mode, choose among different modes for what you're specific situation needs or pick the settings by yourself										
Docking:												
Dock assistance	Optional tool tips, - Clippy but for boating. “It looks like you're trying to dock, would you like some help with that?	Camera feed with “parking guidelines”. Either with live position how the boat is going to move with the current steering or with steering instructions on what to do	Show where the boat will end up in a few seconds with current control settings. Compensate for wind and/or currents	Create a similar system to parking a car in AR, can add safety instructions as well	To motivate, create points on how fast/how many tries it has taken							
Information close to islands	Download packages for specific natural harbors, e.g. depth information	Crowd source other boats with similar depth has been here, then it's possible to moore	Distance from boat to land when docking	See through the hull	Digital manual which will show information about depth and other stuff							
Changing weather conditions for docking over night	Some boats have a wind speed indicator, collect this data to present high wind warnings	Integrate forecast with the AR headset and then show how and where to best dock the boat overnight	Warnings for changed wind conditions to moore at a location over night									
Trip planning:	Sea chart+AR overlay for planning trips	Estimation of weather and visibility in the AR glasses	Create a path and this appears in the headset (similar to maps when driving a car)									
Find natural harbours	AI image recognition	Download history for different natural harbours and show the route										
Full guest harbors, difficult finding spots	Connected harbours: A sensor reads if a spot is occupied and publishes online	QR code at the entry to guest harbors, automatically picking a free spot and then showing the way to that spot	Drones that check for free spots									
Finding service stops	Integrated AI, ask by voice or chat	Service places on map not in AR	Have a checklist on what and how to check that everything is in order before going out with the boat									

Figure F.1: The morphological matrix for the concept generation

G

Kesselring weights

	A1	A2	A3	A4	A5	A6	A7	A8	B1	B2	B3	B4	B5	C1	C2	C3	D1	D2	D3	E1	E2	E3
Navigation																						
A1. Show position at sea	-	0,5	0	0	0	0,5	0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2. Show obstacles at sea	0,5	-	0	0	0	0,5	0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3. Show/identify other boats	1	1	-	0,5	0	1	1	0	0	0	0	0	0,5	0	0	0	0	0	0	0	0,5	0
A4. Show intended routes	1	1	0,5	-	0,5	0,5	1	0	0	0	0	0	0,5	0	0	0	0	0	0	0	1	0
A5. Show speed limits	1	1	1	0,5	-	1	1	0,5	0	0	0,5	0	1	0,5	0	0	0	0	0	0	1	0
A6. Show depth	0,5	0,5	0	0,5	0	-	0,5	0,5	0	0	0,5	0	0	0	0	0	0	0	0	0	0	0
A7. Minimise distractions at sea	0,5	0,5	0	0	0	0,5	-	0,5	0	0	0	0	0	0	0	0	0	0	0	0	0,5	0
A8. Assist driving in low visibility conditions	1	1	1	1	0,5	0,5	0,5	-	0	0	0,5	0	0	0	0	0	0	0	0	0	0,5	0
Vessel data																						
B1. Disp. Fuel consumption	1	1	1	1	1	1	1	1	-	0	1	0	1	0,5	0,5	0,5	1	1	0,5	0	1	0
B2. Active radio frequency	1	1	1	1	1	1	1	1	1	-	1	0,5	1	1	1	1	1	1	1	0,5	1	0,5
B3. Disp. active warnings	1	1	1	1	0,5	0,5	1	0,5	0	0	-	0	0,5	0,5	0,5	0,5	1	1	1	0	1	0
B4. Disp. active systems (light mode e.t.c.)	1	1	1	1	1	1	1	1	1	0,5	1	-	1	1	1	1	1	1	1	0,5	1	1
B5. Disp. current speed	1	1	0,5	0,5	0	1	1	1	0	0	0,5	0	-	0	0	0	0,5	0,5	0,5	0	1	0,5
Conditions																						
C1 Show weather forecast	1	1	1	1	0,5	1	1	1	0,5	0	0,5	0	1	-	0	0,5	0,5	0,5	0,5	0	1	0,5
C2. Show wind (direction and strength)	1	1	1	1	1	1	1	1	0,5	0	0,5	0	1	1	-	0,5	0,5	0,5	0,5	0	1	0,5
C3. Assist on how to drive in different conditions	1	1	1	1	1	1	1	1	0,5	0	0,5	0	1	0,5	0,5	-	0,5	0,5	0,5	0	1	0,5
Docking																						
D1. Assist docking guest harbours	1	1	1	1	1	1	1	1	0	0	0	0	0,5	0,5	0,5	0,5	-	0,5	0	0	0,5	0
D2. Assist docking natural harbours	1	1	1	1	1	1	1	1	0	0	0	0	0,5	0,5	0,5	0,5	0,5	-	0	0	0,5	0
D3. Show free spots	1	1	1	1	1	1	1	1	0,5	0	0	0	0,5	0,5	0,5	0,5	1	1	-	0	1	0,5
Software																						
E1. Tactile feedback	1	1	1	1	1	1	1	1	1	0,5	1	0,5	1	1	1	1	1	1	1	-	1	1
E2. Select information to display	1	1	0,5	0	0	1	0,5	0	0	0	0	0	0	0	0	0	0,5	0,5	0	0	-	0
E3. Automatic contextual information (automatic selection of information to display)	1	1	1	1	1	1	1	1	1	0,5	1	0	0,5	0,5	0,5	0,5	1	1	0,5	0	1	-
Sum	19,5	19,5	15,5	15	12	18	18,5	14	6	1,5	8,5	1	11,5	8	6,5	7	10	10	7	1	15,5	5
Rel	0,886	0,886	0,705	0,682	0,545	0,818	0,841	0,636	0,273	0,068	0,386	0,045	0,523	0,364	0,295	0,318	0,455	0,455	0,318	0,045	0,705	0,227

Figure G.1: The Kesselring weighted matrix for concept evaluation

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