A case study of designing bridge experiences on future ships

Master of Arts Thesis
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Acknowledgements

A year back, I would never think of being able to finish my thesis in such an amount of work. Now, this book is held by my hand, filled with knowledge that has been learnt and gathered by myself from this field.

Here I am satisfied with the efforts and times which I paid on my thesis. It is never my own work to finish such a book. Many friends supported me during the past year.

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Many thanks to Wahlström Mikael, Karvonen Hannu and Mannonen Petri who worked in the same team with me. They put many effort to make this case going on well. I’ve learnt a lot being working with them.

Finally, I would like to thank my friends. They were always there cheering me up and stood by me.
Abstract

This thesis aims to study the experiences that a captain would prefer in future ship operations on a tugboat bridge. The case study is based on “operations on future ships”, a case collaborating with Rolls-Royce Marine and other research companies. In this case study, the subjects covered captains and seafarers who work or used to work on tugboats, cargo ships or supply vessels. Researchers carried out user studies by using methods including field studies and in-depth interviews, which identified several experiences that seafarers may appreciate.

The author concentrates on the tugboat bridge. He set User Experience Targets “sense of control” and “feeling of comfortable in using technology” based on the study findings and developed one tugboat bridge concept. Experts and a top user evaluated this concept.

The results of this study indicate that a sense of control is the experience that captains may expect and enjoy and that a feeling of comfort is still not accepted, though the studies discovered few situations, which seafarers are still suffering uncomfortably.
1. INTRODUCTION

1.1 A new design needed for future bridges

The maritime environment is deeply rooted in traditions, but it has over the last few years experienced an interesting and user-challenging technological development from suppliers of maritime equipment (Bjorneseth, 2011, p.1).

The way of operating vessels changed significantly since automation systems were widely utilized on the bridge and became standard equipment. Woods (2006) indicates through increased control automation, the human role has shifted from an emphasis on the perceptual-motor skills needed for manual control to the cognitive skills (e.g., monitoring, planning, fault management). The automation system is truly a good improvement and it brings many advantages. As a latest and potentiated technology, it is continuously growing more advanced. But researches show (Lutzhoft&Dekker, 2002; NTSN, 1997; Sweller's, 1988; Reason, 1990; Dekker&Woods, 1999), humans are not good at cognitive skills; they are poor monitors of automated systems; they are the main cause of many automation related accidents. This fact raises the questions, “how do we (human and machines) get along together?” and “how do systems support co-operation?” (Lutzhoft&Dekker, 2002). It requires not only technological improvement but also design solutions.

At the same time, due to equipment upgrading, bridge operation varies creating new design needs. It can be seen from the existing bridge and workstation, bridge design has not changed that much. Most designs of the bridge are still function-based rather than user-friendly.

Consequently, there is a strong need to develop the ship bridge design further.
1.2 “Bridge operation on future ships” case

From 2011, Tekes\(^1\) and Fimecc\(^2\) are running a program called User Experience & Usability in Complex Systems (UXUS). It is a 5 years program, collaborating with 5 research organizations and 8 companies. The aim is to improve user experience in targeted usage environments and situations rather than technological pushes with different user interaction technologies.

Rolls-Royce Marine launched the case “bridge operation on future ships” in 2012 within the UXUS program. The target of this case was to innovate, design, implement and evaluate new ship bridge concepts in 2020 that facilitates successful user and customer experience. This future ship bridge case was planned to last two years: the first year is generating a concept of future bridge operations; the second year is to finalize the prototype.

A team of 6 researchers, from Rolls-Royce Marine, Aalto University, Tampere Unit for Computer-Human Interaction, and VTT Technical Research Centre of Finland, formed a multi-disciplinary group to work on this “bridge operation on future ships” case. The case study covers tugboats, supply vessels and cargo ships and will eventually design a scalable concept which can be applied on different types of vessels. This thesis is based on this “bridge operation on future ships” case, with a focus on the tugboat. Due to the confidential issue, this thesis doesn’t include any of the concepts the team designed for Rolls-Royce Marine. Instead, it presents a concept, which is designed only by the author himself. This design is about tugboat bridge operations and has avoided any ideas included in other concepts.

In general, the content of this thesis includes background research, user study, the early concept design stage and evaluation of the “bridge operation on future ships” case (figure 1). These are all the author’s contributions except a few parts with collaborated works which are displayed in a way so the thesis can be understandable and meaningful.

1.3 Why choose User Experience Design

Experience exists everywhere in our life. It is considered as a design objective due to the features of its self-defining nature, its power to make us happy and to energize our behavior (Marc Hassenzahl, 2010). Leaf Van Boven and Thomas Gilovich(2003) produced an experiment about rating the happiness of a purchase. The outcome shows that people who made experiential purchases are happier than those who made material purchases. Marc Hassenzahl (2010) studied several cases and concluded that in general, positive experiences we go through hold more power to increase well-being than any material possession; the value does not lie in the material but in the experiences provided; experiences are highly valued. In the product design field, a new term called User experience (UX) was defined. UX is a person’s perceptions and responses that result from the use or anticipated use of a product, system or service.\(^3\) It is a person’s perception (interaction) to products along two dimensions, as Marc Hassenzahl (2008) identified, which are pragmatic quality and hedonic quality. Thus the satisfaction of both of people’s pragmatic needs and hedonic needs makes good user experience. It is key to provide customers with good systems and thereby increase business success (Roto, 2007).

User experience is taken into account and becomes more and more important in many design areas, for example in consumer electronics, “Having a high quality user experience is one of the most important goals.” (Joonhwan, Sanghee & Sungwoo, 2006).

However, in the maritime domain, Shea and Grady (1998) argue, human factors are rarely considered in vessel design and engineering. Afterwards people start to have con-

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\(^1\)The Finnish Funding Agency for Technology and Innovation (Tekes)

\(^2\)Finnish Metals and Engineering Competence Cluster (Fimecc)

cerns about usability in this field (this could be seen as a concern of pragmatic needs). There is still a lack of attention for user experience, especially the hedonic attribute. The author would like to explore UX with focus on the maritime domain, specifically, in the bridge operation.

As in other human-computer interaction areas, people recognize the limitations of the traditional usability framework to address the non-utilitarian aspects of interaction (Law et al- 2009). Terms like aesthetics (Alben 1996), pleasure (Jordan 2000), emotions (Desmet 2003; Norman 2004), fun (Blythe et al. 2003) have entered the primarily pragmatic-oriented community. This begs the question, what would it be on the ship bridge?

1.4 Research Questions

The objective of this thesis is to study User Experience in a tugboat bridge. The research questions are:

What are the attractive experiences on a tugboat bridge operation?
How can user experience on operations in future tugboats be improved?

Research questions include the following aspects:

1) Identify the operators existing experiences (both positive and negative ones) in the tugboat bridge environment;
2) Find out what the expected UX is that would attract seafarers in their work context;
3) Design the new tugboat bridge operation to see if the UX study has benefited this field.

2. USER EXPERIENCE FRAMEWORK

We cannot design an experience. An experience is generated when a user interacts with a product. This is linked to the hedonic/pragmatic model (Hassenzahl, 2007a), as people perceive interactive products with two separate mindsets: pragmatic and hedonic. Pragmatic quality refers to the product's perceived ability to support the achievement of “do-goals”; hedonic quality refers to the product's perceived ability to support the achievement of “be-goals”. Hassenzahl, Marc (2011) identifies three levels to consider when interacting with a product (figure 2). First you clarify the needs and emotions involved in an activity, the meaning, the experience; and then, it determines functionality which is able to provide the experience (the What) and an appropriate way of putting the functionality to action (the How).

Pragmatic needs mean what and how while hedonic needs stand for why. Experience Design focuses on how to bring the Why, What and How together. UX differs from traditional usability with the respect to both pragmatic needs and hedonic needs for creating a fully satisfying product (Hassenzahl 2007b; Diefenbach, S., & Hassenzahl, M. 2011). A true UX objective is to support Do-goals taking the underlying needs seriously, and design technologies that match those needs. (Hassenzahl 2007b).
The larger context of this research is in the maritime area and the small context is the tugboat bridge. Although the maritime context is such a broad area, which cannot determine tugboat bridge operations directly, it does influence them. The future operations are revealed from the current situation and the trend in the maritime context.

While talking about user experience, the tugboat captain's attitude towards the bridge operation will always be influenced by this larger context.

3.1 Past-Now-Future

The maritime context can be seen as a human sailing history. It has existed for hundreds of years, since people traveled over water, whether for trade, agriculture, transport or warfare, from wooden canoes in the early beginning to giant vessels nowadays. Shipping has a long history; since the 1770s steam powered boats, relying on technological development, increased the diversity of boats to satisfying different specific needs. Following a significant increase in ship sizes in the 20th century, the internal combustion engine and gas turbine came to replace the steam engine in most ships.

As a result, the new power sources created different capabilities to operate ships. Sailors used to have to control the ships manually so had to be fully trained in adjusting sails or controlling rudders. Now captains need to understand large amounts of data information and react by controlling the ship using a console (usually leavers in big ferries today). Operating a ship is never an easy action. The sea is a diverse and complex environment. Once a ship is on the sea, many factors such as wind, current and ice may influence the voyage. Bridge workstation solutions provide equipped machines to support the control, like GPS systems, eco sounders, clinometers and so on. However, unless the ship can be isolated from the environment (which can only exist in fiction movies) external influences cannot be dismissed. Consequently, it raises the design challenge – how can the complex control system be simplified to let the operator be in control efficiently and accurately in a dynamic environment? With the support of industrial development, vessels accommodate to fit specific needs; therefore, they are designed and developed into diversity. These diverse types of vessels are distinct in size, shape, function, equipment, etc. Accordingly, bridges are specialized for every type of vessel in order to maximize usability.

The development of the maritime industrial is not booming consistently, but it never ends. Ship companies and organizations are always seeking for new solutions. Other than existing equipment, what is the future? There are several trends in maritime, which

Forlizzi, J., & Ford, S. (2000) and the UX white paper present a framework of successful UX components: context, user and system (product).

**Context:** UX may change when the context changes, even if the system does not change. The larger context here is the maritime domain while the physical context is the tugboat bridge.

**User:** UX is dynamic, as the person experiencing the system is dynamic. This refers to, seafarer, specifically the tugboat captain, his motivation to use the workstation, his mood, current mental and physical resources, and expectations.

**System:** A user's perception of the systems properties naturally influences UX. Important for UX are the properties designed into the studied system, the properties that the user has added or changed in the system or that are consequential of its use, as well as the brand or manufacturer image. It means the bridge workstation and its built-in automation system.

The research of this thesis therefore is about studying UX in tugboat bridge operations from both pragmatic and hedonic attributes by means of the framework “user, context and system”. The objective is to observe user’s action to know “what” and “how”, and also to understand the motivation “why”. However this study will not cover these three facets equally. With the consideration of them all, the research will focus on the user and their context.
may indicate the possibility of the future.

Environmental concerns. Due to the foresight of energy shortage and the appeal of environmental protection, the new generation of ship design and development are seeking a way to solve environmental issues. In Europe, there are many projects that are funded and promoted to find new solutions. For instance, the EU-funded BESST\(^4\) project was launched in Sep. 2009. This three-and-a-half-year project will consider space optimization and easy maintenance, improved payload and gross tonnage ratios, cost-efficient building and refurbishment processes, improved energy efficiency, and reduced emissions, noise and vibration among others. Another project EfficienSea\(^5\), which began in late 2008, aims to improve maritime safety and the environmental state of the Baltic Sea region through more sustainable shipping. And following the success of an initial program, a joint research project led by marine engine builders MAN Diesel and Wärtsilä, HERCULES-Beta\(^6\) continues to look at ways of reducing CO2 emissions from maritime transport. Its ambition is to reduce fuel consumption by 10% by improving engine efficiency by more than 60% by 2020. These projects can be seen as good examples to show the concern about environmental issue in the maritime context.

Markets globalization. Business is becoming more and more globalized. Safety-and-shipping report\(^7\) shows seaborne trade continues to grow rapidly, playing a critical role in connecting the global economy and driving economic prosperity (see figure 3). The ship industry is strongly influenced by this globalization. In many cases, the components are designed and built separately in different organizations/places/countries and are assembled together in one place. Market globalization has led to longer distance voyages. It raises design issues of ships as they need to consider a wide range of environments. Ships should be able to acclimatize from tropic to arctic area. The Safety-and-shipping report also mentions another issue of increasingly multi-national crews. Language barriers are cited as potential risks, given the dependence on English as the 'language of the seas'. Concerns have been raised about communication in an emergency.

Multi-purpose vessel. Vessels are becoming multi-purpose. Increasingly vessels need to carry out multi-tasks. It requires the vessels to be versatile to cover a wide range of uses. Although "multi-purpose vessel" is not a new term, we can see its increasing need. The varying operational needs of a multi purpose vessel bring new challenges in designing, building, maintenance and operations of the vessels.

3.2 Maritime Safety

Safety is always a vital issue in the maritime domain. Both shipping companies and seafarers are strongly concerned about the ships safety, as they cannot bear any loss. The tragedy of the "Titanic" is not just a sad story seen in the cinema. This event and many like it happen. The complexity of the sea environment makes a safe voyage uncertain.

\(^4\)Breakthrough in European ship and ship building technologies project \hspace{1em} http://www.besst.it
\(^5\)Efficient, safe and sustainable traffic at sea \hspace{1em} http://www.efficiensea.org/
\(^6\)Higher –efficiency engine with ultra-low emissions for ships \hspace{1em} http://www.hercules-b.com
\(^7\)http://www.agcs.allianz.com/insights/white-papers-and-case-studies/safety-and-shipping-report/
Especially when vessel operations require a skillful captain with experienced knowledge, a small mistake may cause a catastrophe. It was not until 1912 when the Titanic sank on her maiden voyage causing over 1000 deaths that the shipping community took safety as a major priority, which led to the Maritime Distress and Safety System. Numerous rules and regulations are made for both the ship equipment and operation behaviors to guarantee the vessels safety. However it is not only regulations; marine training and technologies are improving constantly (see figure 4). These efforts lower safety risks. People hope to avoid a similar tragedy happening again. Among all the improvements, the biggest, or the most successful one within the bridge is the introduction of automation systems. The automation systems take a lot of respon-

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8(from Wikipedia) The Global Maritime Distress and Safety System (GMDSS) is an internationally agreed-upon set of safety procedures, types of equipment, and communication protocols used to increase safety and make it easier to rescue distressed ships, boats and aircraft.

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Figure 4. Key milestones in maritime safety since 1912
(the safety and shipping report)
3.3 Tug Boat

A tugboat is a boat that maneuvers vessels by pushing or towing them. A tugboat is responsible for many tasks such as escort, towage and icebreaking. Its underwater design and hull lines, propulsion system and also mass distribution and winch arrangements have a significant effect on “suitability” for the various tasks (see figure 5). Therefore, tugs are very different in design for performing the various tasks.

![Figure 5. Tug types (http://www.bube.no/Home)](http://www.bube.no/Home)

For ship companies, crews are usually the biggest expense for a boat. So companies prefer to minimize crew numbers. The minimum number of crew on a tugboat is three, including a captain, a bosun and an engineman. In most of the cases the captain takes the tugboat bridge operation alone.

With concern to the bridge operations, a tugboat bridge is relatively small (compared to other ferries). It is usually the size of a normal room; however, it is an important place where many monitor and control systems (winch control panel). A forward maneuver station is located in the fore of the tugboat bridge, where the tugboat pilot who was distracted by a family emergency call when he was steering the barge.

Gcaptain\(^9\) discusses the danger of technology on a voyage. The article\(^10\) points out that the technology on board ships have two aspects: it can create unwelcome distractions, leading to casualties; and duty officers are at risk of being exposed to excessive information and simply being unable to process it all.

It is usually the human error, instead of the machine, that causes shipping accidents. Nevertheless, we cannot simply blame duty officers who for the final incident. According to the NTSB. (1997), humans are poor monitors of automated systems; humans tend to rely on warning systems and not manual checks. Lützhöft, M. H. and Dekker, S. W. A. (2002) emphasized, automation creates new human weaknesses, and it amplifies existing ones.

After Hutchins (1995) conducted a field study on naval vessels, he argued that tools often couldn’t enhance the officer’s ability to do a particular task. More often than not they recast the problem in a different representation that simply sidesteps the need for that task to be done. This means that the tool is often better understood as a notational or representational device. According to my understanding, it explains the drawback of existing automation systems. New technologies in the bridge are considered as tools by users and so they cannot really solve any problem based on human cognition. Bjorneseth, F. B. (2010) also mentions that human element plays the leading part in an accident and it is mostly because of the cognitive load. She gives a suggestion that by caring for the human element at an early stage, expensive retrofitting with varying results can be avoided and will increase safety.

All these safety-related studies give a hint that it is vital to deal with the relationship between humans and machines in the ship bridge design. By caring about user experience, it makes the user and system chime together, which can benefit this safety-critical environment.

\(^10\)Gcaptain, http://gcaptain.com, a famous maritime and offshore news blog
\(^11\)http://gcaptain.com/technology-ships-dangerous-warns/
The aft deck operations require optimal views. Bridge equipment is ever evolving, but now typical bridge house solutions (not restricted on a tugboat bridge) are equipped with the following main systems:

- Manoeuvring chair/controls
- Propulsion controls
- Conning/instruments
- Winch chair/control system
- AH Navigation system
- Radar
- Electronic Charts Display & Information System (ECDIS)
- CCTV
- Radio Communication

Beside these two workstation bridges, there are many tugboats having only one workstation system, which integrates those two workstations together. The integrated system is advantageous for one person to operate. On design matters, the tugboat bridge workstation doesn’t change that much. By looking at a collection of tugboat bridges from the last 30 years (figure 6), it can clearly be seen that the appearance of bridge (and bridge workstations) has had no significant improvement. These tugboat bridge designs follow the same principles. They are all heavy steady workstations, with straight lines, flat metal surfaces and regularly organised consoles (buttons and meters). The design is still “old fashioned” and needs to be radically changed in terms of following technological development and enhancing user experience.

Figure 6. The bridge design evolution of tugboat

12 The source are original from http://www.offsim.no/eng/Products/Offshore-Operation-Simulator
4. USER STUDIES

The user studies in this thesis work include various activities. The target user is a seafarer (captain) who operates a ship. It is a small group of people and they are hard to get in touch with. Luckily in this “operation on future ships” case, researchers were able to connect with a handful of ship companies and finally conducted two field studies and two in-depth interviews with the support of Rolls-Royce Marine.

The author himself conducted the user studies included the three components – users, use context and system, but with a focus only on users. Although this thesis work only refers to tugboats, user studies included other kinds of vessels such as supply vessels and cargo ships. So in this user study, users are seafarers who have work experiences in bridge operations; the context refers to the bridge environment; and the system is about the bridge workstation and its automation system.

In this thesis, the author recorded four user studies, which he participated in (see figure 7). The user studies covered three types of vessels and used methods such as observation and interview. Participants include a tugboat captain, a captain trainer, an ex-captain and a human factor specialist.

The user studies on different types of vessels can bring comprehensive knowledge in relation to bridge operations. Also, the way of comparing bridge operations on a tugboat to operations on other vessels is a good reference in terms of design for tugboat bridge operations specifically.

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<th>User study 1</th>
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<tr>
<td>Vessel type</td>
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<td>Location</td>
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<td>Participant</td>
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<tr>
<td>Participant’s Background</td>
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<td>Research methods</td>
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| Research objective | To get the knowledge about  
- The procedure of a normal tug task;  
- Collaboration and communication between the tugboat and others, e.g. the vessel that is tugged;  
- The interaction between seafarer and workstation. |

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<th>User study 2</th>
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<tr>
<td>Vessel type</td>
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<tr>
<td>Location</td>
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<tr>
<td>Participant</td>
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</table>
| Participant’s Background | - has broad experience from the offshore industry  
both in DP and in all kinds of operations, like,  
anchor handling, subsea construction vessels;  
- 15 years offshore as working himself up to captain  
in the end. |
| Research Methods | Field study (observation and interview) |
| Research Objective | - understand the operations happening in supply vessel bridge;  
- identify mariners experiences on operations;  
- compare the operation differences and similarities of supply vessel and tugboat. |
4.1 Methodology

4.1.1 Ethnography

Ethnography, as Brewer (2000) describes, is a study of people in a naturally occurring setting or “field” by methods of data collection which capture their social meanings and ordinary activities, involving the researcher participating directly in the setting, if not also the activities, in order to collect data in a systematic manner.

Ethnographers are required to respect the culture and people without culture bias. They need to participate in this setting or “field”, to study and to understand people's behavior in this culture. So usually, ethnographical research takes a long-term study, to fully immerse into the culture combining observation with participation.

In UX design, users are located in the core position. For the purpose of gathering user data, ethnography is a most suitable method. In the maritime context, it requires researchers to fully immerse into the domain by means of ethnographic studies. Researchers who have a limited knowledge in the field may find it difficult to grasp a firm understanding of ship operations due to the strong expertise required.

However, in this safety-critical environment, the restrictions limit the way of carrying out a user study. For instance, no one other than crew members can stay in the bridge on a working tugboat. The preliminary research plan was revised many times based on the negotiations between researchers and the participants’ companies. Unfortunately, the long-term user study plan and the participatory under work situation were unachievable; instead, two one-day field studies were executed. In spite of the limited duration of this study, it was still based on how an ethnographer would go about that task. Wolcott (1990) describes that when the observations are only a small part, where the results are needed to gain a fuller insight in how a specific environment functions so information can be utilized to develop products or similar matters. It can be described as micro-ethnography.

The objective of this ethnographic research attempts to:
1) Understand bridge operations;
2) Compare the similarities and differences between tugboat operations and operations on other types of vessels;
3) Find the seafarers needs (including both pragmatic and hedonic needs) within bridge operations.

4.1.2 Field studies

The field studies are a way of collecting empirical material concerning the navigation and transportation demands on vessels. It is always appreciated to get more real life experience and knowledge of the bridge environment and the actions happening in this environment. The field studies were done on a tugboat and a supply vessel.
The preliminary plan was that researchers were to be observers in the bridge and would video record bridge operation activities, in the aim of observing seafarers' natural activities and later reflecting the crew's experiences together. As mentioned before, for many issues, this plan was changed. Ultimately it was agreed that researchers would be able to stay within the bridge at a non-working time. This meant that the company prepared a tugboat pilot voyage and a supply vessel operation simulation. Researchers carried out field studies of the pilot voyage. Although the study didn't reach expectations, it was still a benefit. In such a condition, researchers observed operations and experienced the bridge context directly. This also led to an opportunity to communicate with the seafarers freely. This immediate feedback engaged researchers to enquire about even small actions, which led to a deeper understanding about the reason behinds it. In other words, researchers did observations and interviews at the same time.

4.1.3 In-depth Interviews

While ethnographic observation aims at gaining people's natural behavior and attitudes in the way of avoiding any influences from the observer, interviews are intended to access respondents' perceptions, attitudes and values by interviewers and interviewee having a discussion and interaction. Moreover, in-depth interviews encourage interviewers to learn everything that interviewees might want to know and share about the topic. Hence, interviewers gain in-depth insights. This qualitative technique is effective when the researcher seeks information concerning personal matters, like individual's life experience, values and cultural knowledge about the particular events and phenomena, as well as the insights and methods they use to interpret and order the world (Gubrium & Holstein, 2002).

Usually in-depth interviews are conducted face-to-face and involve one interviewer and one respondent. During the interview, the interviewer is required to engage with respondents by posing questions in an unbiased manner, listening attentively to the respondent's accounts, and constantly posing following-up questions. During the interactive process, the interviewer and respondent together create the shared knowledge through the ensuring discussion (Gubrium & Holstein, 2002). It is not only the content they say, but also the respondents' accounts. Respondents' accounts can be interpreted as the cultural way of packaging experience or self-expression, rather than the evidence of their real experience (Silverman, 2006). Interviewers thus need to pay attention to how the respondents respond— their expression, tone and mood. Accounts should be seen as situated practices which are “local accomplishments” invoking a sense of social structure.

There were four interviews done in the user studies. Three of them were in-depth interviews including a tugboat captain, a bridge simulator trainer and a human factor expert. One pre-captain interview was done via email. Interviews were tape-recorded (except the email interview) and the transcription was written based on the recordings soon after the interviews.

4.2 Tug boat visit

The tugboat is called UKKO (figure 8). She is parked in a harbor in Naantali, a small coastal town in western Finland. The harbor belongs to Neste, an oil company, and is the only tugboat there. She doesn't have many tasks except one or two escorts every week. This was a one-day field study. The research group, including a designer (the author), three researchers from VTT and two workers in Rolls-Royce, were able to be in the bridge and observe while a tugboat captain was performing a pilot voyage. As mentioned before, researchers acted not only as observers but also as participants. The tugboat bridge is a one-man, modern, 10-year-old, integrated ECDIS cockpit bridge. Figure 9 shows a simplified layout. Huge glass windows from ceiling to ground surround the octagon-shaped bridge. The captain's chair is located in the center and has workstations nearby. The whole workstation is painted red, with black consoles on it. The Workstation in this bridge is a combination of maneuver and aft control workstations. It is divided into four parts; two main parts are located on the ground while the other two consisting of communication components are mounted on the ceiling. They all allocate on either side of the chair. In this way all information such as radios, radar and charts are collected around the captain once he sits in the chair. It is convenient for the captain to access all operations. A captain doesn't even need to move from the chair.
This field study started when researchers reached the ship at the harbor. The ship was parked and waiting for the upcoming voyage. The captain first gave a short tour of the boat and then ended at the bridge. The following paragraphs are based on the author's observation of the operations in the bridge and the captain's explanations:

The captain didn't sit on the chair in the beginning; instead, he stood behind the chair and made a call using the radio (The dialogue is in Finnish). It was like an announcement or a request to the harbor service that he wanted to start a voyage. After being accepted, he then did a series of checking operations and explained, “I was doing some preliminary tests when I was speaking there and going through a check list that we have prepared for departure. Now as I'm only doing operations here in the harbor area I use a shorter checklist, so to say, no passage planning… We have prepared passage plans on ECDIS, which we use.” As an experienced captain, he doesn't need a written down checklist. He has the list memorized.

He detoured from the side of the bridge station to the front and sat in the captain's chair. The operation is set up so that feet control some functions. “It (the chair) has two pedals down on the seat; the left pedal is for the winch, the right one for the microphone, so I don't have to take my hands off the rudders. And you make contact with the vessel already before you connect the tug and all the time during operations…” The captain showed his appreciation of this design detail.

There were many apparatus for communication integrated on the workstation, for instance, VHF\textsuperscript{13} DSC\textsuperscript{14} for communicating with the vessel, MF/HF\textsuperscript{15} DSC for long distance calling and radio telephone. Beyond that, much of the communication that happened on this boat was nonverbal. As it was observed, in the departing phase, the captain and the bosun used gestures in communication. For instance, to give the signal of releasing the rope, the captain and the bosun used some gestures to indicate the status. It was after the captain had done the checklist, he directly looked backwards through the window and saw that the bosun was standing on the stern already waiting. He then gave the bosun a gesture signal; the bosun replied a nod to indicate signal received. Then the bosun released the rope, which on stern board ties the boat to the harbor.

Once the rope was released, the captain started moving the stern away from the harbor while the sailor moved to the bow. They did the same nonverbal communication again and the bosun untied the rope on the bow. Afterwards the captain operated and explained: “What I’m doing now is so called slow sidestep, so I’m moving the vessel sideways”. In this session, he paid attention to watch both bow side and stern side of the vessel alternatively. This is demanding work and needs precise control to avoid collision between the boat and pier.

After controlling the boat away from the harbor area, the captain left the vessel sailing in auto mode. The automation system took over the control and the captain explained: “During normal cruising, when I go for example for an escort operation to Utö island, I run an autopilot and a track mode on the ECDIS so I only monitor the navigation… The most important thing is of course optical, so to say optical surveillance of areas around

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{tugboat_bridge_layout.png}
\caption{Tugboat bridge layout}
\end{figure}

\textsuperscript{13}Very high frequency
\textsuperscript{14}Digital Selective Calling
\textsuperscript{15}medium frequency(MF), high frequency(HF)
me, using my eyes. Then I use electronic charts, radar..." So in a usual operation, the 
captain would rather monitor the navigation than take the control himself.

The captain's explanation reveals how the role has changed since the introduction of the 
automation system on board and how seafarers interact with the system. The automation 
system has a significant advantage in maneuvering the vessel. It takes the responsibility 
to navigate the vessel sailing along the predefined route thus freeing the seafarer from 
the long-term manual work. Therefore the seafarer’s task changes from perceptual to 
cognitive – the monitoring.

However in this case, in order to show us the steering control, the captain left the auto 
mode and started to drive the boat manually. The tugboat had two engines at both side of 
the stern and coincidently has two joysticks to control them separately. On these aqua-
amaster vessels, joysticks are able to control the direction of propellers and their pitches. 
In one bridge, the captain can drive on manual with these two joysticks in such a flexible 
way that "The only limitation is your imagination." He then showed us how he interacts 
with those two joysticks. Joysticks are robust. They are designed to be held and can give 
haptic feedback to certain actions. So one doesn't need to keep an eye on it while control-
ling the joysticks. This captain put his attention more on the surroundings, sometimes 
with a glimpse onto the screens and readers to check his manual work.

An escort is one important task of a tugboat. As there was no other boat there for col-
laboration, the captain described how he carries out an escort. An escort lasts for hours. 
The bridge operation is usually easy work as it has routines and nothing special to do. 
However if something happens and situations become uncertain and complex, the es-
cort is relied upon. If emergency situations happen, the operations need to be done fast 
and instantly. Usually the tugged boat gives commands and the tugboat works as an 
assistant. The communication in such a situation also needs to be short and brief. The 
other boat gives a few words of command and the tugboat reacts immediately. Quite 
often an escort happens in bad weather, which increases the difficulty.

This tugboat captain, with years of experience, is quite familiar and proficient in tugboat 
operations. Although the consoles and workstation are full of buttons and meters, he 
had no trouble in using them in this pilot voyage and he operated the boat in a relaxing 
manner. From the talk he expressed his satisfaction of this bridge and the confidence in 
operating it. The satisfaction also comes from his participation in the process of design-
ing the bridge. He pointed out that the metal wire frames around the two front screens 
were added based on his suggestion. It is not for the utility but is to satisfy the captain's 
hedonic needs. Captains can feel more comfortable in automated mode by means of using 
the frames as a feet holder.

4.3 Supply vessel visit

This study was restricted from being a field research environment. Instead, it happened 
in a simulator center. The simulator center is a place where operators can get trained 
before they really go to a vessel and carry out real operations. The simulator center in 
this study happened to be located in Rolls-Royce training center, Ålesund, Norway. It 
is a class B simulator, which means that it is allowed to carry out certificate training for 
DP\textsuperscript{16} operations. Although it is a simulator, the bridge environment and the equipment 
are the same as in a real vessel. The sea environment outside the bridge is also simulated. 
This "field" study lasted half a day. It simulated a supply vessel in a task of offering goods 
to an oilfield. A trainer executed the task. He was new to work as a trainer but has experi-
cence in bridge operations.

The goals of the visit was to study the following issues:
- Characteristics of supply vessel work and the working environment;
- Supply vessel operations in detail, challenging situations and information needs;
- The bridge operation differences and similarities between supply vessel and tugboat;
- The existing and expected experiences.

The "bridge" had a large space. It had a maneuvering workstation positioned on the fore 
bridge and a DP workstation on the aft bridge (figure 10). Both workstations on fore and 
aft bridge had duplicate consoles and chairs. Usually two seafarers work together in a 
bridge for supply vessel operations. They work in cooperation with each other. The tasks 
are divided so that one does the manual operation while the other is on the watch. They 
exchange the tasks if necessary.

From the author's view, this modern "bridge" is designed well. The matt black work-
stations are situated on a gray wooden floor. Well-arranged consoles are integrated on 
workstations with the same sanding plastic material. This material gives good haptic 
feedback. With the entire workstation black, the white colored joysticks highlight them-
selves.

This simulation was set at night so the whole bridge was dimmed and all interfaces and 
buttons were in night mode. (figure 11)

\textsuperscript{16}(from wikipedia) Dynamic positioning (DP) is a computer controlled system to automatically maintain a vessel's 
position and heading by using its own propellers and thrusters. Position reference sensors, combined with wind 
sensors, motion sensors and gyro compasses, provide information to the computer pertaining to the vessel's posi-
tion and the magnitude and direction of environmental forces affecting its position.
The trainer simulated a task of delivering cargos from a harbor to an oilfield. He used to be a supply vessel captain and has years of experience. However, as only he simulated this supply vessel operation, the pattern of collaboration between two seafarers in the bridge cannot be observed and identified. This simulation task includes a process of three steps: steaming towards the oilfield, DP operations and returning from the oilfield.

Steaming towards the oilfield & Returning from the oilfield

Roughly speaking the operations of steaming towards the oilfield and returning from the oilfield are the same. According to the trainer’s introduction, the second person in a standard set up is mainly to observe. Therefore the first person will be operating the ship alone. In this sense, the operations simulated are very close to the real scenario.

The control in this phase is similar as the control set up on a tugboat. However the seafarer used only one joystick in controlling instead of two as seen on the tugboat. The joystick is located in the middle of the fore workstation. The trainer carried out the maneuvering whilst standing the entire time (figure 12). It was observed that he was relaxed, with one hand in his pocket.
The DP operation

When reaching the oilfield, it is required to transfer the operations to DP mode. At this stage it is compulsory for two seafarers to be on the bridge at the same time. The trainer explained: Since one seafarer is taking the responsibility of controlling the ship on the maneuvering station on the fore bridge and the DP workstation on the aft bridge, the other seafarer keeps surveillance moves to the DP operation. They communicate verbally to hand over command of the control.

Bjorneseth, F. B. (2010) recorded in detail about this procedure:

One of the operators is situated on the front bridge and one on the aft bridge.

OP 1 Front Bridge: "Are you ready to take over?"
(Operator 1 asks to assure that operator 2 is ready to acquire command of the vessel.)
OP 2 Aft Bridge: "Yes, ready."
OP 1 Front Bridge: "Giving you command"
OP 2 Aft Bridge: "Command taken"

Afterwards the operation shifted from maneuvering workstation to DP workstation.

The DP station consists of two redundant systems each with an operator chair. The chairs (or DP operation station) have all the necessary functions. On both chair arms, there are buttons, joysticks and small displays. The seafarer is able to do all the DP operations on the chair. This was proved in the observation.

The most challenging situation usually happens when the supply vessel is close to the oilfield. The vessel must keep still in order to avoid the vessel from colliding with the oilfield. Keeping the vessel still also makes it more convenient for the loading/unloading cargo. The DP operation works here as it is a computer-controlled system to automatically maintain a vessel's position in a dynamic environment. The trainer used the joystick in the DP operation too. However the logic behind it is that these controls are received as orders to the DP system. The system visualizes the result on the screen. Once the user confirms the result, the DP system controls the vessel reaching the exact spot with referencing such as current and wind. Obviously the DP operation is slow but precise.

Communication is important in the operations. It is not only limited to the two seafarers in the bridge, but also between the rig and the vessel. It already starts in the 500 safety zone where the trainer made contact with the rig. He needed to get the command for every step, especially when loading or unloading the cargos. They need to match the position properly for a safety rig operation. In this simulation, the conversation transpired as follows:

Captain: Do you want me to get a little bit closer?
[Man on the radio answers]
Captain: I can take it 10 meters closer. A little bit more stern, a little bit more portside.
[Man on the radio answers]
Captain: Okay, I’m moving port now.
Captain doing DP operations
Captain: Are you happy with the position now?

The captain’s chair itself is a small and integrated workstation. So basically the seafarer can access all necessary functions with the consoles and the small screen on the chair. However the observation shows this trainer prefers to use the big screens on the workstation in terms of operations. Although it is a bit far to reach, he bowed and stretched to touch the controls to carry out the operations on the big screen.

Inside the bridge there are many displays providing all kinds of data to seafarers. As he mentioned, some references are important and helpful, like GPS and the positional reference, which he usually read during operations. However in this simulation, the author noticed, when the boat and rig were close, the trainer focused all of his attention to watch the distance directly through the windows instead of checking the data from the displays.

The simulation task was carried out very well. However when we talked to the trainer, he shared some challenging situations he had experienced in the past. Weather is the biggest limitation in most cases. High wind and waves are challenges. “We had an incident with that (the vessel touched the rig), then in the worst case, you get like a vessel hooked up in the wires going down and staying there for bad weather and hit it for a long time; you got a hole in the floater you can say and it’s bad.” He had carried out many operations in fog, where he didn’t have a good view outside. According to his experience, he can do the task if he can get a view of 150 meters in any weather. Otherwise he will wait. Most of the time, it is slow and boring. Seafarers should be patient and keep their focus. The trainer stated, “It’s a difficult question actually to motivate the DP operation. They just have to understand what the responsibility is and how you normally operate it… You do one hour, sitting doing the maneuvering and the DP… And if you don’t manage to focus on your job for one hour, then you should find another job really.”

From this “field” study, the author identified the supply vessel bridge operation including two patterns that are maneuvering and the DP operation. They require different capacities but are both based on joystick and screen controls. The maneuvering operation part is quite similar as the operations on a tugboat. Seafarers usually operate confidently because they are very experienced; but the boredom issue is unavoidable in many tasks. The differences between tugboat operation and supply vessel operation are identified, as the author sees, based on the context and ships utility. Operations on a tugboat are flexible and complicated. It is usually more intensive than the one on a supply vessel as usually tugboat needs to do operations in an emergency situation while operations on supply vessels require more slow motion to avoid dangers (such as in the DP operation). However operations on a supply vessel requires a strong understanding of the system, as seafarers need to have more interaction with the system via screens in the DP operation.

4.4 Ex-captain Interview

An interview with an ex-captain took place after the field studies. The ex-captain said
that she used to work on offshore vessels such as cargo vessels and has over 20-years experience in the field. This interview was done via email. A questionnaire was sent to the interviewee, which covered the following issues:

- Characteristics of cargo ship work and working environment;
- Cooperation and communication;
- Challenging situations she has had to overcome;
- Her experience in the operations.

Her answers and opinions were written down and sent back to interviewers by email. Several key issues were clarified after comparing the field studies to this interview.

**Time & efficiency**

The operations on a cargo ship need to be efficient. A cargo ship is responsible for delivering goods for companies. From a company’s perspective, the first factor is the economic efficiency. Therefore time is the key issue here. Accordingly, the core tasks of cargo ship captains are to keep the schedule at the lowest cost while making sure the ship is safe. So seafarers often need to make fast actions in order to save time, especially when there are some extra forces limiting the operation period, for instance, tides.

**Local knowledge & communication**

She emphasized the challenges of navigating in shallow and narrow waters. This situation requires the captain to have knowledge of the tides, current, local traffic etc. Cargo vessels travel from one port to another so it is beneficial to be able to obtain knowledge from local pilots and harbors. Heavy traffic areas are always a big challenge. It brings huge risks. When passing by the heavy traffic area, captains must have their full attention on the task and often it requires quick judgments. In such an environment, communications between vessels and the harbor are critical.

**Expected experiences**

The bridge on a cargo ship is commonly located on the top of the engine room. The engine runs and causes lots of noise and vibrations. These things cause negative experiences to a seafarer. Alarms can also be a problem. The captain has had bad experiences in frequent non-essential alarms. For example, the anti-collision alarm can sound continuously when approaching a port. She expects a silent, vibration free bridge, with a good view and easy access to the equipment.

4.5 Human-factor expert Interview

Froy, the human factor expert in Rolls-Royce Marine, has put her efforts into studying and taking care of seafarers’ experiences in bridge operations. She did her dissertation on human machine interaction in the marine domain. Afterwards she worked in Rolls-Royce Marine and has participated in many bridge design/development cases.

The researchers conducted an in-depth interview with her. The interview lasted for two hours and gathered fruitful information. She considered the maritime industry to be generally around 5 to 10 years behind technology. One major problem within bridge design is that it lacks an overall plan, as different equipment providers install their products separately. This factor increases the complexity of bridge operations. Ship companies and seafarers have different needs towards a bridge design. Companies look at the design from an economic perspective. Crews are a large expense, so companies are always trying to minimize the number of crew on board. Companies are looking for high technology; highly automated systems on the bridge in terms of reducing the amount of operators. Unmanned vessels and remote controls are two topics they are interested in. The crew cares about how they can use/interact with the workstations. They are afraid of things happening behind their backs. In this sense, they are a bit old fashion and hesitant to use the latest technology.

In her research, she realized that although designers want to make their work more comfortable and easy, seafarers could not give qualified opinions and support in user studies. Seafarers are scared to tell details they don’t feel comfortable with, as they are afraid to be seen as lazy. Furthermore they don’t really care about aesthetics, they only want functions.

She also introduced the two design directions Rolls-Royce is working on now. Rolls-Royce is putting effort into having a common look and feel for user interaction components; and they are trying to simplify the control consoles (e.g. reducing the buttons, simplifying the control panels and the visual of the interfaces). These efforts will obviously simplify seafarers cognitive load and reduce operational mistakes.

4.6 Seafarers and bridge workstations – the user study findings

This user study gathered a mass of data about bridge operations in general and tugboat bridge operations specifically by means of field visits and interviews.

The sea environment as a large context is dynamic and uncertain. A Tugboat, as it is defined by its utility, executes the tasks of towage and escort. It presents itself often in narrow pathways and in bad weather conditions, which increases the operation difficulty. Among the three vessel types, which the research included, the tugboat is the smallest. The bridge on a tugboat is relatively small and is a one-man bridge. The bridge has a lot of equipment so they need to be well arranged. At present, it is a so-called integrated system, which packs all functions into one workstation.

In observations it was identifies that the best optical solution is appealing in every bridge. Captains need a 360-degree view of the sea. A one-man-controlled bridge is designed so that all equipment surrounds the seafarer for easy access. The optical solution is provided as such, the captain's chair is slightly higher than all the other equipment and all the bridge walls have huge glass windows. This solution provides a good 360-degree view, but does have problems in a handful of situations. As observed in the field study, while berthing the boat to harbor, the captain had to stand up and look backwards to the aft ship to be able to control the boat to attach it to the pier. In such a situation, the back of the captain's chair partly blocks his view (in the field study the captain insisted that this situation is totally fine to him; the author still thinks it is a potential risk). The chair is set in quite a high position due to the surveillance requirement. It causes some
discomfort for manual control and the screens in front of the workstation still block the view somewhat.

A seafarer is the only person who operates a tugboat at any one moment. This strongly requires the seafarer to stay at his duty position and be aware at all times. In such a work context, the bridge design should take care of the user’s hedonic needs such as a feeling of comfort.

Compared to operations on other vessels, the seafarers have less interaction with the system within tugboat bridge operations. They either do the manual operations or do surveillance (in auto mode). In manual operations, the seafarer interacts with the workstation mainly using the two joysticks, which act in a mechanical way to pass the orders to the thrusters. The operations based on those two joysticks are quite flexible and can provide a seafarer with many ways in terms of achieving a movement. However, the operations here rely on the seafarer’s experience. While in automation mode, the system controls the boat by itself. A seafarer has no interaction with the system except reading the references displayed on the screens. It doesn’t really help a seafarer to understand the situation once something has happened.

The author analyzed all the user study data by extracting factors of operations. These factors come from observations and interviews, and can be grouped into features of complexity, dynamism, and uncertainty (figure 13). Complexity refers not only to operation actions but also information input. Seafarers execute a task in accordance to all relevant information input such as task demands, company requirements, the traffic situation and the environment situations. They must consider all the information to succeed in the task by means of using the bridge workstation. The equipment has many user interfaces and is controlled by different way. Dynamism means the dynamics of the object of work in the maritime environment. Especially within the tugboat operations, situations change quickly under multi factorial influences. Uncertainty means the system related uncertainty (seafarers cannot understand exactly how the system works) and the environment related uncertainty, and also, information insufficient or information unawareness (seafarers cannot follow the right information at the right time makes information unawareness) cause uncertainty.

Tugboat operations include outside communication and collaboration between the tugged boat/harbor office and the tugboat as well as the inside interaction between the seafarer and the workstation. The seafarer and the workstation interact in such a way that most of the time the workstation executes the preplanned maneuvering operations whilst the seafarer reflects upon the surroundings and the reference data. The seafarer acts, only when something unpredicted happens or in an emergency situation. This can be considered as a joint cognitive system. A joint cognitive system, as Hollnagel & Woods (1983) defines it, is a single, integrated system composed of both human and artificial cognitive systems. When considering humans and technology form a functional unity, in practice, this implies that the bridge (include the bridge interior and workstation) and operators are one united system. So the design of this system requires considering varied inter-related elements, such as: physical settings, learned meanings and notions, communication practices, usability issues in used tools and so on. It especially needs to identify the decision making/problem-solving requirements in this domain (Woods, 1986).

![Figure 13. Features of bridge operation.](image-url)
4.1.1 Problems of the existing system

The bridge workstation tends to be more and more integrated and automated. It reduces seafarer’s manual workload in a sense. However, “the difference between consumer technology and industrial technology is often the safety-critical element” (Bjornseth, 2011, p.24). Hollnagel & Woods (2006) states: “ironically, more autonomous machines have created the requirement for more sophisticated forms of coordination across people, and across people and machines, to adapt to new demands and pressures”. In tugboat operations, the highly automated workstation transfers the interaction of seafarers and the workstation into another way. A seafarer has less manual work but takes more of a cognition load. Sweller’s (1988) cognitive load theory explains the consequences of an increased cognitive load leading to errors and accidents. As the operations are complex and dynamic, it requires the bridge workstation to keep on detecting references and reflect them to operators. In a common view of bridges, meters and screens usually surround the operator. They have to be aware of the data while surveying the surrounding sea of the ship. The operator’s cognitive load is on a high level and then the load can easily become excessive when the stress level increases (Bjornseth, 2011, p.24). Many researches (e.g. Lutzhoft&Dekker,2002; NTSN,1997; Sweller’s,1988; Reason,1990; Dekker&Woods,1999) show that humans are poor monitors of automated systems and humans are the main cause of many automated related accidents. This explains why human errors are a main cause of maritime incidents (e.g. Environment International Ltd., & Washington Oil Spill Advisory Council. (2008) shows human errors are the secondary cause of vessel-related incidents and spills that occurred within Washington waters.)

Another issue is how thoroughly the seafarer can understand the working process. As high technologies are utilized on different ship equipment components, workstations have updated. The station system takes more responsibility from seafarers. In spite of this, it is still the seafarer who makes the final decision. Facing the dynamic and uncertain situation, the core thinking relies on the human. However since machines detect the environment and display the transferred data to seafarers, the referencing data becomes only numbers. If the operator doesn’t know the abilities of the machine, he cannot make the right decision in situations. One example is the grounding of the Royal Majesty. The accident happened because of a lack of coordination and miscommunications between humans and machines, which evolved and deepened over time (Lützhöft& Dekker, 2002). One reason behind it was that the seafarers relied to heavily upon the equipment. They didn’t know the limitations of the machine. It is understandable; perhaps the only person who knows the machine best is the engineer who creates it. In the maritime domain, seafarers have the knowledge of many facilities, for example, GPS, as they have been using it for years. However, seafarers must keep up with new technology and new equipment. Seafarers tend to on their experience in many situations instead of using technology. As the studies show in this thesis, captains state that the references from the machines are important, observations (by looking through the window directly when doing manual operations are even more critical. The data presented by equipment acts as an extra support. Woods (1986) gives a suggestion of how to redesign the joint cognitive system: “using computational technology to aid the user in the process of reaching a decision, not to make or recommend solutions”.

4.1.2 Demands for a new system

Derived from studies in this thesis, the demands of tugboat bridge operations are addressed naturally due to the identified features.

1) Natural human-machine interaction. As mentioned before, the existing operation patterns on a tugboat bridge are either that the work is automated or seafarer takes the controls manually. Either one presents a situation where the existing interaction between seafarer and workstation is poor. The interaction needs to be increased in order for the seafarer to have a better understanding of the working process.

2) Information awareness. It is in no doubt that seafarer needs to be aware of the information displayed by the system. The information, such as gps references, current and wind give support to some extent for a seafarer to make the right decision and to avoid possible danger. Two issues occur in present bridge systems. The first is due to the complexity of technology and the dynamism of the environment. There is too much information displayed to the seafarer and the data is constantly changing. The information causes the seafarer to lose awareness easily. The second issue is that the seafarer may feel bored or fatigued on a long voyage, which again can lead to a loss of awareness. This is dangerous as operations are dynamic and uncertain.

3) System flexibility. The complexities of the operations require a system to be suitable for different operations. The system should be better at adjusting itself in terms of finishing tasks efficiently and quickly. This refers to two levels: on a system level, does the interface and UI need to be changeable for one or several operation tasks and on a bridge level, whether the stable workstation is the best solution for varies tasks.

4) Human–Environment system harmony. The operator, the machine and the environment are balanced and coordinated. Together there should be resilience, affordability and communication. On the one hand, seafarers shouldn’t be isolated from the sea, they need to feel as if they are one with the sea; on the other hand, they shouldn’t be strongly influenced by the environment, such as in bad weather. The system should still be able to finish the work efficiently. When seafarers change shift the workstation should be able to rebalance in order to finish the tasks successfully as seafarers may have different levels of expertise and different preferences in carrying out operations.

5) Readiness to act. Due to the uncertainty of the task the tugboat must be able to respond and change quickly. The tugboat should be ready to act as it can have the majority of the responsibilities in emergency situations. This requires the bridge system to gather data in real time so it can better anticipate the next steps and carry out actions quickly.
5. UX DESIGN

5.1 User Experience Targets

A User Experience Target is one or more experiences, which a designer wants to address in a product. These experiences are preselected and are the directions that the design wants to achieve. Wright et al. (2005) states that we cannot design an experience; instead, we can design for an experience. The UX target method is a way to design for an experience. By using a sensitive and skilled way of understanding our users, UX targets are used as guidelines in designing products. It helps the designer to keep track and make sure the final product will bring the right experiences. There hasn’t been many theoretical frameworks about UX targets until now. However it has been used in many user experience design cases (e.g. Laschke et al., 2010; Roto et al. 2012 Rocla case @ Nordic*CHI). Roto et al. (2008) mentions that in Nokia they also use UX targets (although the paper only refers to the evaluation session). The name varies in articles. Some researchers mention UX goals or UX requirements. They are used in the same way and follow the same principles. Within the UXUS program, these are called in one term “UX targets” and are used in different cases.

UX targets were set within this thesis based on three criteria: the users expected experiences, critical experiences in the maritime domain and the author’s UX vision. After user studies it was clear to see what seafarers wanted within the bridge operations. There are positive experiences they have (or are willing to have) and negative situations/feeling they would like to avoid and reduce in the future. These findings can be concluded to be user expected experiences. In this bridge operation industry some factors are more crucial than others. Many studies have elaborated the important factors. These factors can be identified as critical experiences. Sometimes in one concept it is impossible to cover all the expected experiences; thus, the designer’s vision is the last criteria.

In this concept design the author chose two UX targets:

1) Sense of control. “You have to have the sense of control for the whole operation (tugboat captain interview)” “get the feedback from joysticks (tugboat captain interview)” “feel the boat’s moving (tugboat captain interview)” “(I prefer a) bridge where all functions & screens are easily accessible and visible from the captain’s chair (ex-captain interview)” “they (seafarers) are afraid of losing control to technology; they are afraid of things happening without their knowledge (human factor expert interview)” Seafarers need to be in control of the ship and they require natural human-machine interaction. The UX researchers found that autonomy and competence is a source of a positive experience while using technology (Hassenzahl, 2008; Sheldon et al., 2001). In the bridge operation, autonomy and competence can appeal to the sense of control. The maritime domain is a safety-critical environment. Enhancing the seafarer’s sense of control can benefit safety issues.

2) Feeling of comfort in using technology. Comfort here refers to hedonic needs as it calls for a focus on the self. Bridge operations are a combination of goal-oriented situations; pragmatic attributes (e.g. functionality) are the core demand. However, both hedonic and pragmatic attributes, must be taken into account for creating a fully satisfying product experience (Diefenbach & Hassenzahl, 2011). Hassenzahl (2003) states that only the product, which provides at least some opportunities for being related to the self, is likely to be truly appreciated. This emphasizes the importance of hedonic attributes. Seafarers expect a “silent bridge, vibration free (ex-captain interview)” and “integrated interface (human factor expert interview)”. The messy console and interfaces easily lead to an uncomfortable operation experiences. This is especially true in fast action required situations where this uncomfortable operation is a risk. Many researches and the studies in this thesis show that seafarers are in a high cognitive load in operation. This cognitive load can easily be pushed too far in an emergency situation and cause seafarers’ psychological discomfort. On a long voyage, seafarers suffer boredom. All of these situations address the need “feeling of comfort”.

5.2 Concept design

The design of the ship bridge operations in this study is classed at three levels: the bridge as a whole (meaning the layout and arrangement of the whole bridge), the workstation design (including all the consoles) and interface design (specifying the access to all functions). As a reflection of the user studies, the design in this thesis is limited only on the first two levels, and with a focus mainly on the workstation design. It requires a detailed study and expertise about functions of all the bridge equipment to design the interfaces and is a task to large for a single designer. Thus this design won’t reach that level.

The design process includes a trend forecasting workshop, brainstorming, the initial concept, concept development and finalization.

Trend forecasting workshop

The objective of “bridge operation on future ships” case targets the near future. Therefore the design will be made on a conceptual level. The research group organized a workshop after the user studies. Many trends were collected and presented from interaction areas, collaboration areas, technology areas, future users and design areas. Group discussions within the researchers and maritime domain experts were conducted (figure 14). A few focused trends were selected to help predict the possible future of the maritime domain (figure 15).
Figure 14. Group discussions and voting of trends

Figure 15. The selected trends

Trend 1
Wearable interaction tools.

Trend 2
Real-time collaboration analysis & management.

Trend 3
“Object twitting” – Sensors everywhere in the environment.

Trend 4
Fluid interfaces: haptic technology enabling seamless, gestural, intuitive and ambient interaction between physical and virtual realms.

Trend 5
Physicality, embodied interaction.

Trend 6
Space, Spatiality and Proximity.

Trend 7
Simplicity

Trend 8
Context-awareness.
Brainstorming

As the design focuses on the future the research group did a brainstorming to get more ideas. The brainstorming was carried out with no limitations on ideas. Inspirations came from three sources: first, the findings of the user studies; second, the future trends, which were generated from the trend forecasting workshop; third, science fiction, such as space ship movies. These inspiration headings were developed in the brainstorming session and recorded for further use. (figure 16)

The list of ideas:
Non-screen bridge; Oral control system; Grass floor; Real plant wall; Transformable bridge; Transparent touch screen; Window display; Home-like bridge.

The initial concept

The trend forecasting workshop and brainstorming were group work and afterwards the author worked himself to generate the tugboat bridge concept. The concept came about by screening all of the brainstorming concepts with the following criteria:
Can it enhance the users “sense of control” or “feeling of comfort”?
Does it follow (or not go against) any of the trends within the maritime domain?
Can it be achieved in the near future (technologically and mechanically possible)?

The concept taken forward (figure 17.) was a customizable bridge workstation. It has two components that can both be moved along the tracks. Seafarer can adjust the workstation to either mode according to their needs. They can focus on the console or have their attention on surveillance tasks. The design aims to make seafarers more comfortable by minimizing the number of screens and adding plant slots. The minimization of screens and simplification of the information displayed reduce the cognitive load. Integrating plant slots into the workstation can give seafarer a way to relax.

Two pairs of conflicts

This design is dedicated to achieving the two UX targets. However, this may raise conflicts. In the maritime industry, User Experience differs from customer experience. Here the user refers to a seafarer while the customer refers to a ship company. Research indicates clearly that the company and seafarers have different perspectives. For instance, companies are concerned about economic issues but a seafarer is not. Whose need first should the design of the bridge equipment satisfy? When matching company's requirements first rather than the real users, some of the seafarers needs are ignored or neglected. Seafarers have a strong psychological need to feel comfortable. Companies take this into account only when it increases the efficiency of operations (which leads to economic efficiency), otherwise it is somehow neglected.
At the same time, the maritime domain is a safety-critical environment. Whether ship
companies or seafarers, they all deal with safety as a crucial part of the operations carried out. So the design has to take safety issues first and then the user experience. Especially when the hedonic needs may cause a potential safety issue. The design is trying to get a balance between the two perspectives. This means seeking the best User Experience while keeping safety and economic efficiency a priority. From the user studies and the UX targets, there are two pairs of conflicts in this design that need to be solved:

1) Cognitive load. In the bridge environment, seafarers are surrounded by a lot of information. This information flows by time. Seafarers suffer the problem of having a heavy cognitive load. As it was discussed in the previous chapters, this information-overload causes seafarer's psychology discomfort as well as raising the safety risks. On the other hand, the information is necessary for making informed decisions.

2) Boredom. It has been pointed out that seafarers are quite often bored on long voyages. The tugboat captain described that when he takes an escort task it usually lasts for around 6-7 hours but he doesn't really need to do anything except to be aware. However, neither the ship company nor seafarers themselves dare to provide any leisure/pleasure activities or facilities in the bridge. Any distractions to seafarers may lead to a mishap. However boredom has the potential cause a loss of awareness. In this study, the trainer said “if you don't manage to focus on your job for one hour, then you should find another job really”.

Concept development

The author aims to achieve the two UX targets, which include the feeling of comfort. One path is to reduce the cognitive load and boredom of seafarers. The development phase of this concept is to achieve a balance between the conflicts highlighted.

The cognitive load of seafarers can be specified in operations. In an automated voyage the seafarers’ main task is surveillance. They need to observe the sea surroundings as well as check all data displayed on the screens. At this phase, the data is the main source of seafarers cognitive load. They must keep aware of data to make sure that every facility is in the right mode and working well. While they are doing operations manually, the cognition problem is caused by console design. Every function has its own panel and needs to be controlled in a different manner. Such a messy and irregularly arranged console increases the seafarer's cognitive load as well as the low operation efficiency. One solution developed here is trying to simplify the messy information while keeping the important ones displayed clearly. The amount of screens should be diminished; instead, key information can be visualized on the front window of the bridge. In this way, seafarers don't need to gaze around among many screens and windows. They can be aware of data and sea surroundings at the same time. For consoles, it would be better to generate a common interface. This will reduce the seafarer's cognitive load and increase the control safety. As mentioned before, Rolls-Royce has started to explore this area. The concept is trying to think beyond the common interface to make the whole console flexible and customizable. This approach can enhance the experience of comfort as well as a sense of control.

The escort task usually last a few hours so it is the task which tugboat captains are most commonly bored doing. The idea is to provide distractions in the bridge so that seafarers don't feel so much boredom. However, These distractions should be provided and controlled carefully. They should in no way increase the safety risk. A preliminary idea is to provide the opportunity to plant something as a distraction. Furthermore, the bridge interior can be decorated to a higher degree. The decor can give seafarers a feeling of comfort as well as a small distraction. What's more, seafarers can have their nautical social network similar to facebook. This network can be displayed on the window to make sure seafarers still pay attention on the sea environment while using it. The benefit of using this network also includes enhancing knowledge sharing and communication among seafarers.

5.3 Concept Visualization

The design integrates the control consoles into a multi-touch system. Other than the automation system, seafarers have access to this designed system. They can customize the user interface by positioning, dragging and zooming in and out of every component interface on the surface (figure 18, figure 23). Physical buttons are still available, but act only as key functions and as a backup in an emergency situation. The whole bridge system works more as an assistant to seafarers. For instance, a novice navigator can set the system in a high automation mode. He can only allocate a few important functions on the panel thus the interface and operations are simple. In this situation the operator takes basic control actions with which he is familiar and lets the system take the main responsibility. In contrast to this an expert can have a much more complex interface in order to access all the functions.

Both the user interface and the workstation are transformable. The whole workstation can be integrated as one in the fore bridge or can be split into two pieces moving to both sides of the captain's chair (figure 19). The main display is located at the front window of the bridge. Instead of showing all information it only displays important data to seafarers. For instance the data can be shown in a star graph (figure 20) to minimize the seafarer's cognitive load.

The idea is that the workstation is designed to be part of the bridge design as a whole. The bridge needs to be considered not only as a small room for containing the operation workstations, but also as a work and living space where seafarers need to stay in most of their time at sea. In this concept the bridge includes nice wooden floors, well-designed lamps and a decorated ceiling (figure 22). These nice interior design elements don't help in the operations but can create a comfortable working environment.

The workstation has two slots for plants and integrates a plant water system in the pillars (figure 21). Seafarers can plant in their spare time or utilize the window display to relax (for live video chat and nautical networking).
Figure 18. Bridge control consoles. The control panels are touch screens. All the interface are flexible. Seafarers can add, remove, resize all the interfaces and position one on any screen.
Figure 19. The structure of bridge workstation. The bridge workstation is composed by same components. Thus, the station has two mode for different operation habits or purposes.

Figure 20. The star graph. This figure is an example of how the data can be displayed on the window. Six references can be connected and displayed as a star. If all the references are in the normal range, the point should be in the green area. (like the higher one) If one is abnormal, the point moves into the red area. Seafarers can notice the abnormal data with only one glimpse.

Figure 21. On both pillars, you can grow plants.

Figure 22. The bridge and the workstation.
Figure 23. The rendering effect of workstation concept.
6. User evaluation

6.1 Rolls-Royce Marine internal evaluation

The evaluation was carried out within Rolls-Royce Marine in Alesund, Norway. 11 Rolls-Royce Marine staff participated in this evaluation, with an average of 15 years working experience within the maritime industry (range from 1 year to 30 years). The evaluation was executed not by the author but by the staff at Rolls-Royce Marine. The tugboat bridge design concept was presented together with 9 other concepts (3 concepts each for tugboat, PSV and Supply vessel; these 9 concepts are the research group’s work) to the participants. Every concept is identifiable by their key features. The concept presented in this thesis shows two features: a customized workstation (the deformable workstation) and a flexible user interface. (Refers to the office/home like interior decoration and front window display for entertainment purposes)

The purpose of the evaluation was for Rolls-Royce to decide which concepts/features are successful enough to be further developed. The concepts were presented to participants in a document including pictures and descriptions. Participants then voted for the “good ideas” on a sheet for marking each feature.

The results were 9 “good ideas” votes to the customized workstation feature while there are were only 3 “good ideas” votes to the relaxing options feature. In general, this concept got positive feedback. Participants considered the customized workstation having great potential in use on the next generation of workstations from both the user and business perspective. They mentioned that the modular thinking of a customized workstation is good in terms of reducing cost from the company perspective. However they didn’t like the comfort feature. Participants were worried about the comfortable features leading to potential safety. They also felt that there was little to no benefit for the company.

In conclusion, the evaluators approached the concepts from the company’s point of view. They had a strongly positive opinion about the “customized” feature and a negative opinion to the “comfortable” feature in this concept.

6.2 Anticipated Experience Evaluation

Urban & Von Hippel (1988) has mentioned that lead users were successfully identified and proved to have unique and useful data regarding both new product needs and solutions responsive to those needs. As it was too difficult to recruit many tugboat captains for the concept evaluations, Rolls-Royce Marine approached a lead user. The author arranged a lead user evaluation. The “lead user” had over 15-years experience in the maritime domain with a no-limitation-captain-license. He is an expert in tugboat bridge operations and is currently responsible for risk management in Neste oil.

Other than the company internal evaluation with a focus on screening ideas, this evaluation focuses on evaluating whether users can sense the UX targets and whether users appreciate the experiences in this concept. The data of this evaluation can be used as a source for further developing a bridge operation concept.

Anticipated Experience Evaluation (AXE) was used for the evaluation (Gegner and Runonen, 2012). The AXE approach is for evaluating early product concepts with users. The approach utilizes opposit images as interview stimuli to facilitate the metaphorical thinking and reflection of participants. AXE is designed and developed by two researchers at Aalto University. It is based on the Attrakdiff method but becomes a qualitative method that can provide designers insights on how future users might experience and value a product or service concept. This is why it was chosen for this study.

This evaluation was planned and arranged into three sessions:

1) Concept introduction. The concept was presented to the participant in a way that the author explains his ideas with slides on a computer screen while the participant holds a paper document of the concept description. To get trustful data, the author needed to present the concept as objectively as possible. The paper document helps the participant get back to the concept in the evaluation easily. After the concept introduction, a 1:1 scaled paper prototype was then presented to the participant. The prototype was rough but it included all addressed features. For instance it shows how to customize the user interface and how to transform the workstation. These helped the participant to imagine the user scenarios.

2) AXE approach. When the participant had an understanding of the concept, he was asked to answer the AXE form. The form consisted of image-pairs and scales. The participant needed to first indicate the feelings he gets from the images and then associates them with the concept. The mark on the scale represents which feeling he associates more with the concept and the arrow indicates his preference. In this form the author modified the image pairs (provided by the method) by changing and adding 3 pairs, which could indicate the UX targets. In this evaluation, the participant was filling the form and was interviewed at the same time. Once a mark had been on one scale, he was asked to explain why he associated the concept more with image A instead of image B. Further questions were asked based on the participant’s answer, such as “can you explain in a more detailed manner what makes this workstation trustable?” and “why do you prefer humanity to technology?”.

3) UX targets evaluation. Finally, the UX targets were introduced to the participant and explained. The participant received a form where he gave the feedback and comments of whether he appreciated these UX targets and the way they are presented in the concept.

This evaluation lasted about an hour and the whole process was video recorded. The dialogue was transcribed afterwards. The data was analysis by using the method dis-
The evaluation transcription was partitioned into segments. In the analytical framework, segments were labeled. In perceived product feature parts, segments were mainly gathered on interaction, functionality and presentation aspects. The results show the participant appreciated the new interaction style but worried about functionality. He held a neutral opinion towards the presentation feature. However he also had contradictory opinions. For example he supports the simplified workstation presence but was against the unprofessional feeling, which was caused by the simplicity. Within the associated attributes panel, pragmatic needs contained more text segments than hedonic needs.

On the two main features of the concept, the participant appreciated the customized workstation feature because he liked the idea that users could interact differently in the new workstation. The customized and flexible settings could enhance his capabilities in operation so that he felt "convenient", "comfortable" and had a sense of "ownership". These feelings can refer to a sense of control and a feeling of comfort. However, the other features are considered "useless". He thought that it depended on the seafarer's personal habits of whether they will appreciate the plants and home-like decoration features. Furthermore, he was strongly against the distraction suggestion such of video chats. In his opinion, those distractions may easily lead to ship accidents, though, he admitted the situation is common which duty seafarers chat with their colleagues inside the bridge room.

All text segments can be categorized into positive or negative attitudes:

**Positive attitudes:**
1. The bridge design looks clean and simple.
2. A customized workstation is associated with comfort and autonomy. “You feel you are working on your own vessel”
3. The interface layout is clear. He feels the operation is well managed.
4. Flexible user interface panel simplifies the control. “I feel comfortable if you can move the information (the interface), as you told me, if I can move them to the places I need, I think that’s a good idea”
5. The display on the window to show critical info is good. “It is good that you don’t need to put your eyes to anywhere else if you have all the information on the window.”
6. When you get to understand the new technology, you feel a sense of mastery.
7. The workstation looks valuable. “To me, the workstation looks expensive and I think it is valuable.”

**Negative attitudes:**
1. It is a totally personal issue whether to have plants in the bridge, so the design isn't necessary.
2. Home feeling decoration in the bridge makes him feel like the workstation is an unprofessional environment.
3. He feels strongly against the idea of providing distractions to alleviate boredom.
4. As the design is new and looks futuristic, it raises the feeling of a challenge. He explained that he might change his attitude after using it for a period.

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Figure 23. Data analysis frame (Gegner and Runonen, 2012)
CONCLUSION

7.1 What is the benefit?

The maritime domain is a safety critic environment. Both seafarers and ship companies care about the safety issues and utility in terms of the bridge operations. Thus any idea should meet the safety needs first.

All the studies the author did in the past year help to identify the seafarers' existing and expected experiences in tugboat operations. The user evaluation outcome verifies that user experience design can bring benefit to this maritime domain. Seafarers do appreciate the design outcome and the design satisfies and improves their experiences in bridge operations.

The author used UX design methods to develop the concept. The design process from research, in the early beginning, till user evaluation makes a strong step-by-step case of how to make sure of a successful outcome. UX targets generated from user studies bring clear design direction. It is proved that at least in this case, by bringing UX targets from the beginning of brainstorming, and insisting those targets, the final design outcome will be positive and can bring the right features, which users expect.

The research done in this thesis shows that seafarers want a sense of control. A sense of control is probably the most expected experience. Seafarers have taken years of training to obtain the knowledge and experience of controlling the ship. They want to have this experience reflected when operating the bridge equipment. Seafarers are satisfied with the workstation when they understand the interface and information display, and can operate the ship smoothly and the ship moves as they expect. This is the be-goals and the reason why the seafarer is in the bridge and takes responsibility to control the ship. Furthermore, once the seafarer gets the sense of control, they can promise or they can have the confidence of promising the safety of the ship and crew. The feeling of comfort is an extra experience, which is usually not fully achieved within the bridge at present. This may be looked into again after seafarers obtain a sense of control and can be sure of any safety issues. The bridge operations are not continuously intense work but do last a long time. Therefore seafarers want to be comfortable in using the workstation and in the non-intensive operational periods. They need to be able to relax and reduce the pressure put on them by the operations.

The concept proved that one possible way to improve the experience is to change the
interaction patterns between seafarers and the bridge workstation. In this concept the console is designed to be flexible so that seafarers can customize it and also the data display is presented in a way that seafarers can interact with. These settings, can be seen from the evaluation, to improve the targeted UXs – a sense of control and comfort in using the new technology.

7.2 What did not work?

The design to improve the feeling of comfort in the non-intensive operation period doesn't seem to work (based on the user evaluation). The concept tried to embed the homelike decoration and some extra distractions in the bridge. As the evaluation shows, it does not work, and even worse, the evaluation participants present their dislike and negative attitude towards these features.

One possible reason is that the design went to the wrong direction. Seafarers desire the experience of comfort as a long voyage brings them the negative experiences of boredom and fatigue. The participants felt that the concept actually raised negative issues such as the feeling of an unprofessional and unsafe environment. The author does insist that the suitable distraction benefits the seafarers by means of reducing boredom and at the same time would not increase safety risks. However the design should be developed in another way in terms of meeting comfort as a UX target.

Seafarers tend to ignore bad experiences, which could lead to an improved design. They perceive these bad issues as part of their job, since they are seafarers and companies pay them, they have to tolerate certain issues. Okada (2005) confronts the situation that people make the choice of pragmatic needs although they think that the hedonic needs are more appealing. This can be seen in the research and evaluation phases. Seafarers tended to care more about the utility and usability of the bridge workstation rather than their hedonic needs.

However, it takes time to verify the author's hypothesis. This requires more field studies and interviews. Is this the difference between professional versus consumer products? It cannot be studied in this thesis work but hopefully someone will be interested in this topic and explore this idea.

7.3 What is next?

As the objective of this thesis was to study user experience in tugboat operations and to see if there is any potential and benefit to address user experience design in the maritime area, this thesis is about to end here by finalizing the proposed concept. Although the concept itself needs to be modified a lot to become a product, it won't be continued. The thesis stops at this point but the “bridge operation on future ships” project is continuing. The research group will do more user tests of other concepts and will eventually launch a prototype of the finalized concept.

The conceptual level evaluation is not sufficient to prove the UX targets; especially when talking about the risk topic of bringing suitable distractions to improve the feeling of comfort. More experimental evaluations need to be done. It requires a functional prototype rather than merely a concept to get in-situ evaluation results in order to improve the design. In whatever sense, more user studies need to do be made and more effort needs to be put on this area. It is rather a starting point than the end of a project. It will be of benefit to further explore UX in the maritime area. The author wishes this thesis can inspire more interest and studies of UX in this field.
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