Sondre Ek

# Design of simulator for researching autonomous marine vessels

Master's thesis in Industrial Design
Supervisor: Ole Andreas Alsos
January 2022

Master's thesis

NTNU
Norwegian University of Science and Technology
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## Abstract

There is a lack of accessible tools available for researching autonomous marine vessels. Autonomous marine vessels have been recognized as a potentially transformative technology, and considerable resources are invested to fund research projects related to its development. The aim of this thesis is to design an accessible research tool, using approaches and frameworks from design thinking and game design, to amplify the research efforts of researchers working with autonomous marine vessels.

Using the Double Diamond model of design as a process framework, a simulator for visualization and testing of thought experiments for researchers studying human factors in autonomous marine vessels was suggested as a solution. This decision was based on the needs of researchers and stakeholders at NTNU Shore Control Lab. Through a collaboration with an existing simulator project, the proposed design was then developed as a Unity based visual simulation. The simulator was then used for a pilot study within the topic of attention span of operators monitoring autonomous maritime vessels. The simulator successfully allowed the pilot study to be conducted, and will be used again for later experiments.

Although the development of the simulator was done in a limited timeframe, the successful use in the pilot study indicates that such a tool can create value for researchers working with autonomous marine vessels.



## Sammendrag

Det er mangel på tilgjengelige verktøy til bruk innen forskning på autonome maritime fartøy. Autonome maritime fartøy har blitt anerkjent som potensielt transformativ teknologi, og betydelige ressurser investeres i forskningsprosjekter tilknyttet utviklingen av denne teknologien. Målet med denne avhandlingen er å designe et tilgjengelig forskningsverktøy, ved bruk av tilnærminger og rammeverk fra designtenkning og spilldesign, for å styrke forskningsarbeidet til forskere som jobber med autonome maritime fartøy.

Double Diamond ble brukt som modell for prosessens rammeverk. På bakgrunn av denne prosessen ble en simulator for visualisering og testing av tankeeksperimenter for forskere som studerer menneskelige faktorer innen autonome maritime fartøy foreslått som løsning. Dette valget ble gjort på bakgrunn av behovene hos forskere og interessenter hos NTNU Shore Control Lab. Ved å samarbeide med med en eksisterende simulator, ble det foreslåtte designet utviklet som en Unity basert visuell simulering. Simulatoren ble deretter brukt i en pilotstudie som omhandlet oppmerksomhetsspenn hos operatører som overvåker autonome marine fartøy. Simulatoren muliggjorde en vellykket gjennomføring av pilotstudien, og vil bli brukt til andre eksperimenter senere.

Utviklingen av simulatoren ble gjennomført i et begrenset tidsrom. Til tross for dette indikerer den vellykkede bruken av simulatoren i pilotstudien at denne typen verktøy kan være av verdi for forskere som arbeider med autonome maritime fartøy.

## Preface

This thesis marks the end of an academic road. A long and winding road, culminating in the ascent of "Mount Thesis". Luckily, this final climb was not done alone. I would like to thank the following individuals for their contributions to this thesis:

Mikael Røsbak Hanssen, for a great collaboration on the development of the simulator, for showing great patience in time of technical noobiness on my part, and for introducing me to amazing games.

Erik Veitch, for always having valuable and interesting thoughts about autonomous technology, and for sharing more of your time than I could ever expect.

Ole Andreas Alsos, for giving me the opportunity to work on an interesting project, for inspiring thoughts on autonomous technology, and for introducing me to great people at SCL.

Kjetil Vasstein, for sharing your technical knowledge, and for valuable thoughts on thesis writing.

Kristin Grønhaug Senderud, for trusting that the simulator could be used in your pilot study, and for not giving up on us when faced with countless technical bugs.

## Thesis description

The initial thesis description was written at the start of the project. Throughout the design process, some of the assumptions presented were proven to be wrong, resulting in a change of course. For instance, the title stated that the final outcome would be a video game. The insights found in interviews and literature suggested that a more precise description would be “a tool that is using some of the approaches found in game design”. Another key difference is found in the discussion of what research related to autonomous marine vessels the tool should assist. At the time of writing the thesis description, the idea was to assist research of the algorithm governing the behavior of the autonomous vessel. However, the design process made it clear that assisting the research of human factors related to the autonomous vessel would deliver greater value.



NTNU

Fakultet for arkitektur og design
Institutt for design

**Master's thesis for student Sondre Ek**

A video game for simulating autonomous ferries
Et dataspill for simulering av autonome ferger

NTNU Shore Control Lab is an advanced infrastructure for research and development in autonomous maritime systems, including passenger ferries in urban areas. By enabling autonomous ferries, there will be more opportunities in both urban and coastal transport, which would enable a revitalization and further development of coastal areas. It would also have the potential to create new markets which do not exist today due to high crew costs. A key hypothesis to successfully implement autonomous ferries, is that the ferries can operate safely alongside other vessels in confined environments. To test the behavior of ferries in rare and potentially dangerous situations, without putting passengers at risk, the Shore Control Lab is utilizing computer simulations.

In this thesis, I will explore how the existing simulator can be developed into a serious game, which can be played by researchers working with autonomous ferries. The purpose of such game is to give researchers the opportunity to explore how the autonomous ferry handles different situations, defined by the researchers themselves. This would allow them to get visual feedback, and rapidly iterate on the behavior of the autonomous ferry.

Work may entail, amongst other things:

- Review of previous work from the Shore Control Lab project
- Interviews and conversations with researchers whose work involves autonomous ferries
- Designing game mechanics, in accordance with the needs of researchers
- Prototyping game interface, supporting the desired mechanics/gameplay
- User testing game interface with relevant users
- Presentation of the concept, including a visual identity
- Be part of an interdisciplinary team at the Shore Control Lab

The project is done in accordance with ”Retningslinjer for masteroppgaver i Industriell design”.

Supervisor: Ole Andreas Alsos
Starting date: August 26th 2021
Submission date: January 19th 2022

Trondheim, NTNU, August 25th 2021

Ole Andreas Alsos
Supervisor

Sara Brinch
Head of Department

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# Introduction

In their Foresight 2021 Report, Lux Research ranked autonomous vehicles as the top emerging technology to watch in 2021 (Lux Research, 2020). The report argues that the prospect of fully autonomous vehicles will “open new mobility and logistics possibilities by removing the need for a driver in a vehicle” (p. 6). In October 2020, Waymo, a subsidiary of Alphabet Inc., released the first ever fully autonomous land based driving experience available to the general public (Krafcik, 2020).

This use of autonomous vehicles could also have a profound impact in the maritime sector, according to Allied Market Research (Jadhav & Mutreja, 2020). They estimate the autonomous ships market to be valued at $85.84 billion in 2020, with a projected market size of $165.61 billion by 2030.

The use of autonomous marine vessels is believed to have considerable upsides, such as reduced operation costs, reduced emission from shipping, reduced number of accidents caused by human error, and increased operational safety of vessels (Munim, 2019; Jadhav & Mutreja, 2020).

In Norway, Kongsberg Gruppen is mentioned as a key market player in the autonomous ships market (Jadhav & Mutreja, 2020). According to Kongsberg, autonomous electric vessels should be expected to operate in the Oslo fjord by 2024 (Kongsberg Maritime, 2020). To achieve this, advanced research and development is made in areas such as AI, simulation, hydrodynamics, and human-machine interaction (Kongsberg Maritime, 2020).

The Norwegian University of Science and Technology (NTNU) is one of the actors contributing to the research of autonomous vessels. One of their recent initiatives is the NTNU Shore Control Lab (SCL), researching the monitoring and control of autonomous maritime vehicles (NTNU, 2021). SCL is the primary stakeholder for this project.

## The Research Problem

Autonomous vessels has been recognized as promising technology, with the potential of transforming the current maritime infrastructure. In Norway, considerable resources are invested to fund research projects related to autonomous vessels. An example of this is the SFI AutoShip project, where NTNU received a grant of NOK 96.0 mill (Research council of Norway, 2020).

However, there is a lack of accessible tools available in this research. While there exist tools designed for the research of autonomous behavior, these tools are often proprietary, expensive and/or require expert users due to their high levels of complexity.

As a result, the rate at which research progression related to autonomous vessels is made could be reduced. This is unfortunate, as the reduced rate of research progression is likely to result in a slower output of innovation. This in turn could delay the benefits of economic, safety, and environmental upsides related to the implementation of autonomous vessels.

## Significance of Research

Autonomous vessels have the potential of opening new mobility and logistics possibilities (Lux Research, 2020). By providing researchers with accessible tools that allow them to effectively and efficiently conduct their research, the innovation within the sector can be accelerated, and thus bring the advantages of autonomy closer to fruition. These advantages include increased safety, reduced operating costs, and reduced emissions (Munim, 2019; Jadhav & Mutreja, 2020).



## Background

The NTNU Shore Control Lab (SCL) opened in October, 2021. The lab is currently involved in research projects such as SFI AutoSHIP, Autoferry, and LOAS (Land-based Operation of Autonomous Ships). Their mission is to design safer marine autonomous systems. They work toward this by researching the monitoring and control of autonomous maritime vehicles (NTNU, 2021). To succeed in their research endeavors, SCL is actively seeking tools that can amplify their research efforts.

Design thinking has been recognized as an effective approach to solve complex problems (Razzouk & Shute, 2012). This is done by first finding the correct problem, then finding the right solution (Razzouk & Shute, 2012). Within design thinking, human-centered design is used to ensure that the design meets the needs and capabilities of its users (Norman, 2013). One of the frameworks used to structure the design process is the Double Diamond model of design, which allows the designer to first investigate the problem space before exploring the solution space (Design Council, 2015a).

Game design is traditionally associated with game experiences designed for entertainment purposes (Schell, 2020). However, principles from game design have also been acknowledged as powerful tools that can be applied to areas outside of games (McGonigal, 2011). In human-computer interaction (HCI), the use of game design principles could be considered a way to “enrich current models of product quality with non-instrumental aspects to create a more complete, holistic HCI” (Hassenzahl & Tractinsky, 2006, p. 93).

## Research Aim and Questions

The aim of this thesis is to design an accessible research tool, using approaches and frameworks from design thinking and game design, to amplify the research efforts of researchers working with autonomous marine vessels.

This entails multiple research questions, including:

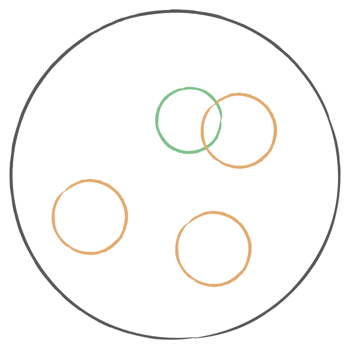
- Which researchers would benefit from such a tool?
- What needs do these researchers have, in relation to such a tool?
- How should the tool be designed, in order to meet the needs of researchers?

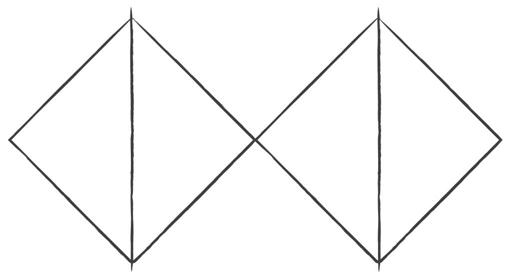
## Structural Outline

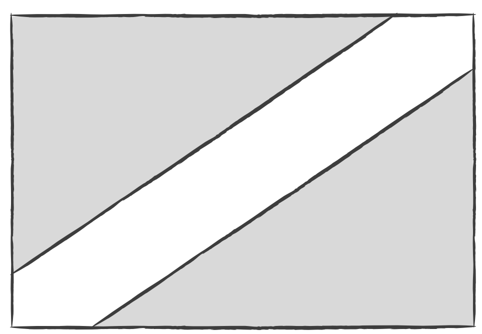
This thesis is divided into six chapters. The “Theory” chapter introduces the theories and frameworks used throughout the project, with the purpose of familiarizing the reader with the models and ideas described in the thesis. The “Process” chapter briefly explains the process used for the project, which is based on the Double Diamond model of design.

In the “Discover” chapter, the findings from the Discover phase of the process are presented and discussed. These findings are then distilled in the “Define” chapter, where actionable insights are drawn from the findings to create a problem statement. The insights from these two chapters answer research question (1) and (2).

In the “Develop” chapter, the search for a solution to the problem statement begins. This is done by exploring the possibility space of the solution, in a divergent manner. Finally, the “Deliver” chapter uses the findings and ideas of the Develop phase, combined with an iterative methodology, to converge on a final design. This final design answers research question (3).







# Theory

This thesis will combine ideas from two areas of design: design thinking and game design. The relevant concepts and frameworks from these two areas will be presented in this chapter. This includes the Double Diamond model of design, the human-centered design philosophy, a brief discussion on defining games, the flow model, and the magic crayon design approach.

## Design thinking

Design thinking can be defined as “an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign” (Razzouk & Shute, 2012, p. 330). The design process starts with an abstract specification, also referred to as a brief, and ends up with the rendition of a product. Parallel to this, the product specifications are being gradually refined (Razzouk & Shute, 2012).

Within this process there are two primary components: (1) finding the correct problem, and (2) finding the right solution. This is one of the primary distinguishing factors between design and most other areas of engineering, as there is a clear emphasis on researching the problem itself, not just creating a solution (Norman, 2013). One of the components of a design process is the mapping of constraints the result must adhere to, as well as deciding at a strategic level which constraints to prioritize (Razzouk & Shute, 2012). These constraints take many forms, such as economic, regulatory, maintenance, and usability (Norman, 2013).

### Double Diamond

The Double Diamond model of design is a framework used within design thinking. The model is a two-part process, coined by the British Design Council in 2004 (Design Council, 2015a). It represents a process where the designer is “exploring an issue more widely or deeply (divergent thinking) and then taking focused action (convergent thinking)” (Design Council, 2015a, para. 4). The process takes the designer from a vague notion of what the problem and solution could be, to a rational argument for what they should be (Nessler, n.d.).

The model is commonly visualized as two neighboring diamonds. The purpose of the first diamond is to understand what the actual problem is, rather than assume. This is commonly referred to as the problem space. The second diamond is referred to as the solution space. It seeks to “combine divergent and convergent thinking to determine an appropriate solution” (Melles, et al., 2020, p. 38).

Each diamond is divided into two phases, for a total of four phases. These are “Discover”, “Define”, “Develop” and “Deliver”. Furthermore, the visual shape of the model represents the divergence and convergence that takes place within each of the two diamonds (Design Council, 2015a).



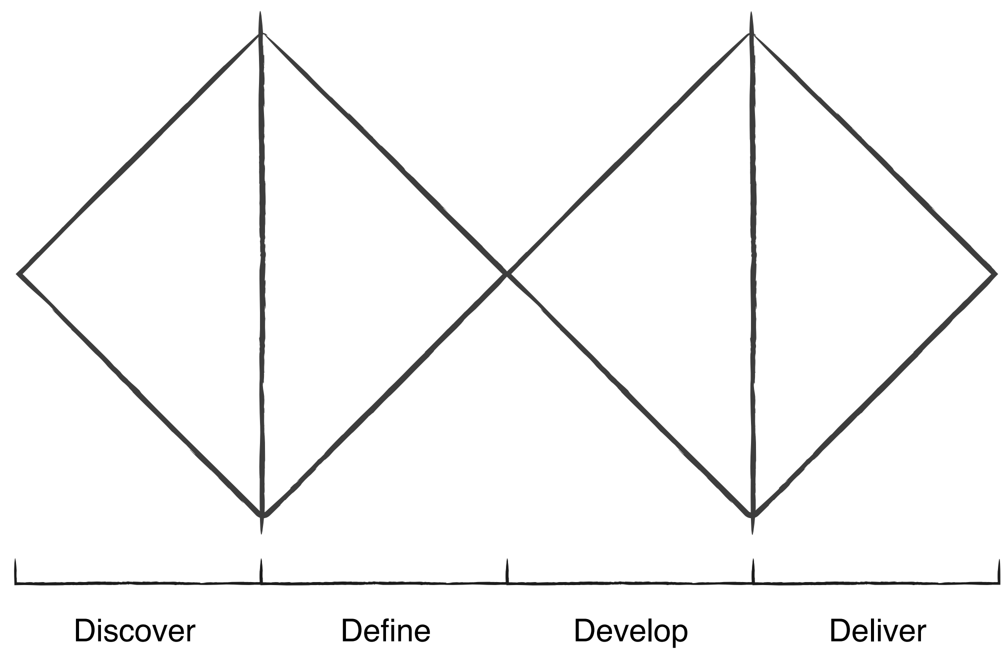



Figure: The Double Diamond model of design.

### Discover

The “Discover” phase is located at the start of the first diamond. In this initial phase, the job of the designer is to question the problem described to them, expanding the scope of the problem, and explore the fundamental issues underlying it (Melles, et al., 2020). This is a highly divergent process, as the designer must widen their perspectives, allowing for a “broad range of ideas and influences” (Design Council, 2015b, para. 3). The Discover phase typically involves the study of the people affected by the problems (Design Council, 2015a).

### Define

The “Define” phase is all about using the insights gathered previously to define the actual problem (Melles, et al., 2020). It could be considered a “filter where the review, selection and discarding of ideas takes place” (Design Council, 2007, p. 14). Upon completing the “define” phase, the designer should be able to articulate a precise problem statement that will guide the process of finding the right solution, when entering the second diamond (Design Council, 2015a). The statement could take multiple forms, such as a “how might we” question (Nessler, n.d.).

### Develop

The “Develop” phase marks the beginning of the second diamond, and seeks to explore the possibility space of solutions to the problem defined in the first diamond (Design Council, 2015a). The designer is again in a divergent period, where different solutions are developed, iterated and tested (Tschimmel, 2012). Some of the methods used in this phase include brainstorming, visualisation, prototyping, testing and scenarios (Design Council, 2007).

### Deliver

In the final “Delivery” phase, designers use their toolkits to converge on the final concept. This involves testing the solution(s) at small-scale, rejecting what does not work and improving what works (Design Council, 2015a). As part of this phase, it is advantageous to systematize lessons from the design process, to inform future projects (Design Council, 2007). The Deliver phase will result in a solution that answers the problem statement specified in the Define phase (Nessler, n.d.).



## Human-centered design

Poor design is often a result of a misalignment between the properties and functionality of the object, and the expectations and needs of its user, leading to frustration (Norman, 2013). To address this, designers utilize a human-centered design (HCD) approach, defined as “The process that ensures that the designs match the needs and capabilities of the people for whom they are intended” (Norman, 2013, p. 9). This is an iterative process, where the designer (1) makes observations, (2) generates ideas, (3) produces prototypes, and (4) tests them (Norman, 2013).

In relation to the Double Diamond model described prior, HCD should not be considered a competing framework, but rather a design philosophy applied in parallel to the Double Diamond process, ensuring a good understanding of people and their needs (Norman, 2013). By using an HCD approach, the designer “puts human needs, capabilities, and behavior first, then designs to accommodate those needs, capabilities, and ways of behaving” (Norman, 2013, p. 8). As such, human needs and capabilities become highly prioritized constraints when HCD is applied to the design process.

The Interaction Design Foundation (IxDF) highlights the design of computers as an area in which HCD has made a considerable contribution (Interaction Design Foundation, n.d.). The first computers, created in the 1940s, were extremely hard to understand. So much so that they required experts to operate them, according to IxDF. However, by considering the human constraints of the users, the computer was made more accessible. By the 1980s, a large portion of smaller computers were used by non-expert users (Interaction Design Foundation, n.d.).

# Lessons from game design

Game design can be considered as "the act of deciding what a game should be", based on a string of decisions made by the designer (Schell, 2020, p. xxxvi). In the domain of game design there is no simple formula that ensures a good game, but rather a patchwork of principles and rules that can help the designer navigate towards a successful design (Schell, 2020). According to Jane McGonigal, good gameplay can activate "all of the neurological and physiological systems that underlie happiness" (McGonigal, 2011, p. 28).

As such, the game designer could be considered a "happiness engineer", as the success of a game is in direct proportion to the level of positive emotions it provokes in the player (McGonigal, 2011). The game designer can provoke these positive emotions by designing for the psychological factors that underlie them (McGonigal, 2011). Today, areas outside of game design have recognized the profound power of this design approach, and are leveraging it in areas such as education, health and social networking (McGonigal, 2011).

The following sections will present some ideas and concepts found within the realm of game design, which will later be applied to the design process. First, there will be a brief overview of some defining qualities of what a game is, before discussing some considerations related to the concept of "flow". Finally, there will be a section discussing the "magic crayon" design approach.



## Defining a game

Throughout the world of game design, there are numerous ways of defining what a game is (Schell, 2020). In his book "The Art of Game Design", Jesse Schell discusses different ways to consider a game (Schell, 2020). By examining how games relate to people, Schell lists ten qualities of games (pp. 41-46):

- Games are entered willfully
- Games have goals
- Games have conflict
- Games have rules
- Games can be won or lost
- Games are interactive
- Games have challenge
- Games can create their own internal value
- Games engage players
- Games are closed, formal systems

He also suggests a different approach to defining games, by studying how people relate to games. By using this approach, Schell suggests the following definition based on the aforementioned qualities: "A game is a problem-solving activity, approached with a playful attitude" (Schell, 2020, p. 48).

## Flow state in games

Coined by the Hungarian-American psychologist Mihaly Csikszentmihalyi, the idea of flow refers to what Csikszentmihalyi describes as “the process of total involvement with life” (Csikszentmihalyi, 1991, p. xi). The core idea of the flow model is balancing the difficulty of a challenge, and the skills of the participant (Csikszentmihalyi, 1991). By finding the balance between these two, the participant will enter a state of flow, sometimes defined as “a feeling of complete and energized focus in an activity, with a high degree of enjoyment and fulfillment” (Schell, 2020, p. 144).

In relation to game design, the idea of flow is key when designing for engaging gameplay (Schell, 2020). In traditional games, finding the right amount of difficulty is often related to finding the right opponent. In video games, it is often the job of the designer to ramp up the difficulty of the game in accordance with the skill development of the player (Schell, 2020). For the designer to create a flow state for the player, the designer must first thoroughly understand the player through a player-centered approach (Cruz & Uresti, 2017).



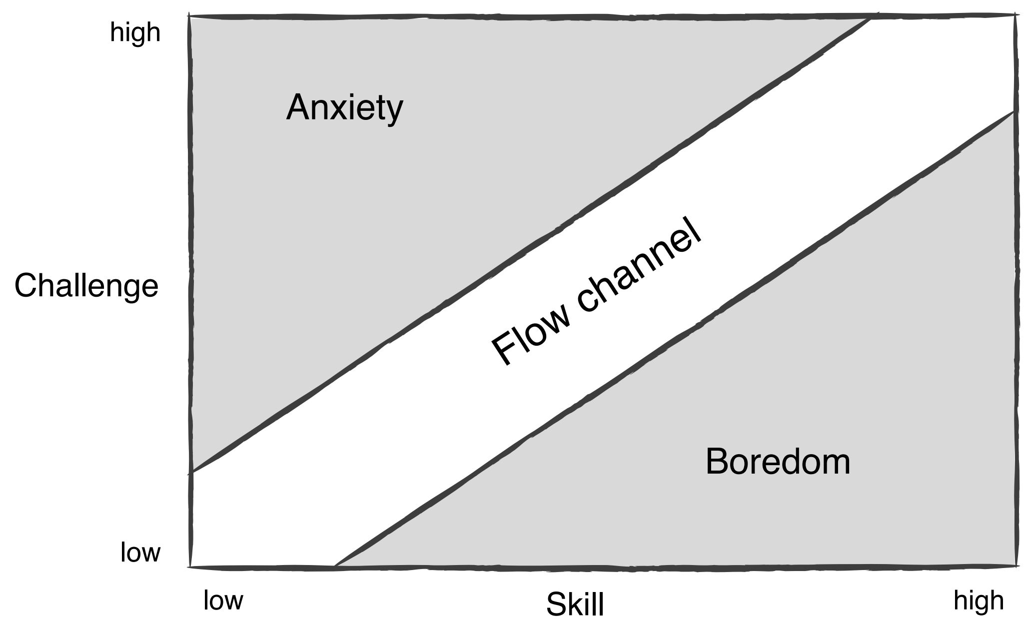



Figure: The flow model.

## Magic crayons

In his doctoral dissertation, Chaim Gingold introduced the idea of "magic crayons" in the design of creative games (Gingold, 2003). Magic crayons are tools that allow players to create desirable outcomes/artifacts regardless of their abilities (Gingold, 2003). In other words, if an unskilled player uses a magic crayon to create something, that thing has a high probability of being interesting to the player.

Gingold (2003) defines four key properties of a magic crayon. These properties are 1) Accessible; they are readily available, cheap, robust and easy to use, 2) Sketchable; creation is effortless and the outcome malleable, 3) Computational; the player is allowed to "engage the procedural qualities of the digital medium and build dynamic things" (p. 62), 4) Expressive; the player can create meaningful worlds.

One way to think about magic crayons is to visualize the possibility space of its outcome (Gingold, 2007). With a traditional creation tool such as Autodesk Maya (Autodesk, 2021), a 3D modeling software, there is a vast possibility space for what can be created. If a 3D object can be imagined, it can most likely be modeled using Maya. However, the number of possible outcomes is far greater than that of the desirable outcomes. It requires skill to navigate towards the desired outcome. With magic crayons, a much larger percentage of possible outcomes overlap with desirable outcomes, making it easier to create a desirable outcome. A consequence of this is that the size of the overall possibility space is reduced, meaning that the magic crayon is more specialized in terms of what sort of outcome it can produce (Gingold, 2007).

An example of a magic crayon is the creature editor found in the video game "Spore", developed by Maxis Studios (Maxis, 2008). The design team, including Gingold, designed the editor to create creatures of high quality, regardless of the skill set of the player. Through simple interactions, any player could create interesting creatures in a matter of seconds (Gingold, 2007). A process that would require high levels of artistic skills, as well as being extremely time consuming, using software such as Maya.



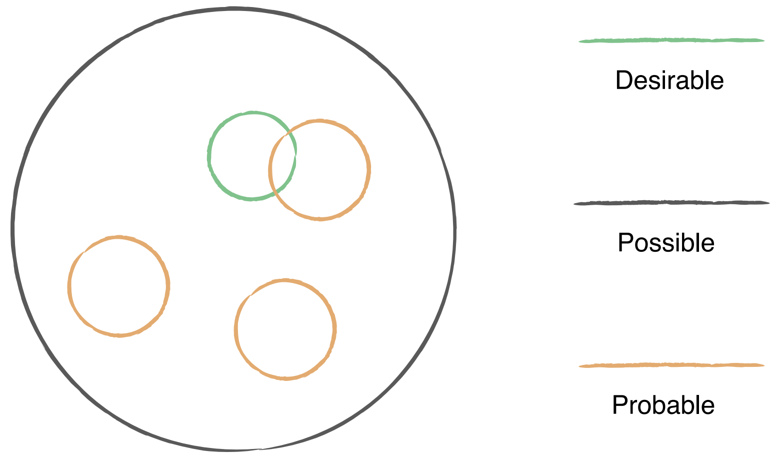



Figure: A visualization of the possibility space of the 3D modeling software Maya. In this possibility space, it is difficult to locate desirable states without high levels of skill.

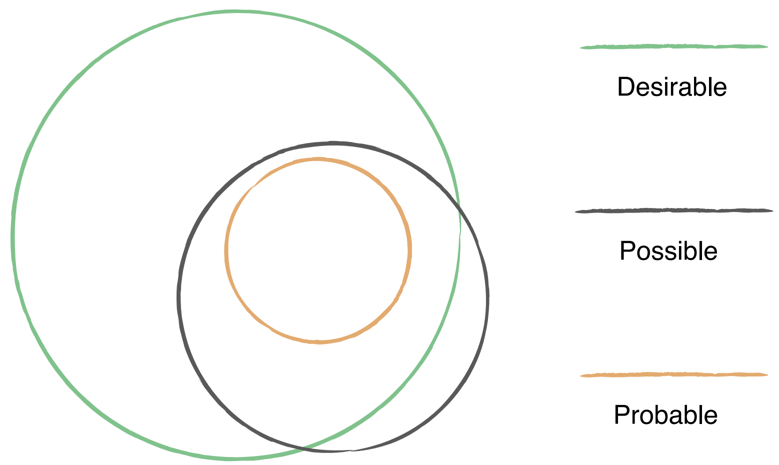



Figure: A visualization of the possibility space of the creature creator in the video game spore. In this possibility space, the player is likely create an outcome that is desirable to them.

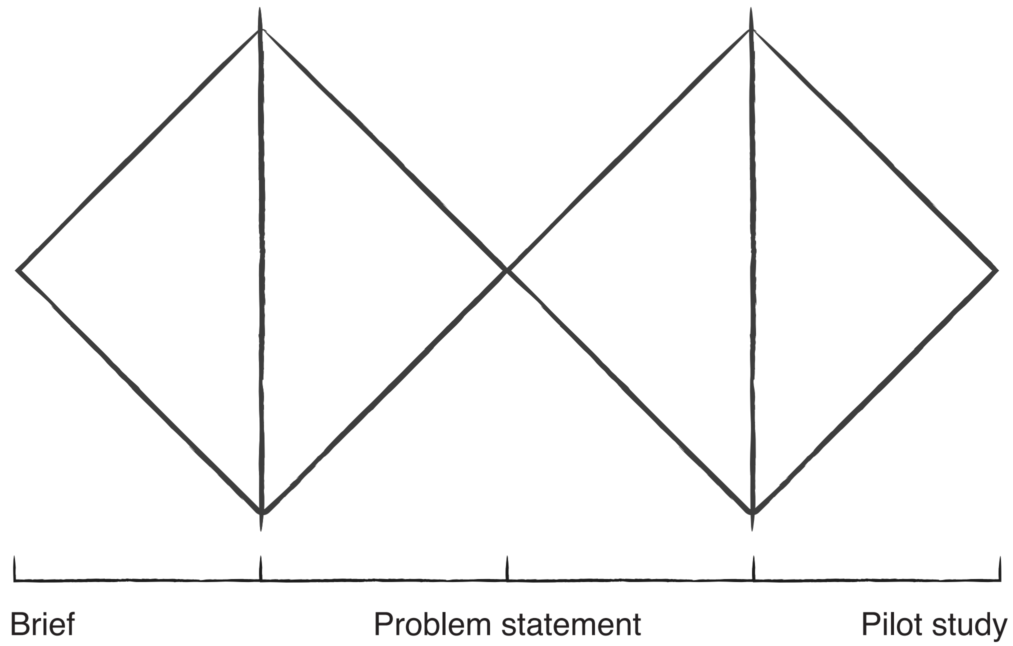
# Process

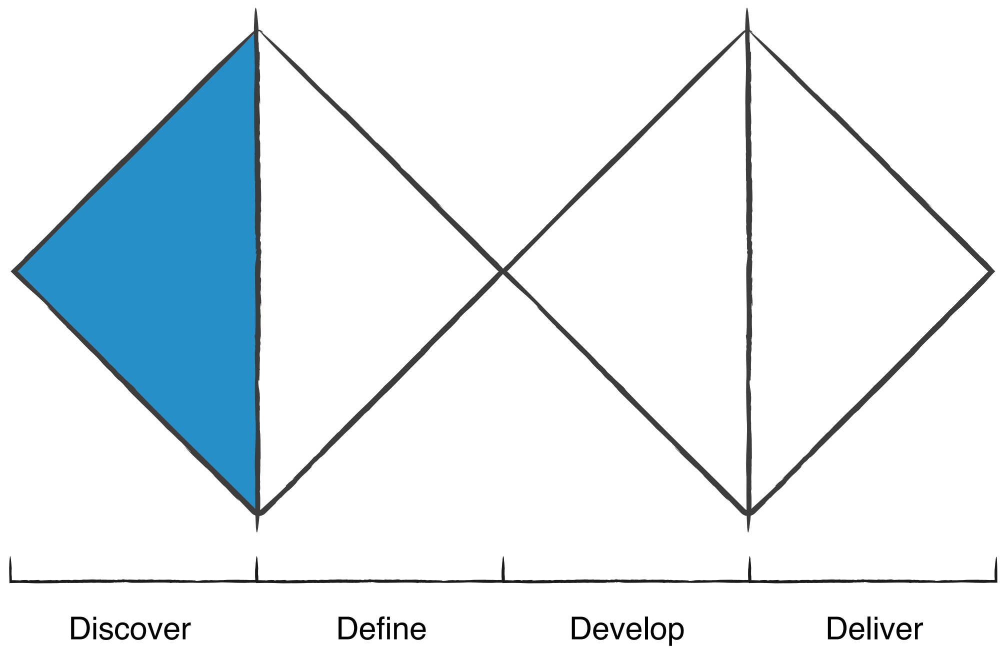
To ensure a project outcome that would meet the needs of the user, while also delivering value to the stakeholders of the project, a design thinking approach was utilized for the process. Specifically, the Double Diamond model of design was used as the process framework, combined with iterative thinking from HCD. It is worth noting that these models and frameworks serve as practical guidelines, and not absolute truths that must be abided at all cost.

In terms of the chapter structure, in particular subchapters within each phase, they may not be listed in an entirely chronological order. The purpose of the chapter structure is not to accurately portray the chronology of information and ideas, but rather present the reader with the train of thought leading up to the final design. As such, the thesis presents decisions made throughout the process as a linear string of choices, rationalized by the findings prior to the point at which the decision was being made. While this was the reality in some cases, most decisions were a result of a more iterative, "back and forth", approach.

The project began August 2021, and completed January 2022. During this period, the researchers and other stakeholders at SCL were a great source for constructive conversations related to the project. They were remarkably generous with their time, and gladly shared their thoughts and ideas. This was key, as it allowed for a detailed and precise insight into their work and ambitions for the future.








# Discover

The intention of this initial design phase was to gain as many perspectives as possible, in order to have an in-depth understanding of the problem and its context. This was primarily done by gathering data from various sources, and getting involved with researchers and other stakeholders. Although the Discovery phase is dedicated to seeking new information and perspectives, there will also be opportunities to find new ideas in later phases, given the iterative qualities of the design process.

Activities partaken in the Discover phase included analyzing and questioning the brief, gathering information about SCL, talking to internal stakeholders at SCL, talking to potential users, and mapping out human actors involved with autonomous vessels.

## The brief

As part of the project presentation, a brief was given by SCL. This brief will serve as a starting point for the project. It should be considered a hypothesis for what the problem is, and what the solution could be. It reads as follows:

"Video games have the potential to be used for AI research, but there are some significant challenges that must be solved to address the complexity of simulating the real world. This includes environmental surroundings, human behavior, artificial intelligence, and interactions between all these elements.

By 2030, there will be fully automated marine vessels in Norwegian waters if we are to believe Kongsberg. To get there, scientists need to understand how AI works in a complex world to make these 'smart' marine vessels safe. In this sense, video games can be seen as a tool for interaction design: managing complexity and exploring solutions without compromising human safety.

In our case, we want to answer the question: can video games be used to rapidly prototype design solutions for unmanned marine vessels operating in a complex world?"



scl shore control lab

Image: The SCL logo

The brief covers a wide variety of topics, including AI research, video game technology, simulation, human behavior, human safety, interaction design, and autonomous vessels. The main concern appears to be the exploration of video games as a tool to navigate the complexity of autonomous vessels. Both in the interaction between the system and its surroundings, and the interaction between human and system.

However, there is little reasoning as to why video game technology should be considered as a tool for exploration. Human safety is mentioned as a factor, and could be a primary reason why "real life" testing is not an option. That being said, there is a wide variety of digital tools that could be utilized to mitigate the risk of violating safety regulations, such as more scientific simulations. Perhaps there are other reasons why video game technology is mentioned specifically?

Other questions also arise from the brief, regarding the scientists and their problems. It is somewhat implied in the brief that there might be value in providing scientists with video game technology that enables them to more effectively prototype their "design solutions". However, it is unclear who these scientists are, and what their background is. It is also unclear exactly what sort of research needs this kind of prototyping tool, and why such a tool is the suggested solution to the problem.

# Shore Control Lab

NTNU Shore Control Lab (SCL) is an advanced infrastructure for research and development in autonomous vessels. The planning of SCL began June 2020, and construction commenced November 2020 (NTNU, 2021). The lab had its official opening 19th of October, 2021.

The SCL vision is “a future where humans and AI work together to enable more resilient autonomous systems”. They intend to reach this future by bridging the gap between reality and virtual simulations, and harnessing the power of human and technology working together. The SCL mission is simple: To design safer marine autonomous systems (NTNU, 2021).

SCL is fully owned and operated by the Norwegian University of Science and Technology (NTNU), and is located at the Maritime Center in Trondheim. The lab is led by the Department of Design at NTNU, and is operated in collaboration with the Departments of Electronic Systems, Marine Technology, and Engineering Cybernetics (NTNU, 2021).


Image: The control room located at the SCL headquarters.
This is where operators monitor autonomous vessels from.



The lab is involved in multiple research projects. The research contribution from SCL is primarily focused on monitoring and control of autonomous maritime vehicles. The research projects are, as of December 2021 (NTNU, 2021):

- SFI AutoShip
- AutoFerry
- LOAS (Land-based Operation of Autonomous Ships)
- IMAT (Integrated Maritime Autonomous Transport Systems)
- SAREPTA (Safety, autonomy, remote control and operations of industrial transport systems)
- MIDAS (Human in the ocean operations of the future)

As part of these projects, SCL is attempting to answer a multitude of questions related to autonomous vessels. Some of these questions include:

- How can trust between passengers and the autonomous vessels be designed for?
- How can autonomous vessels communicate their intentions with other non-autonomous vessels?
- How should autonomous vessels react to canoes, and other smaller entities?
- What is the role of the operator monitoring the autonomous vessels from the control room?
- What should the procedure be in case of an emergency, i.e fire, aboard the autonomous vessels?
- What is the most effective way for the autonomous vessels to dock?

This list highlights the diversity of challenges that need to be handled to succeed with autonomous vessels. They also emphasize the importance of the multidisciplinary approach that SCL is using.

## Initial interviews with SCL stakeholders

To get an understanding of SCLs perspectives, several interviews with stakeholders from the lab were conducted. The ambition with the interviews was to understand their reasons for hosting the project, and empathize with their vision for the lab. As the scope of the project was not entirely defined, there was no need to limit what areas to explore within the interview. The interviews were therefore designed to be unstructured, allowing for effective divergence. During the interviews, several key insights were uncovered.

- *The outcome should let researchers prototype their solutions*
  As mentioned in the brief, one of the intentions of SCL was to allow researchers to "rapidly prototype design solutions for unmanned marine vessels". This was further emphasized during the interviews. It became clear that SCL envisioned that the researcher could somehow externalize their thought experiments. However, not all researchers involved in researching autonomous vessels are technologists. In order to achieve the best result, a mix of technologists, designers and psychologists are needed, according to the SCL. For this reason, the outcome of the project must be approachable to researchers from different backgrounds, including non-technologists.

- *The outcome must be scalable and non-proprietary*
  One of the things that was important to SCL is to ensure that the outcome of the project is scalable and non-proprietary. As of today, much of the tools and software used in researching autonomous vessels is proprietary. This means that researchers are limited in what ways the tools can be modified. If alterations need to be made, they must be performed by the company who owns the tool. This is costly, and can result in a tedious process for the researcher. In some cases, it is even a necessity to employ someone from the company selling the tool, as an expert user is required to operate it. These tools are typically quite expensive, which also reduces their availability to researchers. SCL would like to democratize tools used in their field of research, such that it is accessible to more researchers. This would empower researchers to access and use sophisticated technology in their work. The tools should not be overly specialized, such that its use can be scaled beyond internal use at SCL.



- *The outcome must be a usable tool*
  It was also emphasized during the interview that the project should result in a usable tool, in order to create the most value for SCL. This meant that the project should not end in a design concept, but rather a functioning tool that could be used in actual research. SCL was hoping that the outcome of the project could help them in their upcoming pilot studies, starting Q1 2022. From a design perspective, developing a functioning solution would also benefit the user testing, as it would be more accurate than user testing mockups.

- *There are two primary areas of focus*
  There was also a discussion about what aspects of autonomous vessels researchers were working on. From this discussion, two areas of focus emerged. The first was the algorithm governing the autonomous behavior of the vessel. This included research into how the algorithm perceived the environment, and how it responded to different situations the vessel was exposed to. The research related to this area of focus would typically involve cybernetics and other related disciplines. The second area of focus was related to human interaction with the system. This includes the interaction between vessel and passengers, between other non-autonomous watercrafts and the vessel, and between the vessel operator and vessel. Disciplines such as interaction design and psychology could be relevant in this area.

## Understanding researchers

After the initial interviews with SCL, it seemed reasonable to assume that the end user of the design would be researchers. Therefore, the main interest was to understand this user group at a deeper level. The goal was to establish their needs, and empathize with their current struggles. This was achieved through a series of interviews, discussions and observations involving seven researchers, five of which worked internally at SCL. These researchers had various academic backgrounds, including human-computer interaction, cybernetics and psychology. As with the stakeholders from SCL, these interviews were unstructured. Following are some of the findings that were discovered in this process:

- *General need*
  From conversations with researchers from different disciplines, it is apparent that there is a general need for a way to externalize their thoughts and hypotheses. There is also a general perception that a lack of tools reduces the quality of research, and rate of innovation.

- *Tools must be created from scratch*
  As of today, tools must oftentimes be created from scratch, in order to meet the needs of the researcher. Doing so is resource intensive, and costly. There is a notion that the wheel must be reinvented every time, which seems quite inefficient.

- *Varying technological competence*
  As the researchers come from various fields of research, the technological competence varies greatly. While some researchers are comfortable with computer programming, others are not. This affects what tools they find useful. Tools based on a command line interface, or other non-graphical interfaces, might be inaccessible to non-programmers.

- *Data from use*
  A recurring need from researchers from different fields of research was the ability to store data from the experiments conducted. This was an absolute necessity, as without it they would not be able to use the tool in scientific work. Some researchers also requested a way to visualize the data that was collected.



Image: Researchers utilizing the SCL control room.

- *Reproduce experiment*
  The ability to accurately reproduce the experiments was also a universal request amongst researchers. This would allow them to set up the same experiment multiple times, either conducting the experiments on different users, or tweaking parameters to examine how it affected the outcome. The ability to reproduce the experiment also allowed researchers to build a credible experiment, with a statistically significant outcome.

- *Testing extreme situations*
  How would the autonomous system handle 20 canoes approaching from every angle? How would passengers react if the autonomous vessel began sinking? These are examples of extreme situations, so called “tail events”. In the real world, it can often be infeasible to test these situations. Researchers expressed a desire to test such situations more efficiently.

# Human actors

When considering autonomous vessels from a system design perspective, it can be advantageous to map out the different human actors involved in the system, and specify what their needs are. This project will consider three primary actors: passengers of the autonomous vessel, operators of the autonomous vessel, and drivers of non-autonomous watercrafts. These actors represent both voluntary actors (passengers and operators), and involuntary actors (drivers). The voluntary actors interact with the system by actively seeking it, while the involuntary actors interact with the system as a consequence of being in its vicinity.

## Passengers

The passenger of the autonomous vessel is the most numerous of the three actors. Their motivation for interacting with the system is most commonly based on a need to get from A to B, though it is conceivable to imagine some exploring the vessel out of interest for the technology. These actors should not be expected to have any knowledge of seamanship. For the passenger, key considerations include:

- Trust in the autonomous vessel
- Accessible transportation services

## Operators

The operator is the one monitoring the behavior of the autonomous vessel, ready to manually override the control if required. The operator is not located in the physical vicinity of the vessel, but rather in a centralized control room. The motivation of the operator is to do his job in an effective manner, keeping passengers and other actors safe. The operators should be expected to have expert knowledge of seamanship. For the operator, key considerations include:

- Effective communication with the passengers
- Confidence in autonomous behavior of the vessel
- Information about the state of the autonomous vessel

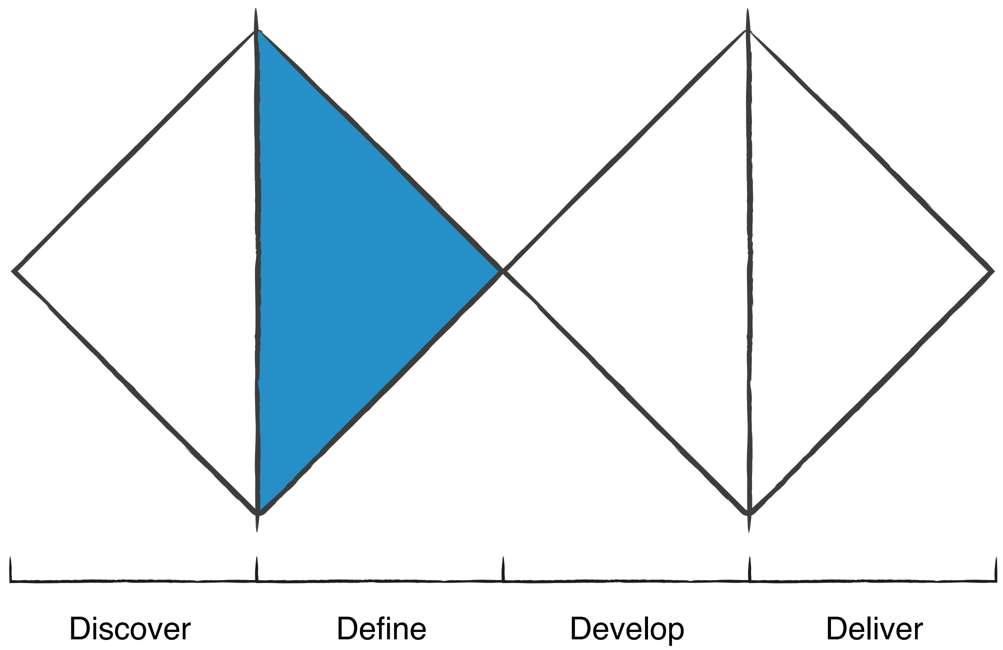


Image: Typical use of the Trondheim canal. A variety of different watercrafts share the space.

## Drivers of non-autonomous watercrafts

The drivers are actors who control non-autonomous watercrafts in the vicinity of the autonomous vessel. This includes vessels, canoes, jet skis, and other watercrafts. The drivers should be expected to have varying knowledge of seamanship, depending on the type of watercraft they operate. These are the only actors who are involuntarily involved in the system. For the driver, key considerations include:

- Predictable behavior from the autonomous vessel
- Effective communication with the operator




# Define

A wide collection of data has now been collected, as a result of the Discover phase. The next step is the Define phase. The purpose of this phase is to distill the data gathered so far, in order to build actionable insights that can be used when designing a solution. At the end of the phase a problem statement, in the form of a “how might we” question, will be defined. This statement will help navigate the solution space found in the second diamond.

Activities partaken in the Define phase included specifying which area of research the project should contribute to, defining the target users, discussing what the desired effect should be for the user, and establishing what platform should be used to deliver the effect.

## Area of research

Which area of research should the outcome of the project seek to assist? This was a key question to answer in order to deliver the most value to users and stakeholders. From earlier interviews with SCL and researchers, there seemed to be two primary directions to take the project. These were:

1. Assist research related to the behavior of the autonomous vessel.
2. Assist research related to human interaction with the autonomous system.

In order to make a more educated decision, regarding which direction to pursue, the dilemma was discussed with researchers from both camps, in addition to SCL as the primary stakeholder. Two key pieces of information were uncovered from these conversations:

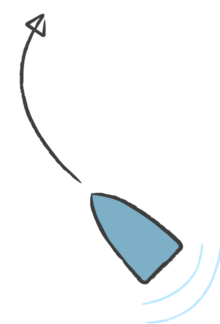
- *There are considerable technical challenges related to exploring the behavior of the autonomous vessel.* As the behavior is controlled by a computer algorithm, this algorithm would have to be part of the solution, in order to create any real value to the researcher. Implementing the algorithm would require considerable technical efforts. This would mean that a considerable portion of the project timeframe would be spent on technical implementation.

- Research related to interactions between humans and autonomous systems is more closely connected to the core activities of the SCL. By choosing this direction, the project would deliver greater immediate value to the lab. Additionally, it would allow the project to work more closely with the other initiatives at the lab. This would make it possible to user test the solution under more realistic circumstances, which is beneficial for the quality of the final delivery.



This highlighted the fact that the topic of human factors in the interaction with the autonomous system was more aligned with the core activities and values of the stakeholder, SCL. In terms of value created per unit of effort, there was also reason to believe that human factors was the correct approach. This was partly due to the technical effort required to implement the algorithm. The opportunity to perform user tests as part of a pilot study also weighed in favor of human factors.

Finally, it was hard to imagine a usable tool for exploration of autonomous behavior to be created within the scope of the project. Primarily due to the technical complexity of the task, and the limited time available. As the SCL were specifically requesting a usable outcome, which would deliver practical value to their research, the direction of autonomous behavior was rendered somewhat improbable. In sum, it seemed to be more favorable to work with human factors, both from a process perspective and an outcome perspective.



## Target users

Now that the area of focus is considered, who will the target user be? Following the decision to focus on human factors, it is evident that the target user will be researchers working in this field. This is key, as there are considerable differences between the background of researchers working within this area, and for instance those researching the cybernetic aspects of autonomous behavior.

From previous conversations with SCL and researchers, it has been established that those researching human factors typically have a background in interaction design, user experience design or psychology. Their work involves both observing/documenting human factors in system interaction, and developing new solutions to improve the interaction.

Traditionally, tools used in research of autonomous systems have been heavily reliant on user familiarity of computer programming and scripting. The scientific simulation CARLA, a simulation used in research of autonomous cars, is an example of this (Dosovitskiy, et al., 2017). The target users are often excluded from the use of such tools, as they are seldom proficient in the required programming languages. It is therefore important that the proposed design does not rely on knowledge of computer programming.

Additionally, it can be argued that research tools have poor usability in general. This typically results in the need for expert users to operate them, which in turn renders them inaccessible to the majority of researchers. It is unfortunate that such lack of usability results in researchers spending considerable time mastering the tool, rather than conducting actual research. Alternatively, the researcher would have to hire an external expert user, which is costly and should be considered unnecessary. To combat this, the design should be based on a deep understanding of the user, and be usable to them without the need of expert knowledge.



It is important to note that the target users also include researchers outside SCL, and even outside Norway. This entails that the research tool must have an effective way of distribution, in order to have a wide reach. It would also be advantageous for the tool to be non-proprietary, allowing for modifications to meet the needs of different research environments around the world.

By following the considerations brought up in this section, the ambition is to democratize the research tool created in this project. This would allow more researchers to gain value from the outcome, and ultimately make research of human factors related to interaction with autonomous systems more accessible.

## Desired effect

An important part of the design process is to determine what value can be created. What desired effect should the design deliver to the user? Throughout the conversations with SCL and researchers, the idea of "thought experiments" had been a consistently recurring theme. There were three aspects to this idea.

Firstly, the researchers had a desire to visualize their thought experiments. A way of externalizing what was in their imagination, by creating some immersive artifact that reflected their thoughts. This would allow the researcher to more precisely consider the thought experiment, as crafting a manifestation would require them to work out some of the details related to the experiment. It would also enable them to effectively communicate their ideas to others, and thus have more constructive conversations about it.

Secondly, researchers wanted to test out their thought experiments in a lightweight and approachable way. This way, the researcher could get answers not only from the conversations that arise from sharing the thought experiment with other researchers, but from testing with users. This included testing extreme situations, tail events, which could not be tested in the real world due to cost or safety concerns. Although the results from the imagined world of the thought experiment would not accurately represent the outcome of the real world, they would still lead to insights about the real world, which could be elaborated upon further in later testing.



Thirdly, it was desirable to create these thought experiments without the need for external help. An accessible tool for them to accelerate their research, and leverage their internal creativity. As creating such thought experiments would be an early stage research activity, it should be an intimate and accessible experience, allowing the researcher to quickly "jot down" ideas. To allow this, the tool must break the norms of rigidness and low levels of approachability found in research tools. Much like the transformation of computers from the 40s to the 80s, the tool must become a personal tool for researchers.

Designing a way for researchers to create thought experiments seemed like the most desirable outcome of the project, based on the findings and insights of the design process thus far. Based on the arguments presented in this section, the desired effect will be to "allow an accessible way of visually creating and testing thought experiments".

## Choosing a platform

The desired effect has now been established, as well as who the target users are. Now onto the next consideration: Which platform would most effectively deliver this desired effect to the user?

There are many relevant platforms to consider. The most apparent might be to deliver the experience by testing in real life scale and situations, alternatively create a scale model of the thought experiments. However, by analyzing the needs of the target user, it became apparent that a digital approach might be more beneficial. These needs include:

*The platform must produce accurate data*
This was emphasized during interviews with researchers. The platform should effectively and reliably produce accurate data from the experiments conducted. Ideally, this should not require extra work on the researchers part, but happen automatically.

*The researcher must be able to reproduce the experiment*
The platform chosen must allow the researchers to conduct the exact same experiment on multiple participants. This means that all the parameters affecting the experiment should, ideally, be completely identical.

*The platform should create a malleable outcome*
The platform should afford malleability, in such a way that the researcher can easily modify and iterate the outcome. This is essential to achieve the desired effect; being able to rapidly externalize and conduct though experiments.

*The platform must be accessible*
Accessibility is also a primary concern, in that it must be accessible to deliver value to a wide range of researchers. The cost of use must be low, such that price is not a factor that discourages use. The effect must be easily distributed and scalable, allowing researchers to gain access globally.

*The platform must be minimize legal concerns*
Additionally, the platform must deliver the effect while still maintaining the legal integrity of the researcher. Put differently, the researcher must be able to conduct thought experiments without acting in conflict with laws and regulations.



These needs reduce the number of options worth considering in terms of what platform should be used to deliver the experience. With regards to whether the platform should be digital, the needs of the researchers unanimously suggest that it should. This becomes evident when comparing the properties of the digital medium with the needs of the researchers. These properties include:

- *Data driven*: Digital solutions are inherently data driven. This allows for collection of precise research data, and accurate reproductions of experiments.
- *Scalable*: Digital solutions are highly scalable. There is little correlation between the number of users and cost.
- *Effective distribution*: There is little need for infrastructure, with the exception of internet connection. Delivery is immediate and cheap.
- *Malleable*: When working in a digital medium, modifications are easy and cheap.
- *Accessible*: Digital solutions can be accessed anywhere, provided an internet connection is established.
- *Fewer costs*: Vessels and other artifacts can be created at no cost. This allows for previously infeasible experiments.
- *Fewer legal concerns*: There is no risk of physically harming subjects participating in digital experiments. There is also no risk of damaging property.

As there is a clear correlation between the needs of the researchers and the properties of a digital platform, it seemed beneficial to create a digital solution. More specifically, a computer simulation appeared to be the most suitable approach. This would allow the user to model experiments, intended for testing of real world situations, in a virtual environment. As such, the researcher would be allowed to conduct experiments in an environment replicating reality, but without the concerns related to legal issues and cost of constructing physical artifacts.

Additionally, one of the inherent advantages of computer simulations is the availability of metrics within the system. In the real world these can be hard to obtain, but in the simulation they are a necessary component in the operation of the system. It gives the developer/researcher all the information necessary for analysis and design. It also gives them the option of storing all the data in the system, thus making it possible to recreate and/or rewind the situation. All the properties of computer simulation combined resulted in a platform capable of delivering the desired effect.

Image: Real life testing can be more accurate, but sometimes unfeasible du to cost, safety and other concerns.



## Problem statement

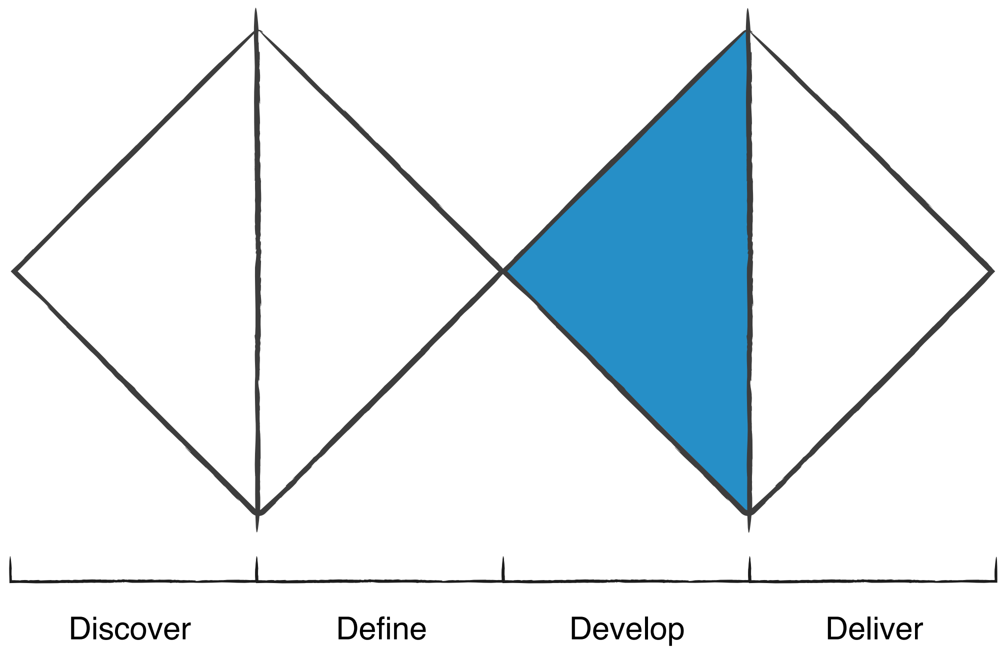
Following the decisions made in the Define phase, it is now possible to phrase a problem statement. The statement will be used as a guide when navigating the solution space in the Develop and Deliver phases of the second diamond. Though there are many approaches to phrasing such a problem statement, it could be argued that a "how might we" question is one of the more constructive approaches. This type of formulation emphasizes the value that can be created with the solution, rather than identifying an existing problem.

The three core ingredients that will be incorporated in the problem statement are:

- Who is the target user?
- What is the desired effect the users should experience?
- How will this effect be delivered to the users?

From these components, the problem statement was derived. It reads:

"How might we allow researchers studying human factors in autonomous vessels an accessible way of visually creating and testing thought experiments, using a computer simulation?"




# Develop

Now that a concise problem statement is defined, the next concern is to explore how this could be solved effectively. What sort of computer simulation should be created, in order to allow researchers studying human factors in autonomous vessels an accessible way of visually creating and testing thought experiments? To answer this question it is necessary to diverge, in order to explore the possibility space of what the solution might look like. Upon completing the Develop phase, there will be a solid foundation of ideas and understanding related to how the problem can be solved.

Activities partaken in the Develop phase included identifying collaboration opportunities within SCL, ideating functionality with researchers, defining design tenets, and developing an early version of the simulator.

## Collaboration with existing simulator

In order to fulfill SCL's explicit request for a functioning solution, it was important to examine possible collaborations within the lab. One of the current projects at SCL revolved around the use of a Unity-based visual simulation to research the role of the operator monitoring the autonomous vessel. It was based on the previously developed Gemini software, an open-source platform developed by graduate students at NTNU (Gemini-team, 2021).

The simulator was being developed by Mikael Røsbak Hanssen, an MSc student at NTNU, who had worked on the simulator as a scientific assistant at SCL summer of 2021. As of autumn 2021, Hanssen was continuing the development of the simulator as a student project, in preparation for his master's thesis.


Screenshot: The existing simulator allowed users to place themselves in a virtual representation of an autonomous ferry crossing.

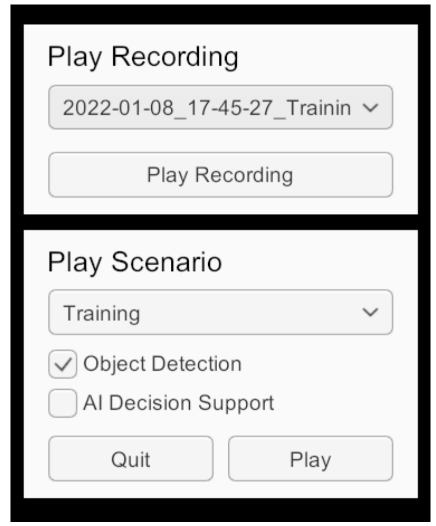
As there were clear synergies in the work of Hanssen and the project described in this thesis, it was decided to collaborate on the continued development of the simulator. The ideation, development and user testing described in the remaining sections of this thesis was done in collaboration with Hanssen, who should also be accredited with the technical implementations of the added simulator functionality. The exception being the implementation of the redesigned user interface, which was done by the author.



In its current state, the simulator did not serve as a way to conduct thought experiments for researchers. Rather, it had a deterministic setup where one vessel traversed one predefined route between two predefined docks. The user could play one of the three predetermined scenarios, but had no option of editing it themself. However, much of the functionality implemented was highly relevant to a thought experiment builder for autonomous vessels. This functionality included:

- Functioning water physics
- An accurate 3D model of Trondheim
- 3D models of the autonomous vessel and other vessels
- Basic pathfinding logic for vessels
- Functioning passenger logic
- Functioning vessel docking
- Support for saving log file

In sum, the existing functionality resulted in a great starting point for further development. The challenge at hand was to transform the simulation from a predefined setup to a setup defined by the user. To achieve this the simulator had to be transformed from a linear "one-size fits all" solution, to a system based and customizable one. If the user is to impose their own imagination on the system, the solution must afford actions that allow this. Although this was a clear shift of design approach from the current simulation, the technical implementation currently in place served as a strong foundation for further development.




Screenshot: The menu of the existing simulator.

## Functionality ideation

Within the topic of human factors in autonomous vessels, there are a huge number of questions worth researching. As a result, a simulation designed to assist researchers explore these questions could support a large variety of functionality. As part of the divergence of the Develop phase, it was interesting to consider many different types of functionality. This led to a series of interviews and discussions with researchers at SCL, where potential functionality was the primary topic. The result was a pool of ideas to consider for the final design. Some of the ideas include:

*Place vessels and docks*
Having the ability to place vessels, both autonomous and non-autonomous, and docks was of great interest to researchers. Additionally, they wanted to define the properties and behavior of these. This way they could set up new test situations in the simulator, for instance an autonomous vessel traveling from dock A to dock B in a populated harbor area.

*Define camera position and properties*
Where is the camera(s) located on and around the autonomous vessel? This affects what visuals the operators can base their actions and decisions on. Using a computer simulation, cameras can easily be moved around. The researcher can also add/remove cameras, as well as set the properties (i.e field of view) for each camera. This way, it would be possible to find the ideal constellation of cameras to serve the needs of the operator.

*Build custom harbor area*
In order to research harbor specific questions, such as camera setup for a specific harbor, researchers requested the ability to build custom harbor areas. This would also allow the researcher to create more realistic user tests with passengers, as the passenger must be presented with a simulation based on their local areas to be fully immersed.



*Visualization of sensor data from the autonomous vessel*
How does the autonomous vessel “see” the world through its sensors? This would be useful information to build trust with passengers, by showing them that the autonomous vessel is in fact aware of its surroundings. It would also allow operators to make more informed decisions, and have a generally better understanding of possible dangers.

*Initialize emergencies onboard the autonomous vessel*
How will passengers and operators react when disaster strikes, for instance a collision with another vessel? How can this experience be designed to be easier to handle for those involved? This is an example of a research experiment that is simply unethical to conduct in real life. Although a simulation would not substitute an actual accident, it could provide valuable information to researchers.

*Allow operator to monitor multiple vessels*
What is the relationship between the number of vessels the operator is responsible for, and their performance? Following this, what is the ideal number of vessels per operator, when considering cost and performance? By allowing the operator to monitor multiple vessels within the simulation, the researcher could answer this question.

# Design tenets

When designing a simulator such as the one proposed for this project, there are many design decisions that need to be made. To guide these decisions, and make the design more coherent, they will be in line with a set of design tenets. The tenets have varying characteristics and applicability, but are all intended to make more rationalized design decisions throughout the process leading up to the solution. Ultimately, the purpose is to deliver a better experience to the researcher using the simulator.

### The simulator should not be considered a game

In the brief of the projects there was a notion that the solution should be a video game. Throughout the course of the project, it has become apparent that this might not be desirable. Why is that the case?

One of the defining qualities of a game is a clearly defined win state for the player; a state which the player should navigate towards, in order to progress within the game. This implies that the game designer should decide what a desirable outcome is, on behalf of the player. This is not applicable to the simulator being designed in this project, as it is the user themself who defines what a desirable outcome is, based on what kind of research experiment they would like to create. Defining a clear win state on behalf of the user would subtract from the research value of the simulator.

Another quality of games is that they are entered willfully, meaning the player approaches the game experience without external motivation. This idea is somewhat conflicting with the role of the researcher, as this is typically a paid profession. It is therefore difficult to imagine a scenario where the majority of users approach the simulator based on an intrinsic desire to participate in the simulator experience. The thought of the simulator being a game for professionals to play in their work is also somewhat contradictory of Schells definition of games, with regards to the questionable degree of “playfulness” that would exist in work related use of the simulator.

These are arguments why the simulator should not be considered a game. That being said, there are valuable approaches and philosophies typically associated with game design that can be applied to the design of the simulator.



### The simulator will be a magic crayon

In order to create a solution that allows researchers to efficiently conduct experiments, ideas from the concept of magic crayons will be applied throughout the design. The premise of a magic crayon is that the quality of its output is disproportionally more desirable than what the skill level of the user suggests it should be. The tool produces a result that is of extremely high quality, compared to the mastery of its user. Especially for users with low levels of mastery. This allows non-expert users to efficiently produce an outcome that is desirable to them, which in turn dramatically widens the amount of users capable of deriving value from the tool. This resonates well with the target audience, who wants to perform experiments without outside help operating the tool, and without having expert knowledge of the tool themselves.

One of the reasons why the magic crayon is capable of producing this effect, is that it is quite specific in the possibility space of its output, resulting in a limited variability of output. This means that in order for the tool to be of value to researchers, the designer must thoroughly understand what sort of output the user would like to create. To achieve this, the designer must collaborate closely with the users, in order to present the users with the pieces they need to build their desirable output. Put differently, the designer must create a possibility space of outcome, within which the user can find their desirable outcome. In this case, the goal is to allow researchers to build experiments related to human factors in autonomous vessels.

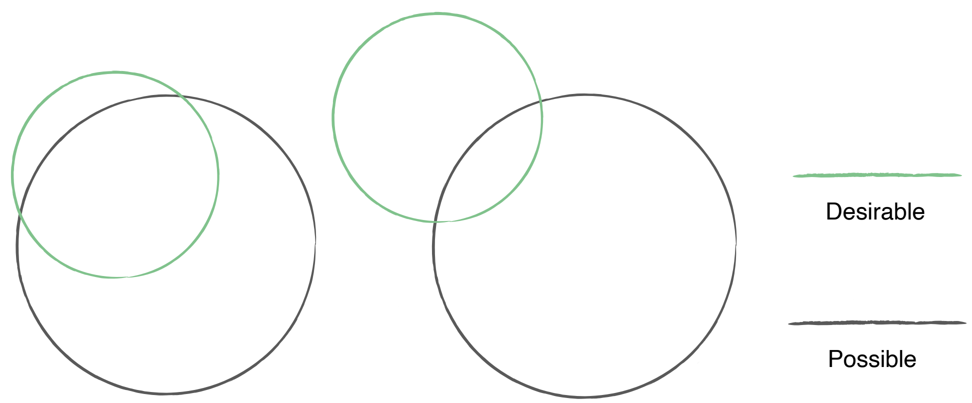



Figure: By understanding the needs of users it is possible to design more favorable possibility spaces. The left space shows a design in line with user needs. The right space shows a design where the design does not allow the desired output.

### The simulator should be of value across all levels of mastery

The magic crayon approach emphasizes the added value the simulator will bring to non-expert users. However, for the simulator to be a truly powerful research tool, it must provide value to researchers across all levels of mastery. This can be considered in relation to the concept of flow. Using this model, it is apparent that the initial level of difficulty should not be too high, meaning that a user with low levels of skill should still be able to master the initial complexity of the tool. Much in the same way games allow new players to experience success, by presenting simple challenges initially.

Equally as important, the tool must host the depth of use to allow expert users to exert their expertise. It should appear simple at first glance, yet have a deep level of complexity the user can discover through the development of their own mastery. To achieve this, it is possible to imagine a design where the effect for users with low levels of mastery resembles that of a magic crayon, while the effect for highly skilled users is more resemblant of a traditional tool, such as Autodesk Maya (Autodesk, 2021). This way it would be possible to guide non-expert users towards a desirable outcome within a confined possibility space, while expert users are given a larger possibility space to navigate with their expertise. This ongoing dance between increasing skill levels and increasing complexity is something the tool should actively facilitate. This can be achieved by thoroughly understanding the user's skill development through a user-centered approach, much like games do with players.



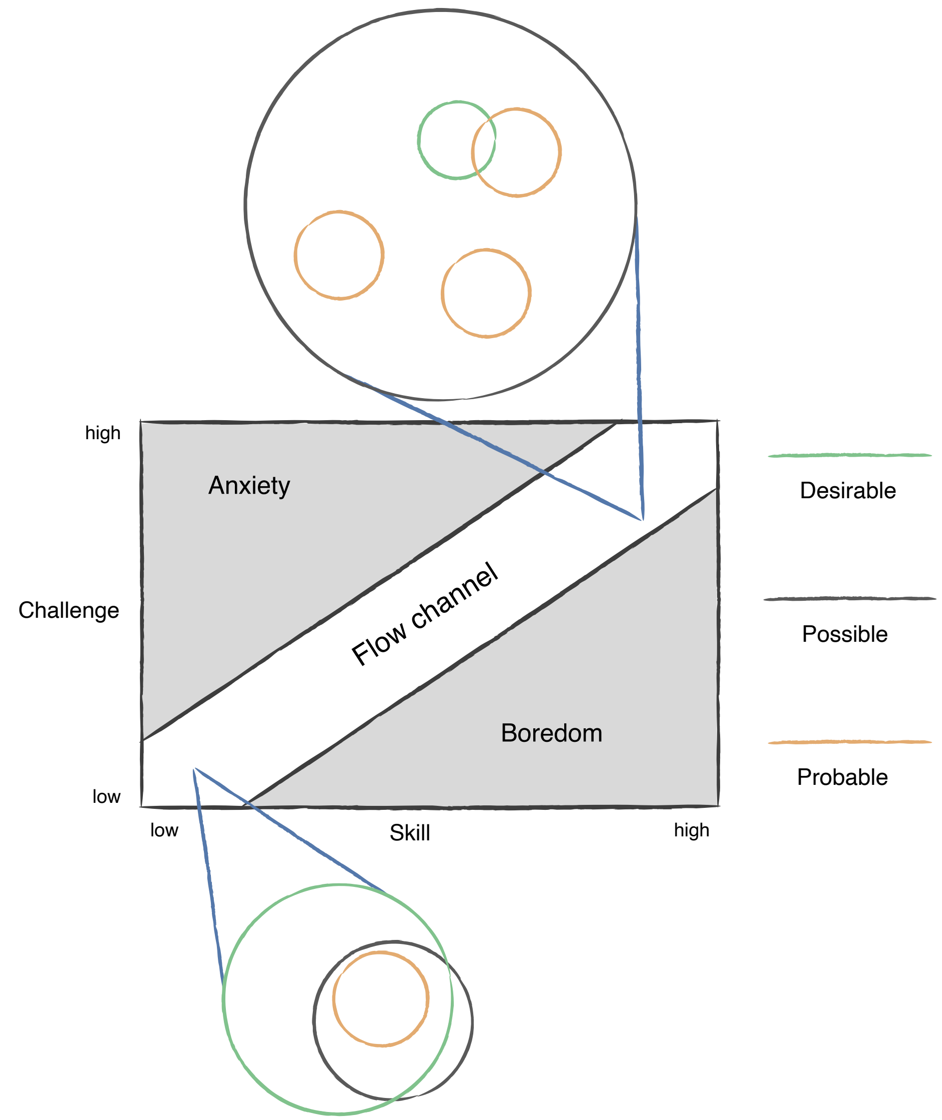


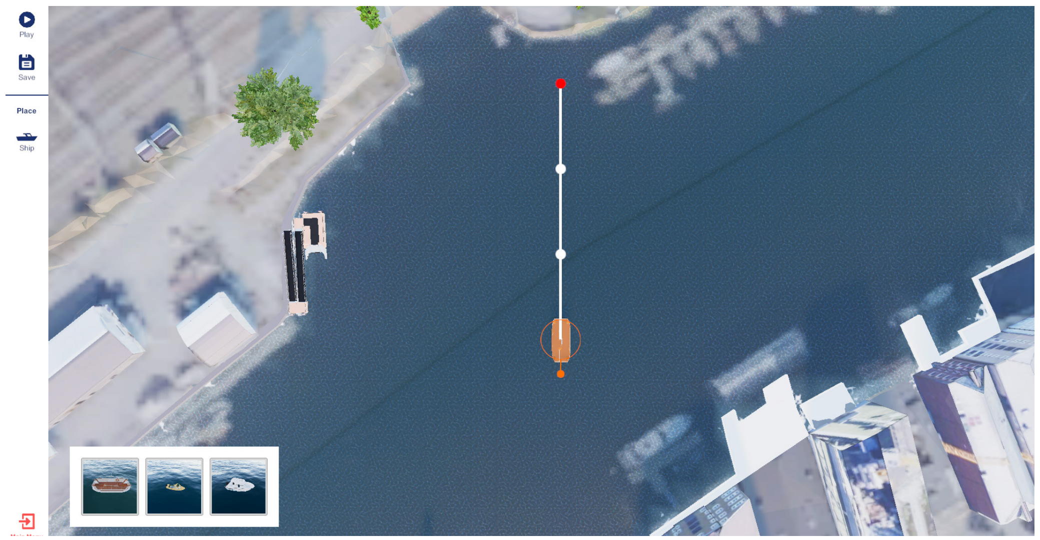

Figure: It is possible to imagine a tool that combines the ideas of magic crayon and flow. This could be done by allowing low skilled users to achieve desirable outcomes through the qualities of a magic crayon approach, while high skilled users get access to a larger possibility space they can navigate with their expertise.

# Early version

Following the ideation sessions, enough insights had been gathered to begin the development of the new simulator. The idea was to transform the existing pre-determined simulation to one where the researcher could define scenarios and experiments themselves. During the early phase of development, the team took a minimum viable product approach, where the purpose of development was to verify that the implemented functionality resonated with researchers' needs. As such, each added functionality was developed to the point where it was usable, but not perfected for the sake of interaction aesthetics etc.

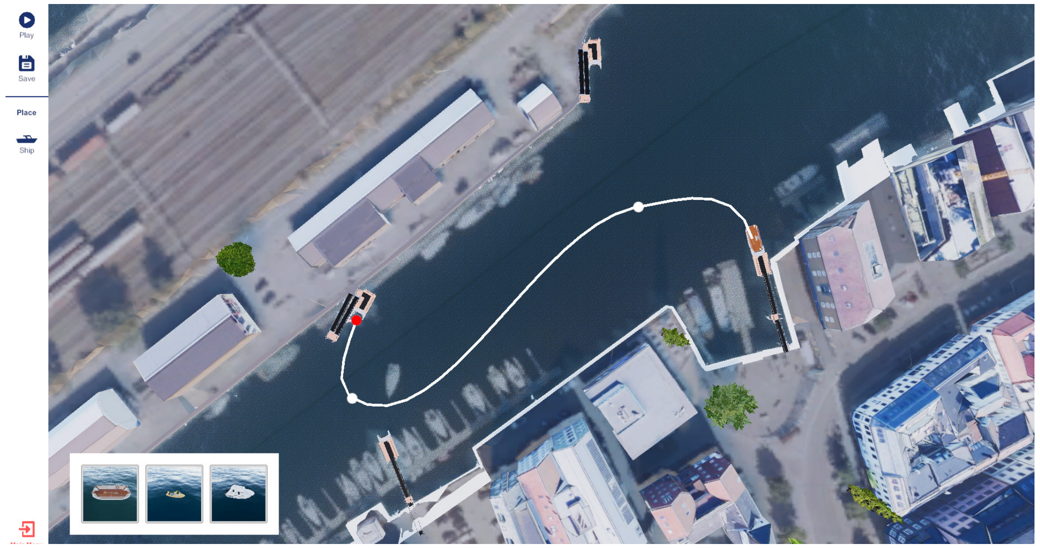
Initially, the implementation involved basic functionality that would serve as a baseline for implementing more specific functionality later. The purpose was to establish a foundation that could later be expanded to include a wide variety of features. This foundation included a new "builder" mode, where the user could design an experiment using the functionality of the simulator. The ability to add vessels, both autonomous and non-autonomous, as well as defining their movement path was implemented as part of the builder. The user could also define what docks the autonomous vessel should traverse between, from a selection of four docks placed in the harbor area. Using the implemented functionality, it was possible to build a basic ferry crossing within the simulator. This was done in three simple steps:

1. **Spawn the autonomous vessel, and drag it to the desired starting dock.**



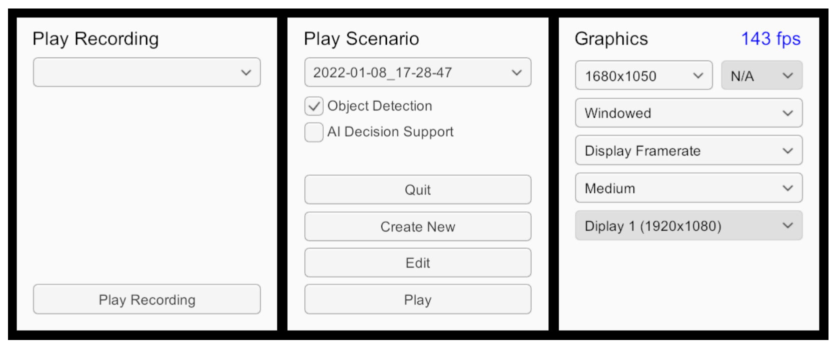


2. **Draw the path of the vessel, by dragging the end point to the desired dock, and defining the curvature by dragging the mid-points.**



3. **Press the play button.**

In a matter of two clicks and five drag gestures, the user could create a fully autonomous ferry crossing, with passengers embarking and disembarking the ferry. If the user then placed a few non-autonomous vessels, and drew out their path, they would have created a harbor ecosystem in the matter of seconds. Although this early version of the simulator was severely hindered by bugs causing unexpected behavior, such as magically spinning vessels defying the laws of physics, it was clear that the proposed simulator design had many of the desired qualities uncovered throughout the design process.

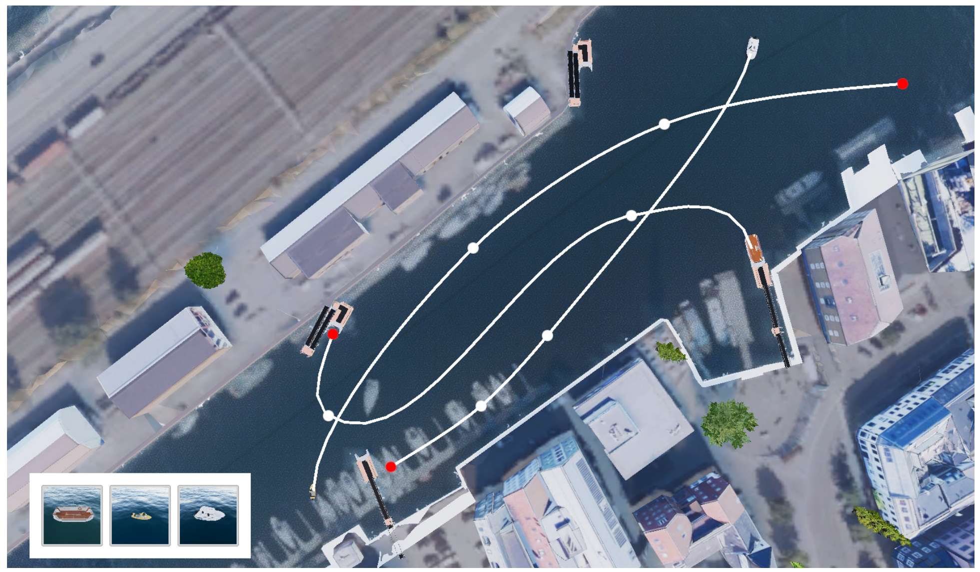



Screenshot: The menu of the early simulator version.

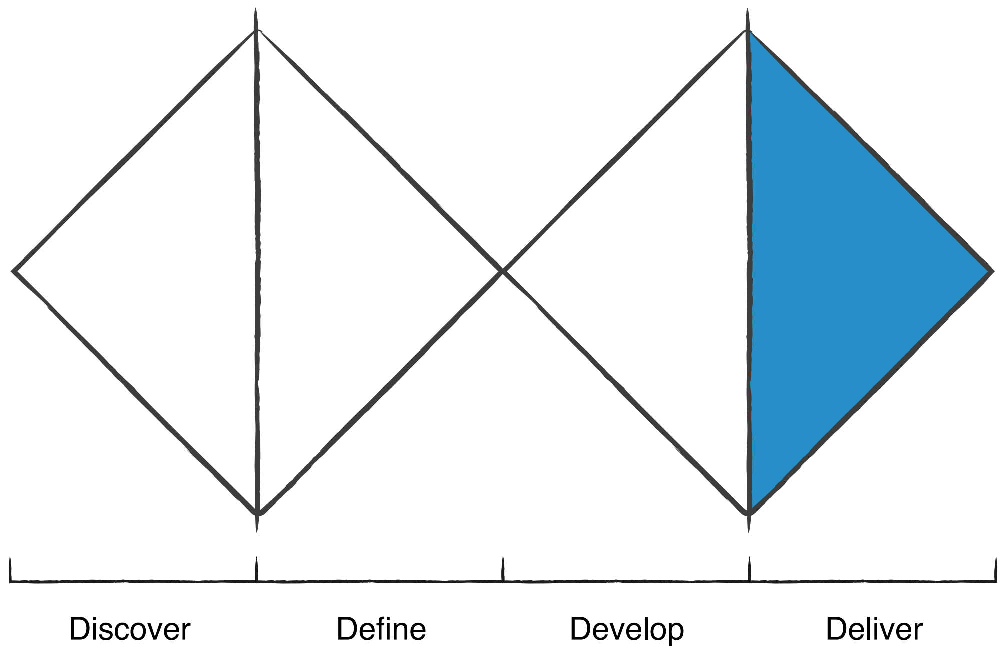
Its qualities closely resembled that of a magic crayon, as it allowed a first time user to create a fully dynamic harbor ecosystem through a few simple interactions, brought to life by computational power. It also allowed the user to move vessels around, and easily change their paths, making it highly sketchable. There was considerable room for improvement in terms of the robustness of the simulator, and its expressiveness, but the foundation appeared promising.

The purpose of this early version was to use it in sessions with stakeholders, in order to verify that the vision for what the simulator should be was in line with the expectations of SCL. Given the close collaboration with the stakeholders, it was unlikely that the simulator was a complete miss. Still, there is a certain value in discussing the actual design manifestation, such as the early version of the simulator, rather than considering ideas of what it could be. The sessions were therefore of great value to the process, as they both confirmed the relevance of the simulator, and cultivated ideas related to further development.

Image: User testing with Ole Andreas Alsos, Head of NTNU Shore Control Lab.



Screenshot: The Trondheim canal, populated with autonomous and non-autonomos vessels. The white lines indicate the vessels path. The red dots mark the end points.






# Deliver

The purpose of the Deliver phase is to converge on a solution, which answers the problem statement specified in the Define phase. This is done by using the insights and understanding of the solution space, found in the Develop phase, and then apply an iterative process to navigate towards the final solution. In this case, the final solution will be an effort to answer the question "How might we allow researchers studying human factors in autonomous vessels an accessible way of visually creating and testing thought experiments, using a computer simulation?".

Activities partaken in the Deliver phase included choosing a case to narrow project scope, detailing the chosen case, specifying required simulator functionality for the case, developing a first iteration of the simulator, reiterating a second iteration based on user feedback, and documenting thoughts for future work.

## Choosing a case

In order to produce real value to an end user, the scope of the delivery had to be narrowed down. There are simply too many subtopics within the topic of human factors in autonomous vessels to cover them all with the outcome of the project. It was therefore decided to choose a case, in which the solution could deliver genuine value to the researcher in their work.

### Areas of interest

To identify a suitable case, the project consulted Erik Veitch at the SCL, who specializes in the research of human-AI interaction and collaboration. According to Veitch, the topic of greatest immediate interest to the SCL is the role of the operator monitoring the autonomous vessel. He recognizes that despite the recent technological advances in AI, humans still outperform the best AI considerably in terms of identifying an issue, and judging the appropriate solution. It is therefore of great interest to study the collaboration between the operator and the autonomous vessel. Within this topic, Veitch had identified six areas of interest:

*Camera properties*
What camera positions, field of view and perspectives would most effectively let the operator have an overview of the situation?

*Object detection*
Would the operator benefit from having assisted object detection of vessels, docks, and other relevant entities? How should this object detection system be designed to be of most help to the operator?

*Attention span*
What is the attention span of the operator? How does passive observation of vessels over time affect performance when intervention is required? How can the control room facilities be designed to optimize attention span?

*Feedback*
What kind of feedback (visual, tactile, auditive, etc.) should the operator receive, in order to design an immersive experience? How does the level of immersion affect the performance of the operator?



*AI decision support*
Would the operator benefit from AI driven suggestions, to support the actions of the operator? How and when should these suggestions be presented to the operator?

*Information load*
What information should the operator be presented with? What is the correct amount of information for the operator to effectively do their job, without suffering from information overload?

### Collaboration with existing research project

Another consideration, related to the choice of case, was the prospect of collaborating with an existing research project. For the project to deliver immediate value within an area of interest, such collaboration seemed highly beneficial. Firstly, it would allow for more accurate user testing of the simulator, as the user would be able to imagine using the simulator first hand. This would be of great significance to the design process, allowing the user feedback to be based on actual need, rather than hypothetical scenarios. Secondly, it would allow the simulator to be used in an actual research project, thus delivering concrete value to the stakeholders at SCL.

Further discussions with Veitch ensued, in order to identify a relevant collaboration. He suggested a collaboration with Kristin Grønhaug Senderud, who was currently writing a master's thesis on the attention span of operators monitoring an autonomous ferry crossing. This was a good case for the project, as it was an opportunity to work closely with existing research. Senderud also had a specific situation in which she wished to utilize the simulator. This was a pilot study, in which she intended to research how the performance of the operator was affected by the length of time they had to monitor the autonomous ferry passively before an incident occured. The pilot study was conducted in preparation to a more encompassing study that would be performed later.

## Using the case as a building block

When comparing the scope of the case (attention span of operators) with the desired scope of the simulator (human factors related to autonomous vessels), it is clear that the case only covers a small fraction of the overall ambitions of the simulator. This is a deliberate design choice. While it is apparent that the simulator must support a multitude of cases in order to be of significance to a wide range of researchers, it is also clear that functionality for all these cases should not be implemented in the simulator simultaneously.

By first targeting a subtopic of human factors, such as attention span amongst operators, it is possible to design a simulator which wholeheartedly understands the needs of those researching this. This effect can later be scaled to include other subtopics, all of which are fully understood and supported by the simulator. The idea is that if enough subtopics are represented effectively, the simulator will eventually have the capacity to handle a wide range of research questions found within the topic of human factors. When taking this perspective, each case can be considered a building block for the simulator. In itself a single building block will be quite limited, but together they form a strong foundation for researching human factors in autonomous vessels.

With regards to the magic crayon design approach, it is vital to fully understand and support the specific task the simulator must handle. Otherwise, the limited possibility space of outcomes offered to the user would not encompass the desired outcome the user had in mind. The result would be a simulator that was of no value to the target user. This further strengthens the argument of slowly building the simulator one case at the time, in close collaboration with the users and their needs.

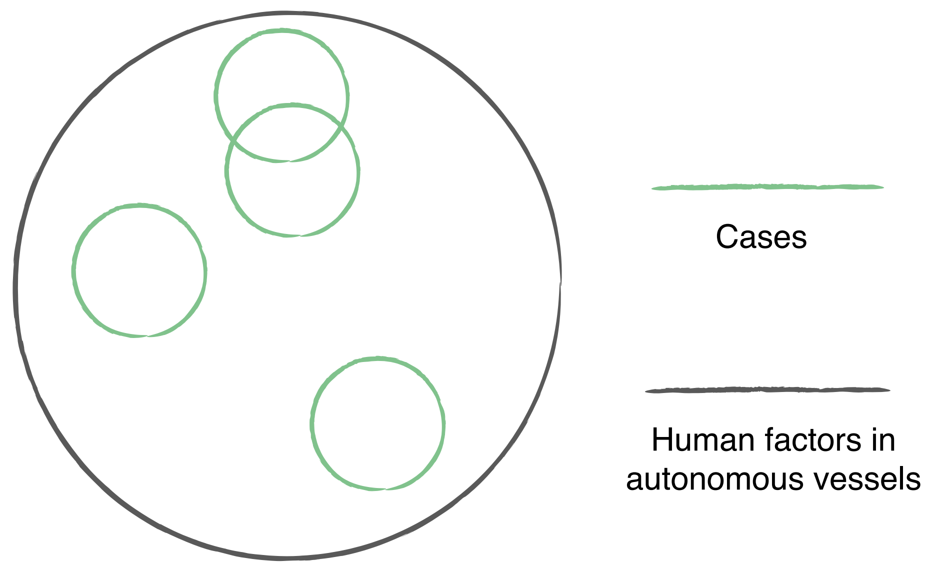



Figure: By building the simulator case by case, the entire topic of human factors in autonomous vessels will eventually be represented.

# First iteration

The decision to scope in on attention span as a case resulted in a clearly defined goal, which was to develop a simulator that would allow Senderud to build the experiment she had in mind for the pilot study. As the date of the pilot study was fast approaching, the development of the simulator had to be laser focused, only implementing functionality that was directly relevant to the pilot study.

## Experiment description

To ensure that the functionality of the first iteration supported the experiment intended for the pilot study, Senderud created a detailed description of how she envisioned it. The purpose of the experiment was to see whether the length of time an operator had to passively watch an autonomous ferry before taking manual control would affect the performance of the operator. In this case, performance related to the operator's ability to safely steer the ferry back to a dock, after an emergency took place.

To test this, Senderud wanted a fire to occur aboard the ferry, prompting an alarm to the operator. The alarm would force the operator to take manual control of the ferry. While steering the ferry towards the nearest dock, a non-autonomous vessel would steer towards the ferry, colliding if the operator does not change the path of the ferry. This would serve as a test to see if the operator was being sufficiently alert to the situation.

The experiment would be conducted in two variations. The first group of operators would have the fire occur after 5 minutes, the second group after 35 minutes. It was emphasized that the experiment should be exactly the same for the two groups, with the exception of time before fire occurred, in order for the results to be comparable.



## Required functionality

This description was then deconstructed, specifying exactly what functionality needed to be implemented in order to allow the creation of the experiment. The idea was to specify functionality that would serve the purpose of this single case, while also being general enough to be of value to other cases later. The following functionality was deemed necessary:

- Start a fire on board the autonomous ferry after a specified duration of time
- Initiate an alarm when the fire broke out, such that the operator must take manual control
- Start movement of non-autonomous vessels, such that its path would cause a collision with the ferry if the operator is not paying attention
- Display message of completion once operator had manually driven the ferry to a dock after the fire has occurred
- Ability for the researcher to duplicate the experiment, to set up multiple variations with varying parameters (such as time)

# Implementations

## Emergency alarm

An emergency alarm was added, which would display when the fire action was triggered. This would activate a rather intrusive sound, and require the operator monitoring the ship to take control and steer it back to the dock. A visual representation of the fire would also occur on board the autonomous ferry.

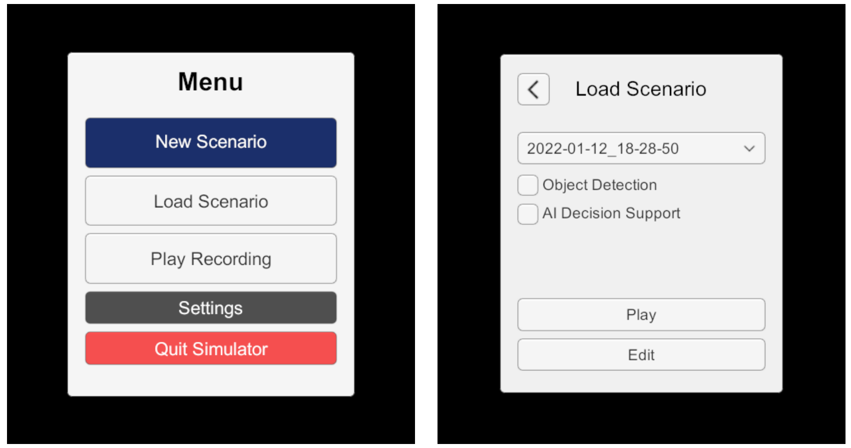

Screenshot: An emergency has occurred, and the autonomous vessel require manual takeover.

## Placing docks and dock snapping

The simulator now allowed the user to place docks in custom locations, by accessing the new dock menu, and selecting one of two dock types. The ability to "snap" the autonomous vessel to docks was also added. This meant the user would not have to be as meticulous in the placement of the vessel for it to recognize the presence of the dock.

## Redesigned menu system

The previous menu design had created some confusion, by presenting all information in one flat structure. The new design simplified the interactions, by breaking down the menu into a more branching structure. For example, loading a scenario now required the user to first click "load scenario", then select the file they wanted to load. Previously, this was all done from the main view of the menu.

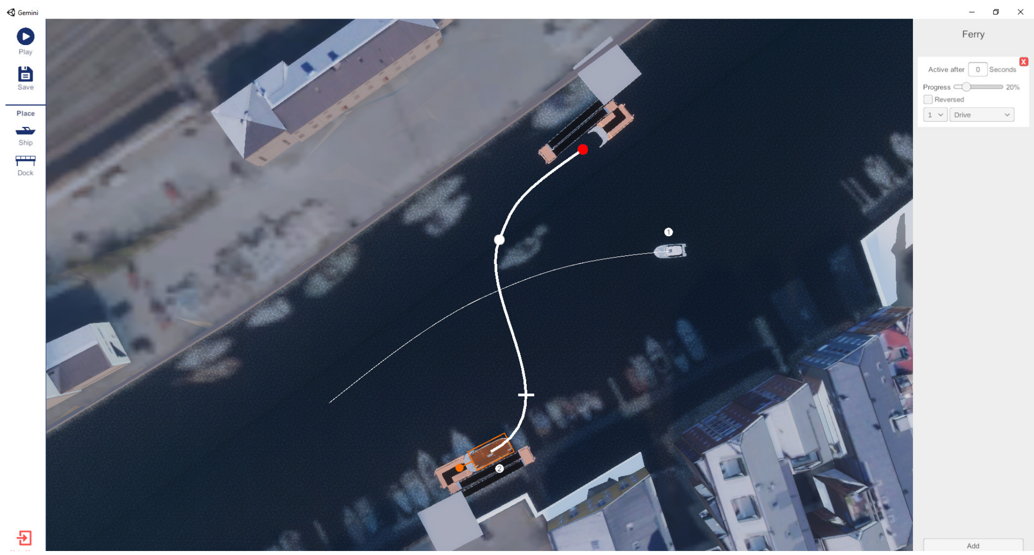


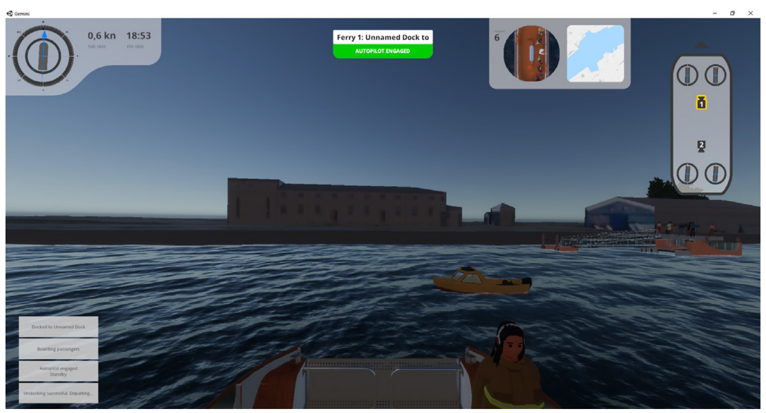

Screenshot: The redesigned menu system.

Screenshot: Users can now place and rotate docks.

### Action triggers

The addition of an action trigger system was the biggest technical implementation of this iteration. This allowed the user to define a trigger that would activate some event. The interface supporting this functionality was found on the right edge of the screen, and appeared when a vessel was selected. Using the action trigger system, the user could define that an action should occur when the ship had traveled a certain distance between two docks. It was also possible to add a delay, such that the action could only occur after a set period of time. The action types added in this version were fire on board the autonomous vessel, and the activation of non-autonomous vessels.




Above screenshot: Action triggers starts movement of non-autonomous vessel when autonomous vessel reaches certain point.

Left screenshot: Planned scenario is playing.



## First user test

Following a period of intense development, the functionality had reached a stage where it was ready for testing. It was therefore set up a remote user test with Senderud, where she would attempt to build her experiment using the functionality of the simulator. Unlike the session conducted with stakeholders using the early version of the simulator, the purpose with this test was to test the usability of the implemented functionality, rather than verifying expectations. During the test it became apparent that there were some key issues that needed to be resolved. These were related to both technical difficulties and lack of clarity in the design.

The most immediate problem was the ubiquitous presence of bugs within the program, as this resulted in the user test being less than optimal, given the number of times it had to be paused in order to fix a bug. Still, it was highly valuable to identify the bugs that had not appeared during internal testing.

From a design perspective, the most issues occurred when Senderud attempted to set up triggers and actions. It was unclear where such functionality would be found in the interface, and once found it was difficult to understand how the system worked. It was clear that the user's expectations of how to trigger an action did not correspond to the design, and it was therefore necessary to revise the approach that was taken to action triggers in this iteration.

There were also difficulties related to the navigation of the camera within the experiment builder. This was a result of the user trying to move the camera while simultaneously moving objects within the world. This had not been considered a possibility during development, and required a redesign of the camera controls.

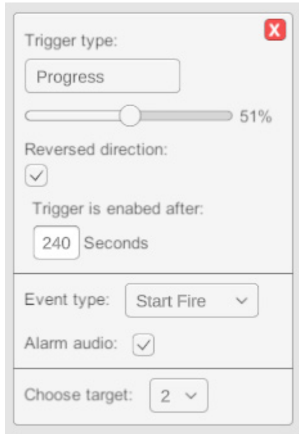
# Second iteration

Using the insights from the first user test, work began to develop a second iteration. This primarily involved ironing out the technical flaws from the first iteration, but also redesigning the action/trigger system in order for it to match the expectations of the user more closely, as well as some other functionality that had been requested. The purpose of this iteration was to have a version that would effectively allow Senderud to conduct her pilot study at the SCL headquarters.

## Implementations

### Changes to action trigger

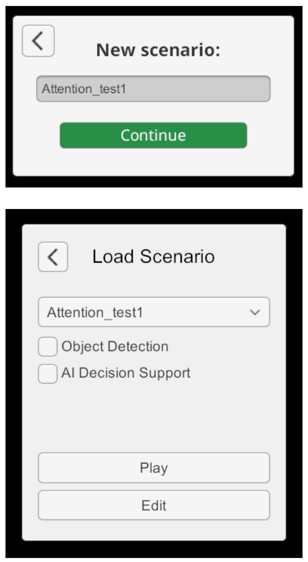
Based on the feedback from the previous iteration, alterations of the action trigger system were made in this version. This included a rearrangement of the order in which choices were made when creating a new trigger. Additionally, labels were made more elaborate and informative. The ability to enable/disable the alarm audio was also added.




Screenshot: Redesigned action trigger system

### Custom file names

Previously, the file names had been based on the timestamp of when the file was created. This led to confusion when working with multiple files. As the pilot study would involve the use of two files, support for custom file names were added to the simulator. The files would be sorted according to the time they were last edited.




Screenshot: Custom name file support



### Scenario completion

Upon docking after an emergency, a “scenario complete” dialog would now appear. The dialog displayed the time it took to complete the scenario, and allowed the user to either edit the scenario in the builder, restart the scenario, or return to the main menu.


Screenshot: Menu displayed when completing scenario.

### New camera controls

A more complete camera control system was added to the simulator, in order to satisfy the need of moving the camera while placing vessels and docks. This was accomplished by allowing users to move the camera by moving the cursor to the edges of the screen. Support for moving the camera by right click and dragging was also added.

## Pilot study

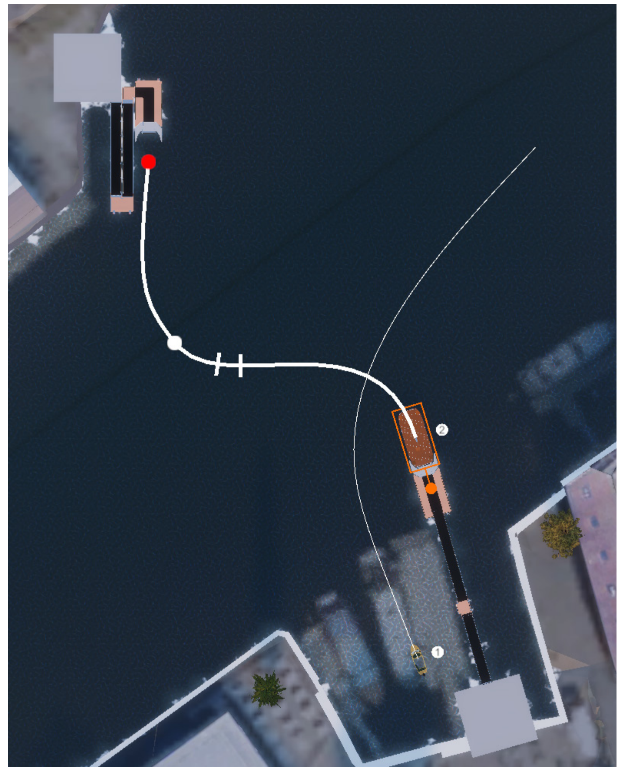
After implementing the new functionality, and fixing a great number of bugs, the simulator was installed on the computer used in the SCL control room, which was where the pilot study would take place. As the simulator had been specifically built for this pilot study, it was important that it allowed Senderud to conduct it successfully.

On the day of the pilot study, the experiment was built in the simulator. It was built in two variations: (1) a variation that would trigger the fire after approximately 5 minutes, and (2) a variation that would trigger the fire after approximately 35 minutes. It was therefore vital that the experiment could run on the simulator without technical flaws for the full length of the 35 minute variation.

The final experiment setup consisted of one autonomous ferry, and one non-autonomous vessel. The ferry would traverse between two docks for either 5 or 35 minutes, before an action trigger would start a fire onboard the ferry. This would alert the operator, who would take manual control. Upon approaching the dock, the non-autonomous vessel would be sent towards the ferry by a second action trigger, forcing the operator to act in order to avoid collision. This setup worked effectively, and created the effect that Senderud had described in her initial description of the experiment.

The experiment was conducted on four different operators, with the simulator functioning as expected on all four occasions. This allowed the pilot study to be conducted successfully.





Screenshot: The final setup of Senderud pilot study. As the ferry is approaching the dock, the non-autonomous ship heads out in collision course.

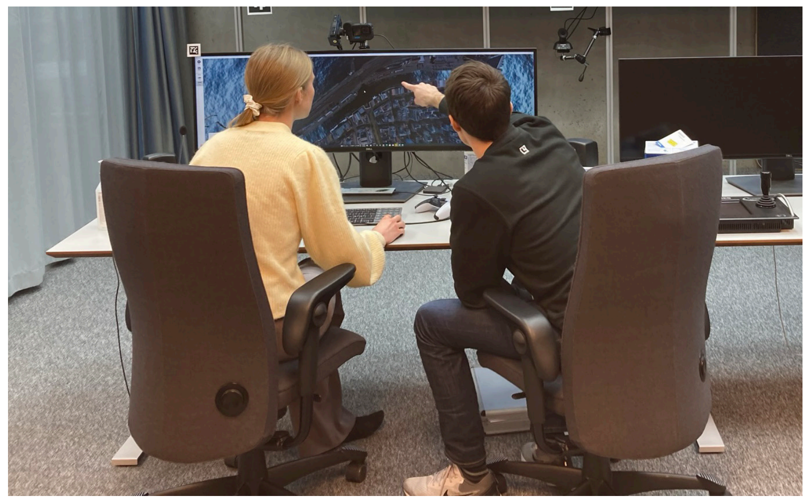


Image: Final preparations of the pilot study experiment.

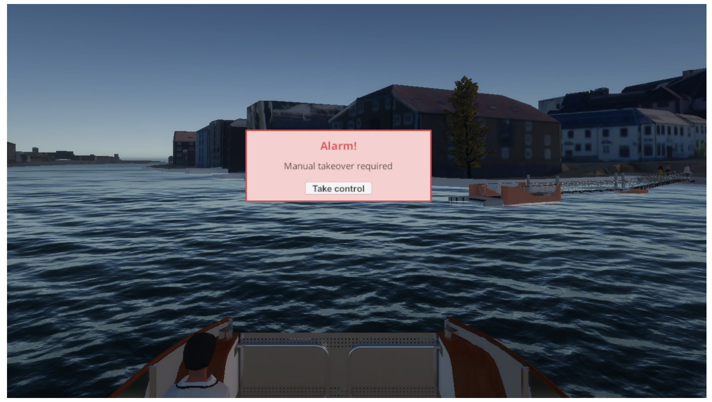
## Future work

Where should the simulator go from here? There is little doubt that the work described in this thesis should only be considered a start. Although it did deliver value to this specific case, it would be of little use in most other scenarios. The functionality must be expanded for the simulator to deliver value on a general basis. Two possible continuations of the work are:

- *Elaborate with more cases*
  Given the successful use of the simulator in the aforementioned pilot study, it would be relevant to identify other projects related to the research of human factors in autonomous marine vessels, and collaborate with these much the same way as with the attention span case. This way it would be possible to keep building the functionality and scope of the simulator one case at the time, which would allow for the intimate understanding of user needs required to make successful additions to the simulator.

- *Platform for sharing thought experiments*
  It would also be interesting to consider the opportunity of connecting the researchers creating thought experiments using the simulator, and allow them to share the experiments and their outcome. Such a network could accelerate the rate at which ideas spread in the research community. An aspect to this could also be the implementation of crowdsourcing, leveraging the competence of the community participating in the use of the simulator.






Screenshots: The pilot study experiment from the operators point of view.

# Conclusion

By using approaches and frameworks from design thinking and game design, this project has designed and developed a research tool that enabled a pilot study in attention span amongst operators monitoring autonomous marine vessels.

It would be imprecise to conclude on the general applicability of such a design approach, based on this one specific application. However, it can be noted that the approach did create a tool that provided great value to its intended use case.

It should therefore be considered relevant to further investigate the use of the design approaches described in this thesis, in the design of tools used to research human factors in autonomous marine vessels. There could also be opportunities found in the application of these approaches to tools used in other areas of research.

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