Bjarte Knappen Røed

Designing for high-speed ships

Thesis for the degree philosophiae doctor

Trondheim, June 2007

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Product Design

NTNU

NTNU
Norwegian University of Science and Technology

Thesis for the degree philosophiae doctor
Faculty of Engineering Science and Technology
Department of Product Design

ISBN 978-82-471-2520-5 (printed version)
ISBN 978-82-471-2534-2 (electronic version)
ISSN 1503-8181

Doctoral theses at NTNU, 2007:115

Printed by NTNU-trykk

Contents

Figures, Tables and Examples

Figures

Tables

Examples

Photos and figure - acknowledgements

Photos on figure 1-1, 3-2, and 9-1 by K. S. Gould.

Photos on figure 4-2, and 4-4 by C. A. Bjørkli.

Photos on figure 7-3 by H. Hanasand.

All other photos by the author.

Figure 9-1 (right) by permission of Kongsberg Defense and Aerospace.

Executive summary

Fast patrol boats are high-speed vessels operated by the Royal Norwegian Navy (RNoN). These ships are 36,5 meters long, have a beam of 6,2 meters and operate at high speed (32 knots – 16,5 meters per second) in very restricted waters. The fast patrol boats are war ships and navigation tasks performed by the crews are different from those in civilian high-speed craft. A team of five persons navigate the fast patrol boats, and navigation is based on traditional means such as visual observations and paper charts. The person leading the team is the navigator.

The ships were built in the late 1970s and upgraded in 2001 when new navigation equipment was installed. However, the crews criticized the modern navigation equipment for being complex and difficult to use. In 2002, an upgraded fast patrol boat collided with a rock during high-speed navigation. The accident resulted only in material damage. Following this accident the RNoN acknowledged the need to gather knowledge about human factors and design of navigation equipment.

Navigating a fast patrol boat is about operating a complex socio-technical system. Strong demands are put on both people and their tools. In order to design usable navigation equipment for these ships, one has to have knowledge about the ships' task, the crew that carry out the navigation, and the contexts in which navigation takes place. To gather such knowledge, this study observed several navigation teams at work and used different approaches to structure and describe the work of navigation teams.

A hierarchical task analysis was conducted in order to describe navigation in accordance with procedures and established best practices. The assignment navigate to destination was the highest level of the navigator's work. The assignment included the navigation tasks; plan, start, monitor, change course, and arrive. For each navigation task, a detailed analysis was conducted. It was found that the crews used

work practices that emphasize efficiency rather than accuracy in e.g. position fixing. Although efficiency was given priority, the navigation teams controlled system variation in order to keep the ship within safe waters.

A usability study was conducted. This study treated navigation equipment that had been fitted when the ship was upgraded. A cognitive walkthrough was conducted in order to evaluate whether human factors guidelines were applied in the design of the modern navigation equipment. In total 30 usability findings were described. The study suggested that navigation equipment to little extent were user-centered. The navigation teams compensated for lack of usability by expanding actions and by modifying the equipment.

The framework of distributed cognition was used to describe the observed work of the navigation teams. Distributed cognition suggests that cognitive processes are not bounded by the individual person, but are distributed between humans and the physical artifacts they use. Humans and artifacts that participate in goal directed processes are said to be in a functional relationship. Within the functional relationships information trajectories describe how information is gathered, shared and used. Functional relationships are not static but can configure depending on the context. In studies of distributed cognitive processes, investigating physical representations are important as these are outside the head of the people, yet within the cognitive system.

The navigation team and their artifacts were described as one cognitive system where the crew and their tools were functionally related. Navigation was in most cases founded on a detailed plan. The navigator drew lines and symbols in nautical paper charts in order to represent the plan. The navigation plan was a resource for the teams' actions and the charts were a frame of reference for the teamwork on the bridge. The crew enriched their tools in order to improve communication and information retrieving. For instance, information important to navigation was to large extent noted in the chart. Another example was equipping the bearing device with small pins in order to feel the direction of the device. Artifacts were also used to support the navigators' memory. Pointing the bearing device in the direction of the upcoming course meant that the navigator did not have to remember the sailing direction. The dynamic properties of the system did on the one hand provide barriers towards erroneous actions. The crewmembers monitored each other's tasks and corrected mistakes when necessary. On the other hand, when the functional relationship was not held together, the result was entropy.

The framework of activity theory was used to provide further descriptions of the navigation teams' work. Activity theory focuses on people working in a context. In this study, activity was regarded as situated actions taking place in shorter time frames. Activity theory claims that the elements of the activity encompass the persons and their use of tools towards a conscious goal. Further, the goals of the activity are influenced by the outcome of the activity and by specific constraints.

Activity theory describes the structure of navigation at different levels. The basic constraints that influenced the navigation teams were related to the space available to maneuver the ship, and to the conditions for making visual observations. Crewmembers' behavior was not constant, but directed towards different motives depending on the circumstances. The crew usually carried out goal related tasks. However, in some cases the crew directed their work towards the operations of equipment or towards solving problems. The framework of activity theory described how internal and external factors influenced the focus of the teams' work.

Both distributed cognition and activity theory findings suggested that the teams frequently used artifacts for purposes beyond their initial scope of design. For instance, bearing devices were used to augment navigators' memory.

Based on the knowledge gathered from task analysis, the usability study, and from the frameworks of distributed cognition and activity theory, a design study was carried out. Four prototypes were produced in order to explore possible design solutions that could improve the thinking and cooperation for the navigation teams. The prototypes included an automatic steering system, an electronic chart, alarm panels, and audio alarms. The prototypes emphasized the use of physical representations and perceptually rich interfaces. The interfaces used for instance sound, vision, and tacitle feedback.

Applying human factors principles in design suggested several design solutions that possibly could improve navigators' working conditions. However, there is a risk that new design will create opportunities for new types of failures. For this reasons, user evaluations were suggested as a necessary part of design development. However, user evaluation was outside the scope of this study.

This study suggested two outcomes of a design processes. One outcome is the improvement of the design in question. The second outcome is the design seeds, that is concepts and techniques that can be reused in other development settings.

Development on navigation technology is at present an industry with strong engineering influence and traditions. This study suggested that a user-centered approach should involve engineers and work through the engineers' domain. It was suggested that a design process for development of navigation equipment would benefit from being multidisciplinary, iterative and utilize user evaluation.

Preface

For many of us, work is routine and it is normally not necessary to think too much about the basic foundations of what we do. However, there can be situations where one feels it is necessary to stop doing the everyday things to reflect upon the very basis of what one is doing, and to question one's beliefs. Sometimes an entire industry must question its beliefs. When serious accidents occur there is a demand to understand and explain the causes of what went wrong. An accident that led to questioning the beliefs about how people and advanced technology jointly cooperated was the accident at the U.S. Three Mile Island nuclear power plant in March 1979. Until the Chernobyl accident the partially core melt down of the Three Mile Island plant was the world's worst civilian nuclear accident. The accident initiated massive scientific activities and led to new insights and knowledge of how people think and act when working with advanced technology. New knowledge was obtained on how to organize work between computers, automation and people in order to achieve better performance and safety.

There is at least one other situation that could lead to questioning the beliefs of one's work. When introducing new technology into a field of work, the workers' old beliefs may be outdated. In maritime navigation, sailing a ship used to be a job carried out by highly experienced persons. Their tools were simple to look at, but required experience to apply. Personal experience has usually been a mark of quality for a mariner. The last decade has introduced new technology to support the person who is responsible for sailing the ship safely from harbor to harbor. This person, the navigator, has experienced a revolutionary change of the work place. On modern ships computers and automated systems carry out many of the tasks that used to be manual tasks. The autopilot steers the ship, satellite navigation continuously displays the ship's position, electronic charts provide information of the environment, and there is automatic presentation of the course, speed and route of other vessels in traffic. A modern ship is fully capable of sailing from port to port without any human input during the voyage.

The Royal Norwegian Navy (RNoN) has in the recent years introduced technology to support the navigators. At present in 2006, the RNoN is about to make the step from manual navigation to automated and technologically supported navigation. This introduction of technology should warrant a question of basic beliefs because what is believed about navigation stems from the years where automated systems were not common. This case study of the RNoN's fast patrol boats can be seen as an attempt to question beliefs and gather knowledge about how people use their tools to navigation high-speed ships.

In order to question beliefs there is a need for theory. Theory can be like a pair of glasses, when you put them on the glasses highlight some things and downplay other things. Depending on what theory is brought to the field, different things are emphasized. If we put a physiotherapist and a technologist on the bridge of a ship they will probably note different things. The physiotherapist will probably note uncomfortable working positions, the technologist will probably note areas that can be supported by technology. There is a plethora of theoretical frameworks that can be applied to the domain of ship navigation. The theory that this study brings to the navigation domain is theory about how people think, interact, use and develop relationships with the tools and the environment of their work. It is believed that findings from this type of theory could lead to knowledge that can be applied in the design of new tools for supporting navigators. The theory that this study brings to the navigation domain is within the field of *human factors,* a discipline that investigates and gathers knowledge about human behavior in socio-technical environments and emphasizes the application of such knowledge in design (Wilson 2000).

David Woods metaphorically described human factors research as cleaning up after the parade (Woods 1999). This metaphor demonstrated that in many work domains new practices, organizations and tools are taken into use. When things fail, researchers carry out studies and provide explanations for how things went wrong. Of course, this is not the full picture of the role of research but it points to the often found gap between research and application. This study is an attempt to join research and application. Rather than wait for new navigation equipment to be designed and then research the implications of the new equipment, this study aims to observe an area of work, describe what is going on, and predict what will mark design solutions that support the work of the persons involved.

One thing is to obtain knowledge from observations and theoretical analysis, another thing is to transform these findings into concrete solutions. In psychology there is a distinction between the internal mental idea of something, and the external manifestation of something. One thing is to have an idea of something e.g. building a house, another thing is to externalize this idea, that is to build a house. Those who have built a house would probably have realized that their mental models did not cover all aspects of house building, and probably also that their mental models developed during the building phase. Good ideas does not always survive meeting reality. In order to attempt to join theory and application, this study will externalize knowledge in terms of prototypes.

This case study of fast patrol boat navigation will emphasize understanding and descriptions of the navigation domain, and how navigation is carried out on these ships. Structured approaches and theoretical frameworks will be used to gather knowledge and understanding of the work of the people involved. The results obtained will form a basis for design solutions. The structure of the thesis is as follows:

Chapter 1 introduces the field of naval fast patrol boat navigation. The chapter argues that this field should be regarded as a complex socio-technical system, that is a unit where people and technology interact, and where the environment poses challenges for effectiveness and safety. The chapter also outlines previous research on ship navigation.

Chapter 2 describes the theoretical frameworks and the methodology that this study is based on. The two major frameworks are the ones of *distributed cognition* and *activity theory*. Very briefly said, distributed cognition is about how information is obtained, used and propagated through a system that includes both people and artifacts. Activity theory describes the goal-directed and contextual work of people. The findings from these frameworks are presented in later chapters.

Chapter 3 introduces the five persons that constitute the navigation team on board the fast patrol boats. Their work and their tools are described along with the details of the ships where the study took place. The chapter also provides a quick guide to fast patrol boat navigation.

In chapter 4, a task analysis of fast patrol boat navigation is presented. Navigation can be divided into a planning phase, start of navigation, monitoring the plan, change of course, and arrival at port. The team work and tasks are here broken down into sequences.

Chapter 5 is a usability study of the most modern navigation equipment on the ship. A cognitive walkthrough is conducted, The chapter emphasizes how the artifacts on the ships' bridges correspond with general human factors design guidelines.

Chapter 6 describes the work of the navigation team by using the framework of distributed cognition. The bridge of the fast patrol boat is regarded as one cognitive system, including the persons and the artifacts they use. Information is gathered, treated and passed on between the people and artifacts involved.

Chapter 7 uses the framework of activity theory to describe the goal directed work of the navigation team. This framework emphasizes the how work is influenced by context and the tools available to the operators.

In chapter 8, the knowledge obtained by task analysis, the usability study, and the frameworks of distributed cognition and activity theory is applied in a design process. Prototypes of steering systems, alarm panels and electronic chart interface are described.

Chapter 9 comments upon aspects of the technical development in the maritime industry. The industry has traditionally been technologically focused. In the future, more technologically complex systems are likely to be developed. This chapter comments upon how a user-centered design approach can provide valuable inputs for future development.

Chapter 10 presents the proceeding and outcomes of this study in a condensed manner.

Acknowledgements

This thesis was founded by the Royal Norwegian Naval Academy Navigation Centre. This project could not have started without the support at the Naval Academy from Tor Vestlie, Harald Rikstad, Ole Kristian Karlsen, Steinar Nyhamn, and Stig Andersen Waage.

Thanks to my supervisor Thomas Hoff at the Norwegian University of Science and Technology. He introduced me to the field of product design and thereby starting this project.

The project could not have been completed without cooperation from the fast patrol boat community and especially the navigators involved in this study. My colleagues in the navy, especially at the Naval Academy, have also given important support.

There are two friends and colleagues that I could not have completed this study without. Cato Bjørkli has supported, explained and encouraged enormously throughout the whole project. Kristian Gould has with never ending enthusiasm raised fruitful discussions about human factors and ship navigation.

Hans Bjelland has largely contributed to my understanding of design work. Vigleik Norheim contributed to prototyping and provided valuable thoughts upon user interfaces. Thanks to Kongsberg Maritime for lending us their facilities in our design of prototypes.

I am very grateful that professor Bente Moen at the University of Bergen included me to section of occupational medicine, and that Berit Larsen organized everything for me there. Thanks to all colleagues at the University, especially Inger Haukenes and Dordi Høivik for discussions and encouragement.

Thanks to the Maritime Human Factors Research Group for discussions, support, and being a network for maritime human factors issues. Thanks especially to Margareta Lützhöft who some years ago very forcefully introduced me to the field of maritime human factors.

And last, many thanks to my nearest and dearest: Kasper, Pontus, Mille, Emma and Carina Elén.

Bergen 18 January 2007

1 Introduction

A Norwegian fast patrol boat is speeding at 32 knots (16.5 meters per second) on the Norwegian coast. It is winter and the ship proceeds through the dark and cold night. The ship passes snow-covered islands, the sea is dark and the ship ploughs through the waves. The ship has been underway since the morning, which means that the crew has been on watch for nearly sixteen hours. The weather is quite good compared to what could be expected for this time of year; light wind and scattered showers.

On the bridge of the ship, the navigator is half standing, half sitting in his chair. The navigator is controlling the ship's course and speed. He is also keeping an eye on his other team members; the ship's safety is depending on the whole team. The helmsman, standing to the navigator's left, is accurately steering the ship, turning the wheel to starboard and port to keep the ship on course. The navigator picks up his binoculars and looks into the dark. There is light rain, but visibility is good. "Come port to three-one-one degrees", the navigators orders. "Port to three-one-one…. Three-one-one on", the helmsman replies. A light buzzing is heard from the wheel, indicating that the helmsman works hard to compensate for the waves that try to bring the ship off course.

"Next course is three-zero-eight, distance one point three". The voice belongs to the plotter, standing at the chart table behind and to the right of the navigator. The plotter has the chart in front of him and reads to the navigator the courses that are planned. The navigator acknowledges "Roger". The navigator needs to maintain night vision, and for that reason there is virtually no light on the bridge. This means that to read the chart the plotter uses a dimmed torch. The small light spot covers only a few square centimeters and reading the chart is like watching through a keyhole.

"Ship in red five, showing red light". The outlook shouts a report into the bridge. The outlook works outside the bridge and communicates with the navigator through the door in the aft of the bridge. The speed wind adds to the strong breeze, making the outlook's work place rather noisy. "Roger" – the navigator has to shout back, if not the outlook will not hear that his report has been acknowledged.

"What do you think of the vessel in red sector", the commanding officer asks. The commanding officer is located to the left of the navigator. In narrow waters and during dark hours the commanding officer is present on the bridge. He half sits on the chart table, half stands on the floor. The work place of the commanding officer is not a very comfortable position. The commanding officer monitors the radar, while the navigator relies on other means for navigation, such as the ship's compass, log and lighthouses.

"The ship in red sector is cleared to port, the dangers on this course are the small islands on my port side, passing distance zero point fifteen nautical miles". The navigator answers the commanding officer's question. Suddenly; "LAND AHEAD", the lookout shouts. "REDUCE SPEED..", the commanding officer shouts, "I AM…", the navigator shouts, "HOLD ON".

The ship crashes into a rock. The collision throws the crew forward. "DING-DING-DING", the emergency alarm sounds. Surprised and confused the crew put on their life vests and rapidly proceed to their emergency positions. All are drilled in what to do in case of a grounding and they manage to keep the ship floating. The five other ships of the squadron have been alarmed, and are arriving the scene to provide assistance.

The accident described is a freely constructed accident that represents factors found in several accidents. The accident also demonstrates some of the important issues in this type of navigation; the team work that is necessary in order to navigate the ship, the speed of the ship that demands effective and timely work of the team members, the challenging environment that the work takes place in, the small margins related to errors, and last but not least the serious consequences of errors. Together, these issues point towards the fact that in this domain there is a lot to be understood if one aims to successfully support the people in their work.

1.1 Norwegian fast patrol boats

The Hauk-class fast patrol boat has a length of 36,5 meters, a beam of 6,2 meters, a displacement of 160 tons and a speed of 32 knots (16.5 meters per second, 59.2 km/hour) (Jane's 2005). The fast patrol boats are specifically designed for high-speed navigation in very narrow in-shore waters. Very briefly explained, navigation is the process of directing the movements of a ship from one geographical point to another.

During the Cold War, the Norwegian Navy was trained and equipped to obstruct an invasion of the country. An invasion of Norway would mean that the attacking force would need a fleet to move in large amounts of troops and military materials. The way to obstruct an invasion was to attack when the invasion fleet entered the Norwegian territorial waters. Attacking at the border of Norwegian territory had several naval tactical advantages. First, a fleet needs to enter Norwegian territory through one of the fjords. This means that one could predict points where an invasion fleet had to pass. Second, the Norwegian navy could use the inshore waters for their own protection. Several types of ships in the navy were designed to operate in littoral waters. The ships that to the fullest extent were designed to use the inshore waters for protection were the fast patrol boats.

Figure 1-1: Hauk-class fast patrol boat.

In order to use the possibilities for protection that the geography offers, ships should have the potential to navigate at high speed. This can be explained by an example. Two ships, A and B, are spotted at the same location at a given time. Ship A can sail at 15 knots while ship B is able to sail at 30 knots. One hour after the initial observation, ship A can theoretically be anywhere within a radius of 15 nautical miles from the initial position. Ship B can be anywhere within 30 nautical miles from her initial position. If we calculate the areas that the ships theoretically can cover in this one hour, the result is that ship A can be anywhere within a circle covering 706 square nautical miles, while ship B can be found within a circle covering 2826 square nautical miles. This example demonstrates how increased operating speed improves the ship’s protection because the increased speed increases the area that must be searched in order to find the ship.

The need for speed on fast patrol boats is grounded in the need for protection against enemy forces. Although inshore waters provide protection, operating in confined waters can be risky (Cockroft 1984). The high operating speed places special demands on the persons navigating these ships. The navigation tasks performed by the crews of fast patrol boats are fundamentally different from those in both merchant shipping and civilian passenger high-speed craft (Gould, Røed, Koefoed, Bridger and Moen 2006). First, the fast patrol boats have unique tasks and operational demands. The ships are war ships; their ultimate tasks are to attack other ships and defend themselves. This is what their training is aimed towards. Second, the environment in which the ships operate is very challenging. The inshore coast of Norway is one of the world's most difficult areas to navigate, thousands of small islands, shallows and narrow straits must be passed, often during extreme weather conditions and also in 24-hour winter darkness (Kjerstad 2002b). The environment is used for self-defense, so the more hostile the waters are, the better it affords self-protection. Third, there are factors relating to the organization on board the ships; fast patrol boats do not operate with multiple shift-systems. This occasionally leads to extended periods of sleep deprivation for the officers onboard. Also, fast patrol boat crewmembers are generally younger, and have a different educational background and level of experience compared to merchant mariners. Bridge crews operate with different crew sizes, and use other navigation principles than most merchant ships.

1.2 The fast patrol boat as a complex socio-technical system

The Hauk-class fast patrol boat is navigated by a team of five persons, working at the bridge of the ship. At first glance, the work of the navigation team seems straightforward. On the bridge there are people doing their job, carrying out their tasks in the way they are educated and trained. They use equipment that is suited to their purpose. They have procedures and established practices that guide them in their work. However, going deeper into the structures can reveal a more complex reality.

On the bridge, the persons and the artifacts compose a complex system. Vicente (1999) describes a complex socio-technical system as one that rates high on the following dimensions: Social, large problem space, dynamics, time constraints, uncertainty, disturbances, distributed, heterogeneous perspectives, mediated interaction, automation, coupling of systems, and hazards. In the following these dimensions will be described with regard to the fast patrol boat navigation, i.e. the persons and the equipment on the bridge of the ship.

The navigation team is a social organization in the sense that it involves people. The organization consists of five persons that must work individually and cooperate to make the ship proceed safely and effectively. People are generally more varied in their performance than machines, and for this reason a social organization opens up for variable performance. A social organization has a strong need for effective cooperation between the people within, e.g. clear communication and knowledge of each other's work is necessary in order to coordinate the actions involved (e.g. Salas, Dickinson, Converse and Tannenbaum 1992; Endsley, Bolté and Jones 2003).

Operating a fast patrol boat means that the persons involved in navigation must relate their work to a large problem space composed of many elements and forces. There are large numbers of potentially relevant factors that the navigation team must take into account. The ship operates at sea, which means that the environment exerts forces on the ship. The forces from wind and sea can be considerable during heavy weather, and heavy strain can be placed on both the ship and the persons on board. The ship operates night and day. During dark hours the crew must carry out their work with restricted light, in winter time the temperature can drop below freezing point.

Navigation is dynamic in the sense that work conditions and the response to the conditions vary over time (Norros 2004). As other types of control work, such as in control rooms, the workers relate to a process in which environmental factors influence the performance and the outcome of the process. A major issue with dynamic systems is the worker's need to anticipate the future state of the process and then act in due time. In order to predict the future movement of a ship, the navigation team must monitor, evaluate and control e.g. the heading of the ship, the speed, the drift caused by currents and wind. Dynamic systems often have large time constants. For a fast patrol boat operating at high speed, a major time constant is found in the process of reducing speed. Stopping the vessels takes 2 minutes. Faster reduction of speed is possible, but the resulting excess heat can damage the engines.

Another aspect of a dynamic process is the uncertainty involved. An important issue for the navigation team is the uncertainty of the ship's position. When the exact position of the ship is measured, this rapidly becomes historical data. In fast patrol boat navigation, the ship's position is found typically every fifth minute, which means that most of the time the true state of the ship is not exactly known because of reasons such as imperfect sensors and subjective evaluations. The ship's speed and heading can be accurately measured. Other factors such as drift from wind and currents must be subjectively evaluated. As time passes, the ship's position becomes more and more uncertain. Finally, even if the exact position in the chart could be established, the charts have an error margin of plus/minus 50 meters in the representation of land and other solid objects.

The high speed of the fast patrol boats means that there is limited time available to carry out the required tasks. In complex systems, time is regarded as the most prominent factor that influences the quality of work (Hollnagel 1998, 2002). This means that several tasks must be conducted simultaneously. It also means that the team must make trade-offs between effectiveness and thoroughness (Hollnagel 2004). For the navigation team accuracy is not paramount for many of the tasks they carry out. It is often better to estimate a good enough position quickly, rather than measure a very accurate position half a minute later.

The navigation teams are subject to variations in their work. This means that the crewmembers must be adaptive and vary their performance in order to keep the outcome constant. As an example; steering the ship is a task that is typically dependant on contextual factors. The ship's trajectory relative to the waves is important for how much rudder the helmsman must apply in order to steer a straight course. While a power plant control room itself is subject to few contextual changes, the bridge of a ship can be situated in several contexts. In rough weather the movement of the ship can strongly influence the working conditions of the crew. During dark hours the lack of light constrains the crew's visual ability. The presence of natural variations implies that the team must distinguish normal variance from variance that is caused by failure and abnormal conditions.

The bridge of the fast patrol boat is a distributed system. That means that each crewmember carries out parts of the work, where all parts are necessary to ensure safe navigation. This teamwork depends on effective cooperation between the persons in the team. Although the persons work together in a confined area, the work is distributed in the sense that one person steers the ship, one observes the environment, one reads the chart, and one collects the information required to know the ship's position, direction, and speed. In addition to the interaction between several people, several artifacts are used in the navigation process. There is not one piece of equipment that alone can do the complete task of navigation. As different artifacts have different functions and provide different information, the navigation system is also distributed with regard to artifacts. For example, the radar is used for detecting land and vessels and the charts are used for representing the environment surrounding the ship. For the navigation team it is necessary to collect and integrate information from these sources.

As well as the individuals on the navigation team having different tasks, they also have heterogeneous perspectives. The individuals normally understand the team's work and purpose with reference to their own tasks, background and experience. Factors that influence the performance of one member do not necessarily influence another's task. Low temperature mainly affects the lookout who is placed outdoors, the rest of the team is comfortably placed in the bridge house. The speed of the vessel does not influence the lookout much, as his task is not that sensitive to time constraints. However, the plotter who reads the chart is influenced by the vessel's speed. Also, the differences in background and experience imply that the persons on the team might have different personal senses of the work (Perrow 1984).

The navigation team obtains a lot of information by looking out and directly observing the environment. The person that does this to the largest extent is the lookout, whose task is to observe and report issues important to the navigation. Not all types of information can be directly perceived and for that reason the team also mediates interaction with instruments. When a value is not directly observable, a person must relate to a representation of the value. The helmsman cannot directly sense a geographical direction and must act on the basis of the direction represented on the compass display. The engines' revolutions per minute are represented on dials. The radar provides a representation of the objects surrounding the ship. Interaction by instruments also implies that persons cannot directly create a change, but must bring about a change (Petersen 2004). The helmsman cannot directly change the heading of the ship, but by manipulating the steering system a change can be brought about.

Some parts of the navigation team's work are automated. Automation is a means to make work effective, and some processes cannot be run without automatic control. On the fast patrol boats reducing speed is a task that requires careful operation of the maneuver handles. Operation beyond tolerance limits can lead to damage to the engines. For this reason the ships are equipped with computer engine controls. The navigator is responsible for initiating speed reduction and monitoring the system. The knowledge required to monitor a system is different from the knowledge required to carry out the work itself. Use of automated systems imposes high attentional and knowledge demands on the operators. The operators need to be aware of the automation's status, behavior, intentions, and limitations (Sarter and Woods 1997). Another aspect is that automation requires operation within certain limits. During abnormal situations outside these limits, the workers must play the role of problem solvers and compensate for the lack of automation.

Complex socio-technical systems often involve several coupled subsystems. Coupled systems can be described by the degree of coupling, and by their interaction properties (Perrow 1984). A system can be tightly coupled or loosely coupled. A tightly coupled system has no slack between two components, i.e. what happens directly affects what happens to the other. On the other hand, a loosely coupled system has more flexible performance standards. The ship's bridge is a loosely coupled system. The cooperation between people opens for several ways of achieving the goal of the team.

Interaction within the system can also be described as linear or complex. Linear means that parts of the system interact in an expected or fixed sequence. Complex interactions mean that interactions occur in an unexpected sequence. A ship normally responds to steering inputs in a linear way. However, effects from shallow water can cause complex interaction between the steering system and the ship.

The last point made here is about the potential risk and hazards connected to operating outside the safe boundaries of the system. The main types of accident related to the performance of the navigation team are groundings and collisions with other vessels. When we regard navigation accidents, groundings and collisions, fast patrol boats suffered 16 larger accidents between 1990 and 2005 (Gould et al. 2006).

14 accidents were groundings, two were collisions. Two of these accidents led to injuries on people, and in total 12 persons have suffered various degrees of injuries from fast patrol boat navigation accidents in this period. On average a navigation accident in the Norwegian navy costs 2.8 millions NOK (ibid.). This sum includes only work and materials, and does not reflect change of plans, lack of training, or other secondary costs.

According to the criteria forwarded by Vicente (1999), the bridge of fast patrol boats can classify as complex socio-technical system. But why is it necessary to put this label on the bridge of the ship? One reason is that in order to design something that can support the work, one should aim to understand the domain in question. The understanding of the domain will influence the choice of theoretical frameworks and the methods that are applied in order to study the domain. Describing the bridge of a fast patrol boat as a complex socio-technical system pinpoints that the domain requires a broad understanding when one aims to design equipment that meaningfully supports the workers, and that technical solutions are not sufficient to achieve safe navigation.

1.3 Design in complex socio-technical systems

In a complex socio-technical system there is a fine-tuned relationship between the people and the equipment that is used. For instance, in a car the driver is usually familiar with how to operate the different equipment on board. If one makes changes to the driver's workplace, like mounting a satellite navigation system in the car, this is likely to change the work of the driver in some way, presumably create a need to pay attention to how to operate the new system. This shows that artifacts in the joint human-technical system should be regarded as more than just objects. A car-based satellite navigation system enables the driver to know where he or she is. However, the introduction of such a system also influences the tasks of the driver and e.g. focus of attention. From the system view, artifacts carry with them an implication for the interplay of people, technology, and work (Woods 1998; Woods and Hollnagel 2006).

Designing is about introducing new artifacts into a field of work. Usually a new design is made in order to improve something. A design is thus based on assumptions on how to make improvements. This view on design is expanded by Woods (1998) who argues that design is not only hypotheses about how to improve work, design are also hypotheses about how artifacts shape cognition and collaboration within a human-technical system. Such hypotheses can be explicit and express how one believes that the design will influence the interplay between people and technology; what are the benefits and what are the undesired consequences of the new design. Even if the designers have not thought about how the artifacts will influence the field of work, implications for the joint system are embedded in the design, and design can be regarded as implicit hypotheses of how work is influenced. Technology is not neutral, it always carries with it some implications for the persons and work (Woods and Hollnagel 2006). Several design approaches advocate an iterative process where new designs are developed step by step (e.g. ISO 13407).

In a technical approach to design, the technical or formal qualities of the artifact are the major concern. Formal qualities are about the functions that allow the user to achieve goals. However, ensuring that the piece of equipment has the formal technical qualities is not necessarily enough for a successful implementation in a complex socio-technical system. This is a trivial point, but nevertheless there are recent examples of products that have entered the commercial market, products that could have caused serious problems for the users. Example 1-1 describes a type of navigation equipment interface that was launched on the Norwegian market in 2005. This product is technically a very good product, it satisfies all technical requirements.

However, the producer admitted that there are issues connected to the human-technology interaction that were not thought of.

Example 1-1: A story of product development.

A navigation equipment manufacturer presented its new and improved radar. On the operator interface two functions were located next to each other. One was the *range* function which is used to optimize the radar picture for the navigator particularly in narrow waters. Beside it, and with an identical button, the manufacturer had placed the *stand-by (STBY)* function. This function stops radar transmission and leaves the radar display dark. Pressing stand-by instead of scaling could leave the navigator virtually blind. Confronted with the obvious problem of pressing an unintended button, the company representative admitted that they "had not thought of it that way".

Figure 1-2: Radar interface.

A second example describes how the joint human-technology focus must compete with the technology approach to design. An idea of what design solutions that would support the user may exist. However, in the design process other issues, issues that are not connected to improvements of the joint human-technology system, can overrun this idea. Example 1-2 demonstrates this.

Example 1-2: A second story of product development.

The Royal Norwegian Navy and a major Norwegian navigation equipment manufacturer had formed a working group in order to arrange the layout of the bridge of a navy high-speed vessel. The group had agreed on the position of different functions on an armrest control. The armrest control is the interface which the navigator uses to interact with the electronic chart, the radar, and other technical systems. The group had agreed upon an asymmetric position of functions to make it easier for the navigator to operate the controls without having to look at functions.

However, at the next group meeting all controls were arranged symmetrically. The production engineer explained why; “we sorted out the symmetry because it was bad. The lower controls are now placed in full circle. We were so pleased with the new look so we added our company’s logo in the middle”. Unfortunately the engineers were so satisfied that they had already put the control in production. The ships were equipped with the symmetrical control panel.

Figure 1-3: Armrest control interface.

Example 1-3: Improving an interface.

The Hauk-class bridges were retrofitted with new throttles for controlling the engines' rounds per minute (rpm). When operating the throttles, the engines will change their status and the ship will change speed. The throttles can be operated in two modes; automatic or manual mode. In automatic mode the rpm are changed according to a computer algorithm. In manual mode the rpm are changed as fast as possible. If one wants to make an emergency stop, the throttles should be in manual mode. In manual mode reduction from full speed ahead to stop takes about 10 seconds. In automatic mode reduction from full speed to stop will take 2 minutes, but provide less strain on the machinery.

Change between automatic and manual mode is done by operating buttons beside the throttle. To indicate the system mode there are light diodes. These diodes provide such strong light that they negatively influence the navigator's night vision. In order to dim the light, many crews have made dark Plexiglas plates that are placed over the handles. In order to operate the mode change buttons, holes are cut in the plexiglas. Placed over the diodes, the plexiglas is fastened using velcro. During sailing these plates tend to move out of position. If the navigator wants to change mode, it is necessary to operate the buttons. However, if the plate is out of position, the holes in the plexiglas do not correspond to the interface underneath it. The improvement made by the fast patrol boats crew can under certain circumstances mean that they are not able to shift mode quickly enough.

Figure 1-4: Improvised solution for dimming lights.

A purely technical focus can lead to design of artifacts that carry with them unanticipated implications for the use and for the users. Several authors have described how workers adapt to such situations and often compensate flawed design solutions (e.g. Carrol, Kellog and Rosson 1991, Vicente 1999, Dekker 2002, Lutzhoft 2004). When a product is not based on a foundation of how it will influence work, it opens up for unplanned and even potentially dangerous ways of use, where the users fit the artifact to their work domain. The term "system tailoring" (Norman 1988) denotes how users create their own changes to the system or interface in order to make it fit the use or the working context. Example 1-3 shows a case from the fast patrol boats.

The previous examples have described how a technical focus addresses only parts of the joint human-technical system and thereby opens up for potentially unwanted effects. In the examples, the design potentially placed problems on the user. The designs of the interfaces were such that the users were likely to push the "wrong" buttons on occasion. The examples show that a technical focus risks causing problems for the human user. Further, in the same way as a technical focus addresses only parts of the complex socio-technical system, a focus on the humans involved does not address the necessary issues for design.

The term *human error* is a term that at least has two different meanings (Dekker 2002); one meaning is where human error is regarded as a cause of accidents. In this view human error in terms of e.g. inaccurate assessments, wrong decisions, and bad judgments are the cause of accidents (ibid.). Another meaning of human error is that people's behavior made sense at the time and in the circumstances they were in, and that human errors are symptoms of problems deeper within a system. Seeing people as the cause of accidents is not uncommon. Generally speaking, when accidents occur, there is often a search for the causes (Hollnagel 1998, Dekker 2002). Commonly the person(s) in the sharp end of the system are blamed for what happened. Describing human errors as causes for accidents can lead to the belief that the people operating a complex system are the real problems regarding safety. In literature there seems to be agreement that between 60 and 90% of all system failures are caused by human errors (Hollnagel 1998). In the maritime domain human factors related accidents are reported in the range from 65 to 96 %. Sanquist (1992) attributes 65 % of marine accidents to human error. Blanding (1987), Bea and Moore (1993), Kjerstad (2003), and Rothblum (n.d.) reports a staggering 96%.

What is then the role of people in navigation? On the one hand research reports that humans make errors (Perrow 1984; Reason 1990; Hollnagel 1998) and that humans often cause or fail to avoid disasters. On the other hand people are known to be adaptive, learning, collaborative, responsible, and creative (Woods and Hollnagel 2006). Example 1-3 also described how people work in order to make artifacts more supportive in their work. Are the people potential culprits or are they necessary part to make the system function? In this thesis, this question will not be answered because it is probably the wrong question. The question assumes the wrong unit of analysis as it brings the person to focus. In order to look closer into a complex socio-technical system, *the system should be the unit of analysis* (Vicente 1999; Hollan, Hutchins and Kirsh 2000; Dekker 2002; Woods and Hollnagel 2006).

This section has argued that neither a technical focus nor a human unit of analysis address the problem of design in complex socio-technical systems. The unit of analysis should be the complex system; the people, the artifacts, and the interaction between them. What we want to achieve is to design artifacts that shape interaction between people and technology in particular and favorable ways. For design of navigation equipment on fast patrol boats our unit of analysis means that we should study the people who are working with navigation, the equipment they use, and that the study should take place where the work is normally done, that is on the ship.

1.4 Previous research on maritime human factors

This thesis aims to use research findings as a basis for design, and for that reason one should have an overview of previous maritime human factors research. As previous sections have described, this thesis will study the work of crewmembers involved in navigation, including the artifacts and equipment that they use. From this point of view, studies that have a similar focus are a natural starting point.

When we first look into research that has taken the complete system as the unit of analysis, an obvious start is *Cognition in the Wild* (Hutchins 1995a). In this work, Hutchins reported how people interact with artifacts in order to navigate large military ships. Hutchins claimed that knowledge was distributed between people and artifacts, and that cognitive processes included both types of agents. Lützhöft (2004) carried out ethnographical studies on ship bridges and reported how people and artifacts interact. The study reported that technology could improve performance, but often systems were insufficiently integrated and posed high demands on the users. Norros (2004) provided a framework that was used to model the domain constraints and reveal the habitual ways of acting that were found in studies of navigation of commercial cargo ships. Norros (ibid.) advocated the need for a new type of absorbed coping that makes use of the new technology and cooperation.

Bjørkli, Øvergård, Røed and Hoff (2006) studied control aspects of navigation on Hauk-class fast patrol boats. The study reported how the navigators match the control capabilities of the system with the demands of control. Olsson and Jansson (2006) used a control engineering approach in a study of fast ferries. They reported that navigators spend much time gathering information from different sources, and advocates that design of ship bridges should focus on the needs of the navigators.

Gould et al. (2006) studied investigation reports from 35 navigation accidents in the Royal Norwegian Navy between 1990 and 2005. The study reported on the presence of factors which influenced the likelihood of an error occurring in the total socio-technical system. The study found that factors related to task requirements were most common.

None of the studies that take the total system as unit of analysis have an explicit ambition to derive design implications for artifacts within the system. The second area to be covered regards research on the impact of new technology in the maritime domain. Several authors have generally pointed out that new technology can provide benefits for the navigator. Edmonds (1999) describes the potential electronic charts have of reducing errors, in particular connected to chart corrections. Lützhöft and Dekker (2002) claim that automated systems have the potential to improve performance. Lee and Sanquist (2000) argue that technical innovations influence navigators cognition and work. Articles have been published describing the background and development on ships' bridges. Hedestrom and Gylden (1992) describe the trend of integration displays. Røed, Gould, Bjørkli and Hoff (2005) describes the development from manually operated navigation equipment to computerized equipment.

When it comes to the benefit of particular systems, little research has been carried out. Sauer, Wastell, Hockey, Crawshaw and Downing (2003) point out that although automation plays an increasingly important role on the ship's bridge, empirical research on the effectiveness of alternative bridge design is limited. Hockey, Healey, Crawshaw, Wastell and Sauer (2003) claim there is little knowledge of patterns of workload in the maritime domain, despite the concerns of information overload (e.g. Edmonds 1999).

Empirical research in the maritime domain commonly includes use of simulators in order to control factors that are uncontrollable on board a ship. Several studies have been conducted in navigation simulators. Donderi and McFadden (2003) studied the implications from different configurations of electronic charts and radar. The study found that chart and radar presented as one overlaying display scored higher on evaluation of navigation situations. In another study Donderi, Mercer, Hong and Skinner (2004) found that electronic charts produced better performance and reduced workload compared to paper charts. The study recommended that electronic charts should provide optional radar overlay. Sauer, Wastell, Hockey et al (2002) used a computer simulated bridge to study the effect of integrated displays versus separated displays. The study found probable benefits of integrating the bridge's primary information sources. Hockey et al. (2003) studied cognitive demands of collision avoidance under pc simulator trials. They found that a higher level of collision threat and uncertainty about other ships' intended actions were associated with increased mental workload and with reduced performance on secondary tasks. Lee (1996) observed that although a collision avoidance system could monitor an increased number of vessels and reduced the workload, it also increased the need for interpretative skills and knowledge of various predictor functions.

Sauer et al. (2003) argue that controlled simulations are valuable tools for investigating design issues for ships' bridge automation. However, no such studies are known. Bjelland, Røed and Hoff (2005) studied the use of haptic feedback in speed control on fast patrol boats. The study suggests that haptic feedback is a potential way to improve electronic interfaces, however no design solutions were developed based on the study's findings. Some studies can be found reporting on general usability issues connected to fishing aids (Mills 2000), design of marine interfaces in general (Mills 2005), and usability issues connected to communication equipment (Tzannatos 2002, 2004). These studies report on user problems and provide design guidelines rather than carrying out concrete design work.

1.5 Summing up and pointing out further directions

This chapter very briefly described issues of fast patrol boats and the navigation of these. The main points were that navigation should be regarded as working within a complex socio-technical system. Navigation is a type of work that involves people's interaction with technological artifacts. The work of the navigation team rates high on dimensions that characterize such a system. Issues connected to navigation were the social nature of the system, large problem space, dynamics, time constraints, uncertainty, disturbances, distributed system, people's heterogeneous perspectives, mediated interaction, degree of automation, coupling of systems, and hazards.

Design of equipment for use in complex socio-technical systems should take the whole system as the unit of analysis. Focusing only on technical aspects fails to address how the joint human-technology system functions. Artifacts also carry with them implications for how the system of people and artifacts function. Woods (1998) claims that a design is a hypothesis of how an artifact shapes cognition and collaboration.

There is little research in the maritime domain that describes navigation from a complex socio-technical system perspective. There are also few examples of design research within the navigation domain. On the combination of these two issues, design development based on research findings, no previous research has been identified. As this chapter has outlined, design development based on research findings should be regarded as a viable way of system improvement. Winograd (1987) puts it this way; "designing things that make us smart depends on developing a theoretical base for creating meaningful artifacts and for understanding their use and effect". In order to follow this path, there is a need for theory and methods that support the creation of such a base.

2 Theoretical frameworks

One of the basic aims of this study was to question the beliefs about navigation. As the previous chapter described, navigation of fast ships is complex work. To pursue an investigation into this complex field of work, theory can help limit the scope and define the focus of the study. This chapter elaborates on issues connected to the theoretical frameworks that are applied in the further study. Issues treated in this chapter are; what do we want theory to address in our investigation? And, what do we want theory to support? The chapter then presents two theoretical frameworks that will be the basis for the investigation of the work of the navigation team. Finally methodological issues are elaborated on.

The first question to be elaborated on is what do we want theory to address? If we adopt the view that artifacts shape collaboration and cognition (Woods 1998) this implies that the theoretical frameworks of this study should address collaboration and cognition. Collaboration is here broadly understood as people involved in team work or work with material tools in order to create something. Collaboration is about how people work together in an everyday setting. In order not to limit our focus of the study, the term is loosely defined and should also encompass interaction between people and the tools and artifacts that are used in the work setting.

Cognition is, broadly speaking, about mental actions and processes of acquiring knowledge and understanding through thoughts, experience, and senses. Because we are studying a socio-technical system there are two aspects of cognition that are of interest. First, because teams are involved rather than individuals, theory should address the relationship between teamwork and cognition. For instance, thoughts may be shared and calculations may include several persons in order to obtain a result. Second, because people work with artifacts the relationship between cognitive work and use of artifacts should be addressed. Authors (e.g. Norman 1988, Zhang and

Norman 1994) have described how representing a problem influences the cognitive work needed to solve the problem, e.g. using pen and paper for mathematical calculations requires different cognitive work than mental calculations.

Another term that should be clarified, is the term *context*. Context can broadly be understood as the environment or surroundings such as demands and resources, physical working environment, tasks, goals, organization. More precisely, the context is those parts that are relevant for cognition. One could also explain it as that something is inside the head, but the head is inside of something. This something the head is inside of is the context. Authors have pointed out that cognition is always embedded in a context (Miller and Woods 1996). Taking this as given, the theory applied in this study should address the relationship between context and cognition.

It is now clearer what to address, and the next question is: What do we want theory to support? Halverson (2002) discusses the how theories might be useful to the studies of human-technology systems[1], and emphasizes the capability of a theory to guide our observations towards salient and important aspects of the phenomenon in question. Further, the theory should enable us to make inferences that are useful in some form of application. Halverson thus adopts a pragmatic view of theory, and proceeds to present four attributes for evaluating the pragmatic value of theories. First, there must be some *descriptive* power, that is, the theory must help the researcher to make sense of the phenomenon studied. Secondly, the theory must have *rhetorical* power that enables the mapping of conceptual structures to real world observations. Further, it should help us to convey our findings to others. Third, there is the *inferential* power where researchers are able to go further than the directly observed and realize important interactions or features of the system studied. Fourth, theories should

---

[1] Halverson (2002) originally discusses of computer supported cooperative work (CSCW's). However, the same line of arguments is arguably valid for the study of human-technology systems.

contribute to the *application* of the knowledge and observations gathered. Here, Halverson points to how theories might inform design.

The previous sections outlined how a theoretical framework should address collaboration, cognition and context in the study of navigation. Further, the theory should support us in obtaining and applying knowledge into the domain. Several approaches to the studies of human cognition and collaboration exist that might correspond to the specifications that have been outlined. Some of the most prominent approaches are very briefly mentioned below. *Ecological psychology* (e.g. Gibson 1986) suggests that people pick up information from the environment, and that there is a direct link from perception to human action. Examples are found in stair climbing (Warren 1976), and nuclear power production (Vicente and Burns 1996). *Naturalistic Decision Making* (e.g. Klein 1993) suggests that people in operational settings assess situations and identify actions that will work, rather than analyzing for an optimal solution to the problem. Examples of decision making are found amongst firemen and air fighter pilots. *Situated Action Models* (Suchman 1987) describes how solutions to problems emerge from the particular setting rather than from explicit plans. Suchman studied how office workers collaborated and interacted with office equipment such as photocopying machines. The term d*istributed cognition* was coined by Hutchins (1995a). From studies of the work of the navigation team on board U.S. naval ships, Hutchins challenged the traditional view of cognition, and claimed that cognition was not bound by the individual but could take place between persons or between persons and artifacts. *Activity theory* (e.g Nardi 1996a) studies the goal-directed work of people and their use of artifacts. Examples of application are found in education, therapy, and technology.

All these above-mentioned approaches could probably bring our attention to interesting aspects and be applied to gather knowledge in the navigation domain. However, in order to study the complex socio-technical system, made up of people and artifacts, the frameworks of distributed cognition and activity theory were selected. Distributed cognition and activity theory are both theories about cognition and collaboration (Nardi 1996b; Halverson 2002). Both distributed cognition and activity theory address how cognition takes place in the real world. The following chapter gives a description of the theoretical frameworks. Using distributed cognition and activity theory has methodological implications. These implications are treated towards the end of this chapter.

2.1 Distributed cognition

Traditionally, cognitive psychology has tended to concentrate on the structures and use of knowledge in the individual mind (Clark 1997). Cognition has been bounded by the body or skull of the individual person. Taking the individual as the unit of analysis has been convenient for laboratory experiments, and the understanding of cognition at the present time is to a large extent based on such experiments. This experimental approach has however resulted in limited knowledge of how cognition takes place in real world settings (Hutchins 2004).

Distributed cognition is a term used by Hutchins (1987) in arguing that for many purposes cognition is shared among several agents[2], and that without this sharing some goals could not be achieved. Hutchins' approach is that cognition is about information processing and this process is not limited to an individual's brain. In the real world information is processed and passed between people and artifacts (Hutchins 2004). The questions that distributed cognition addresses are *what do people have to know to do what they do* (Hutchins 1995a) or *what do people do with their minds* (Hutchins 2004)? According to Hutchins, these are questions where no good answers can be given at the present time. The reason for this lack of answers is

---

[2] "Agent" in this context means a person or artifact used to produce an effect.

that the questions refer to knowledge of the real world. Science knows little about how cognition takes place in the real world, and distributed cognition attempts to systematically explore real world phenomena (Hutchins 2004).

2.1.1 Theoretical concepts

Distributed cognition extends the reach of what is considered cognitive beyond the individual, to encompass interactions between people, their resources and material in the environment (Hollan et al. 2000). When such agents participate in a goal-directed process they are said to be in a *functional relationship*. The terms cognitive and functional are closely connected. Distributed cognition looks for cognitive processes wherever they occur on the basis of the functional relationships of elements that participate in the process (ibid.). Examples are found in airline cockpits where the pilot and the air-speed meter form a functional relationship. The goal of the cognitive process is to gain knowledge of the plane's air speed (Hutchins 1995b). Another example of a functional relationship is how the navigation team on a U.S. naval ship collaborate and use artifacts to determine the ship's position (Hutchins 1995a). To form a functional relationship it is not enough that agents have spatial co-locations. For instance, an artifact on a ship's bridge will not be subject to analysis only because it is located on the bridge. The artifact must be in a functional relationship to other agents to be subject to analysis.

A tenet of cognitive processes is the *information trajectories* within the functional relationships (Hollan et al. 2000). Information describes anything that can be perceived and communicated by individuals, and that is connected to the context. Within functional relationships, information trajectories are used to describe how information is gathered, how it is shared between agents and how information is used within the process. An example of an information trajectory is how bearing measurements are taken by using a bearing device, the measurements are passed between several agents and eventually drawn in the chart (Hutchins 1995a). While the functional relationship encompasses several agents, an information trajectory forms a path between the agents which information follows. Within a functional relationship several information trajectories may exist. Hollan et al. (2000) describe how these stable patterns of information trajectories reflect the cognitive architecture of the process.

Functional relationships and the information trajectories within, are not static. A dominant feature of the functional relationship is that it can *dynamically configure* itself to bring other parts of the system into coordination to achieve functions depending on the context. An example of a configuration is when one member of the navigation team needs extra support when learning how to correctly perform his task. An extra person on the team supports the new member and additional information is gathered from additional sources (Hutchins 1995a, Lützhöft and Nyce 2006). In this example both the functional relationship and the information trajectory change. It is however possible to have a change of information trajectories within an unchanged functional relationship. Since the functional relationships are dynamic, also temporary and opportunistic configurations should tell us something about cognitive processes.

Central to the study of distributed cognitive processes is the use of *physical representations* and the way people use these in their work. By representation is meant a symbol or substitute that stands for, or takes the place of, or represents another thing (Reber and Reber 2001). An example is how a ship's position is represented by a symbol in the chart (Hutchins 1995a). Representations are inside of the functional system, yet outside the heads of each one on the navigation team. The strategies people develop to exploit the physical properties of the representations themselves are of particular interest. An example of the use of representation is from ship navigation, where the knowledge required to operate a calculation ruler is a different type of knowledge than is required for doing the calculation itself (Hutchins 1995a).

2.1.2 Summing up

Distributed cognition provides a framework for describing information processing in context where several agents act together. Such agents can be persons and artifacts. In addition to the information processing, the framework focuses the dynamical properties of cognition.

2.2 Activity theory

While activity theory is the commonly used term, the full name of the paradigm is the *cultural-historical activity theory.* The full name points back in history to the cultural-historical school of Russian psychology, mainly to the 1920s and 1930s and the work of L.S. Vygotsky, A.N. Leontev, and A.R. Luria. Towards the end of the Cold War, activity theory became increasingly known to Western researchers. In 1986, the First International Congress for Research on Activity Theory was organized in Berlin (Engeström 1999). Human-computer interaction was one field of research that adopted activity theory ideas (Kuutti 1996).

Activity theory is a multidisciplinary paradigm focusing on people in context. The term *activity* broadly encompasses what people do in their everyday practices. Activity theorists argue that cognition in everyday practice is not discrete acts (e.g. observation, planning, inference, execution) taking place in the brain of the individual. From an activity theorist's view cognition is located in the everyday activity. What one does is impossible to extract from the social world. Activity theory is about understanding the unity of consciousness and activity in everyday practice, and for this it offers a descriptive tool and some highly specific terms.

This study of fast patrol boat navigation emphasized the people who directly participated in an activity and the immediate context in which the activity took place. In this study, the framework of activity theory was used to provide a descriptive framework for situated actions, i.e. episodes that took take place in a limited period of time. In the following the framework activity theory is described and the activity as situated actions are elaborated on.

2.2.1 The structure of an activity

Activity theory analyzes human beings in their natural environment. The activity itself is regarded as the least meaningful unit of analysis (Leontev 1974). The basic structure of an activity is described on Figure 2-1. The person or persons involved in the activity is denoted the *subject*. The specific study decides whether the subject is an individual or a group. The subject is involved in a joint goal-oriented activity. The subject directs its doing to an *object*. An object is something immaterial and abstract such as a plan or a vision of an end-state (Kaptelinin 1996). What is important is that the object gives the activity its direction.

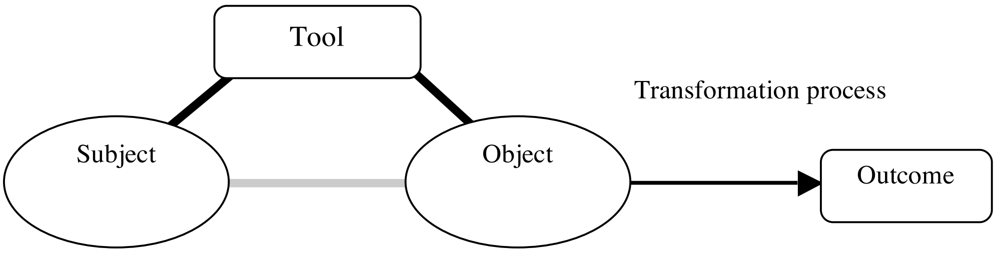


Figure 2-1: The basic structure of an activity (Engeström 1999).

The subject does not directly relate to an object, but indirectly by the use of *tools*. Tools can be external (e.g. a hammer) or internal (e.g. a concept). It is important to note that the use of tools itself is not the activity. The tools *mediate* the activity. The motivation for the activity is however to be found elsewhere than the object. The *transformation* of the object into an *outcome* is what motivates.

An example of an activity can be car driving. The subject is the driver. The tools are the car, including pedals and controls. The object is the driver's mental sense of the controls such as throttle and clutch, and how these should be operated. When underway, the driver operates pedals and the steering wheel and hereby mediates the activity. The mental sense of the control's function directs how driving is carried out. The driving is motivated by a desire to move the car to a destination. The outcome of the activity is the track the car has moved along.

From the triad in Figure 2-1, the outcome of activity appears too limited to particular situations and limited timeframes. The representation does not account for the societal and collaborative nature of actions. To include these aspects the triad can be expanded. Engeström (1999) suggests the following complex representation of an activity:

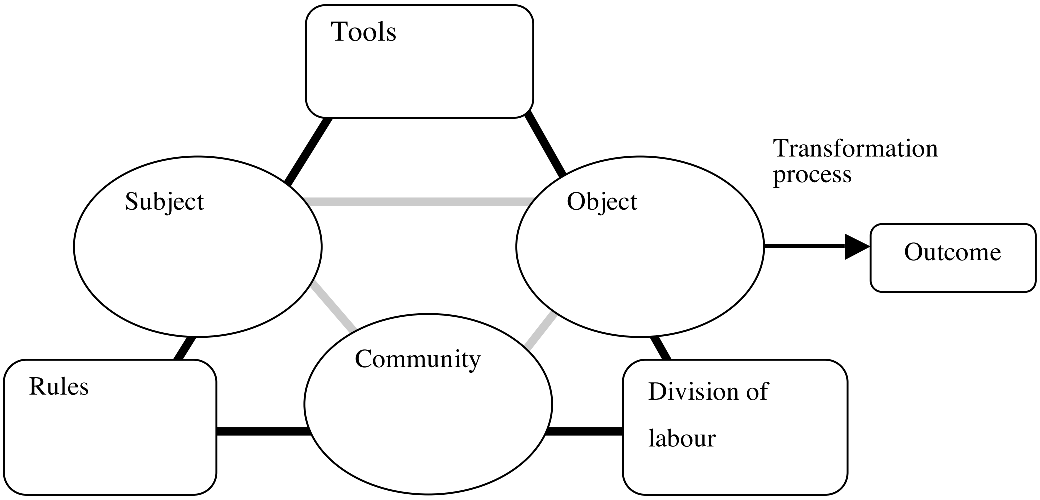


Figure 2-2: A systemic model of activity (Engeström 1999).

Rules cover both explicit and implicit norms, conventions, and social relations within a community. *Community* describes the social aspects, that is other persons relevant to the activity. The subject relates to the community by rules. The community relates to the object by division of labor, which refers to the explicit and implicit organization of a community.

A more thorough discussion of the complex systemic model of activity can be found in e.g Engeström (1999) or Nardi (1996a). The framework of activity theory encompasses a complexity of relationships and psychological terms. Several authors have pointed out that the framework and its terminology is complex in use (e.g. Nardi 1996a, Vicente 1999). To reduce the complexity this study will use a simpler model of activity. As further sections will describe, focus of this study will be on situated actions.

2.2.2 Activity as situated actions

The study of navigation is limited to the people who directly take part in the activity, and the immediate context in which the activity takes place. To model behavior generating mechanisms in maritime navigation, activity is regarded as situated actions taking place over shorter periods of time. The situated action model of activity departs from the triad presented by Engeström (1999) and is elaborated on by Norros (2004). The model is shown in Figure 2-3 as follows:

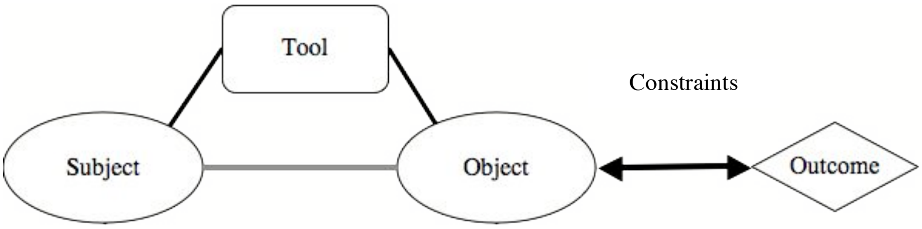


Figure 2-3: Representation of situated actions (Norros 2004).

The subject is the persons involved in the activity. The subject's activity is goal-oriented and directed towards the object. The subject relates to the object indirectly by using tools, and thereby mediating the activity. On one side, the object directs the activity, on the other hand the transforming of the object into an outcome motivates the activity. The relationship between object and outcome is a two-ways relationship, where the outcome and object mutually influence each other. This relationship is also influenced by functional characteristics of the environment (constraints). In the following the principle of mediation will be elaborated on, and also general principles of activity theory will be described in more detail.

2.2.3 Mediation

Activity theory emphasizes how the subject uses tools in order to transform the object into relevant outcome. Rabardel and Beguin (2005) elaborate on the concept of mediation, and discuss the *instrumental mediated activity*. This process refers to an approach where an instrument or tool is seen as a composite entity made up of the tool structure and the subject's scheme (Béguin and Rabardel 2000). While a tool includes both a thing and a sense of how to use it, an artifact is just the thing itself. The notion *tool structure* refers to the structural and formal aspects that refer to how the artifact was produced or built. The notion *scheme* refers to how the subject organizes his or her behavior, that is, the internally structured set of action features that can be generalized and applied in different settings by the subject. The tool and the subject's scheme thus mediate activity together into some form of synthesis. *Reflexive mediation* refers to creating relations between the tools and the subject, and how the subject uses tools for support. An example could be how people use color codes in software applications to memorize the state of ongoing processes. *Inter-personal mediation* concerns mediated relationships with others. Examples are computer programs where people elaborate on other people's previous work.

2.2.4 Principles of activity theory

A basic principle of activity theory is the principle of the unity of consciousness and activity. The meaning of consciousness is the human mind as a whole, and activity means human interaction with the objective reality. The principle states that the human mind emerges and exists through the interaction between humans and the environment (Vygotsky 1960, Kaptelinin 1996). From this principle it follows that the human mind can only be analyzed and understood within the context of activity. Consciousness is hence not given a priori, but produced, which means that consciousness is generated by actions, in a context, over an amount of time.

A second basic principle of activity theory is that of internalization and externalization. Internalization is the process where the subject develops an inner representation of the world. Externalization is the process where the subject brings inner properties back to the world outside. For instance, making a cup is the externalization of the subject's personal sense of a cup. The mechanism of internalization-externalization is described as:

> …Internalization can be observed only via some form of externalization, and externalization results feed into a further internalization process. The use of internalization/externalization terminology entails a clear decision to separate the person and the social world in inclusive ways that allow us to look at the process of their relation. (Valsiner 1997).

One fundamental assumption is that external and internal activity have the same general structure, and thereby all activities have both an external and internal side (Leontev 1974). In the externalization process, the subject is directing activity towards an object. In the internalization process, the activity itself is influencing the inner properties of the subject.

A third principle covers the hierarchy of activity. While the object is stable over longer time, activity is also realized within shorter timeframes and this activity takes place on a lower hierarchal level. At the top of the hierarchy is *activity*, which is always directed towards a motive. Subordinate to activities are *actions.* Actions are directed towards conscious goals, where a goal is structured by a mental representation of the result to be achieved (Leontev 1974). Goals are reached by sequences of actions and are realized through *operations* that correlate with the actual conditions of the activity. The conditions can also be regarded as the reference frame for the operations. This hierarchy is described in Figure 2-4.

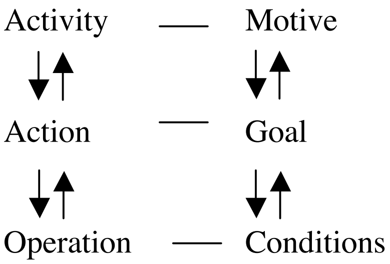


Figure 2-4: Hierarchical levels of an activity (Kuutti 1996).

Figure 2-4 also shows that parts of an activity can take place on different levels in a dynamic way, e.g. as in driving a car. The activity itself correlates with the motive and need for safe transports from point A to B. Subordinate to the activity are the actions such as aiming to use the right gears. The goal is fulfilled through a series of operations, e.g. the manual operation of the gear lever and the clutch. Operations are carried out under certain conditions such as the technical status of the car. A change in these conditions may influence the operations, e.g. if one gear is jammed.

2.2.5 *Misfit in the activity*

There is no such thing as one single isolated activity in the real world. Kuutti (1996) describes this as “activities are not isolated units...they are influenced by other activities and other changes in their environment”. Activity interacting with the real world is causing disturbances and clashes, but this interaction also develops the activity. The dynamics of the real world makes it necessary for the activity itself to be dynamic.

The environment in which an activity takes place changes in time and space. For instance, a car driver may suddenly experience a slippery road, a condition that is limited in time and space. In the real world a distinct feature of the context is change and development. To describe the misfit towards other activities or within the development of a single activity the term *contradictions* is used (Kuuttii 1996). However, contradictions can also occur because external sources influence the activity, such as in the slippery road example. Contradictions can be regarded as a term that describes the fact that the world is dynamic, the activity is a small part of the world and the activity’s lack of fit to the dynamics of the world.

Within activity there are different levels of contradictions. These levels correspond to the levels shown in Figure 2-4. The principle of hierarchical structure uses the term correlation, where operations correlate with conditions. The dynamic world changes the context for the activity. This means a change in the conditions as well. A change in context and conditions puts other demands on the activity. Again, the car on the slippery road can be an example; change in conditions (entering a slippery road) makes the driver use other operations than on dry road, e.g. the steering wheel must be carefully operated. While the contradiction affects correlation on the operation-condition level, it may or may not affect the action-goal level. Although the conditions change, the goal, e.g. to steer the car, can probably still be reached.

However, the activity-motive level is unchanged. The conditions of the road do not change the motive of safe transport.

Contradictions affect the hierarchy of activity. At the operation-condition level, a contradiction means that operations must be modified or new operations must be utilized. A major change in context can make a large impact on the hierarchy; the occurrence of contradictions may impact on the activity's goal or even motive. If a car driver experiences difficult conditions, the goal of steering the car or even the motive of safe transport are not longer reachable. The contradictions can hence move within the hierarchy much in the same way as the activity itself as indicated in Figure 2-4. In activity theory contradictions are seen as sources of development; activities are virtually always in the process of working through contradictions (Kuuttii 1996). Breakdowns draw attention not only to the history, but also to the future of the system (Norros and Savioja 2006).

The consequences of contradictions may vary from none to catastrophic. In activity theory two different degrees of seriousness are normally applied. The least serious is the *focus shift* (Bødker 1996). An example of a focus shift is when a car driver explains features of the car to the passenger while driving. In this situation, the driver can easily redirect the focus to the original operations. More serious consequences of contradictions are denoted *breakdowns*. These occur when the activity is affected by larger changes in the conditions, such as technical breakdowns (Bødker 1989). The example of a car entering a slippery road must be considered a breakdown because an external change in conditions influenced the activity in a way that affected the operations carried out.

The consequences of changes in conditions are described as shift of focus or breakdown. The consequences are qualitatively described, and to understand the activity, the description of the breakdown or shift of focus is important as such.

Breakdowns are considered more serious than focus shifts, but one cannot quantify how *much* more serious they are. Further, one cannot quantify how many breakdowns that will occur before an activity havoc is a fact. Again, it is the qualitative description of the effects of change in context that is important.

2.2.6 Constraints

In Figure 2-3, the reciprocal relationship between object and outcome is indicated by a double arrow. This suggests that the object is not exclusively regulated by the subjects, but is also attuned with *outcome features* that refer to characteristics of the environment relevant for the activity. Norros (2004) discusses how situations in work practices are the interaction between the world, the subject, and the representation of the world. This implies that the subject must somehow appropriate how outcome and thereby change in the context sets new frames of reference for the achievement of the object motivating the activity. Norros points to Gibson (1986) and his concept of constraints to explain how outcome features may be understood. Constraints are functional characteristics of the environment that are observer-dependent. In this study's application of the concept, it is suggested that there exist constraints that are equally system-dependent so that different systems (e.g. different vessel classes) adapt and exploit different constraints. The specificity of such constraints corresponds to the features of the system capabilities and dynamics. For further discussion of constraints, see Gibson (1986), Vicente (1999), or Norros (2004).

The notion of outcome features underscores that the subject is embedded in the context, and thus refers to the setting of modern work practice in complex systems. Elaborating on this approach opens for viewing the transformation of object into outcome more as an adaptation to the given environment. The object is then not some abstract formulation of a 'static end-state' to be executed, but a desired state to establish and uphold through continuous activity in face of variance and disturbances.

This means that the subject has to relate to the constraints of the context during the transformation/integration process.

2.3 Methodology issues

The frameworks of distributed cognition and activity theory can presumably describe and explain the work of fast patrol boat navigation teams. The frameworks regard cognition and interaction in socio-technical systems. Both frameworks also emphasize the need to investigate persistent structures in work settings, rather than focusing on moment-by-moment particulars. This focus has practical methodical implications. Nardi (1996b) outlines four implications for studies of work in context[3].

First, the research time frame should be long enough to understand what directs the users' actions and goals in work. Because context significantly can influence actions and goals, there is a need to study work over time in order to be able to separate contextual variations from longer-term formations. Also, the development and changes in longer-term formations can be important to understand the domain in question.

Second, attention should be given to a broad pattern of work rather than narrow episodes. In order to understand context, complexity, and dynamics of the domain, broad patterns should be analyzed. Looking at smaller episodes can be useful, but not in isolation.

Third, a varied set of data collection methods should be used without relying too much on any one method. Preferably, the methods should capture the task and the

---

[3] Nardi describes implications for activity theoretical studies. The same principles are in this study applied also to the framework of distributed cognition.

context as the people experience them. In addition, methods should document what has happened. As the understanding of work and context develops, the methods should preferably allow the researcher to revisit the material collected.

The fourth and last point is that the researcher should commit to understand things from the workers' point of view. There is not a need as such for going native, however some aspects of work practice require domain knowledge in order to discover and to understand the significance of small actions, gestures or contextual changes. Another argument is that knowing the tasks prescribed is another matter than understanding how the tasks are carried out for real. In work-studies, a major issue is understanding collaboration and cognition as it is carried out.

Approaching a work study guided by the four principles indicates that structure will emerge during the study, rather than be determined on beforehand. This implies a flexible and broad approach to the domain. The principles also suggest in-depth knowledge of fewer subjects rather than investigating a limited amount of variables in a large amount of subjects.

2.4 Conclusion

This chapter has focused on cognition and collaboration in order to gather knowledge of the work of the fast patrol boat navigation team. Cognition and collaboration are not only regarded as something that occurs between people, but also between people and artifacts. Knowledge obtained by using theoretical frameworks that emphasize cognition and collaboration can presumably inform design of artifacts that improve working conditions. The framework of distributed cognition brings into focus how information is gathered and processed in a cognitive system that encompasses several people and their artifacts. The more complex framework of activity theory emphasizes the goal-directed activity of people, how activity occurs on different levels, and how goals change and develop. Using the two theoretical frameworks has some methodological implications. Studies of the domain in question should have a broad approach, using multiple methods for data collection and analyzing a broad pattern of work. Rather than specifying what to look for beforehand, findings are likely to emerge as a result of the study.

3 Welcome aboard

This chapter introduces the characteristics of the Hauk-class fast patrol boat, and describes the tasks performed by the these ships. The crewmembers constituting the navigation team are presented, with a description of their functions in the navigation task. To better understand the work of the navigation team, a quick guide to fast patrol boat navigation is provided.

3.1 The technical specifications of a Hauk-class

The Hauk-class has a length of 36,5 meters, a beam of 6,2 meters, a displacement of 160 tons and a maximum speed of 32 knots (16.5 meters per second- 59.2 km/hour) (Jane’s 2005). The Hauk-class fast patrol boats are specifically designed for high-speed navigation in narrow in-shore waters. The total crew consist of 24 persons - 10 officers and 14 enlisted sailors. Officers are professional military sailors and have been educated and trained at naval schools and training establishments. Enlisted personnel are enrolled in the armed forces for one year and are trained onboard the ship. When the ship is underway, five crewmembers are simultaneously involved in the navigation task.

The Hauk-class fast patrol boat were built between 1977 and 1980. A total of 14 vessels were built. The Hauk-class ships were all given names from different coastal birds, such as Hauk (Hawk). The ships are currently equipped with two torpedoes, six anti-ship missiles, and a light anti-aircraft missile system.

The ship is divided in two sections. In the middle of the ship there is a bulkhead (a dividing wall), which purpose is to seal off half the ship in case of heavy damage. In the aft section of the ship there is an engine room, were two diesel engines produce just over 5000 kW. The engines are connected to one propeller each. Just aft of the engine room is the engine control room. From this room the engines are controlled and looked after. Further aft there is a toilet and three officer cabins, followed by the galley and the enlisted crewmembers mess room. This is where the enlisted part of the crew eat their meals.

Starting from the bow and proceeding aft, the large room in the front part of the ship is where the enlisted personnel have their bunks. Twelve persons share a room of approximately 20 square meters. At daytime the bunks are taken down and used as sofas. Further aft there is a cabin, shared by three officers. The officer's toilet is also found in this area. Going further aft, one enters the operation room also denoted the command- and information centre.

The operation room is the heart of the ship. A first time visitor will directly note the number of computer screens. The purpose of the operation room is to obtain knowledge of what happens around the ship. The crew monitors other maritime traffic, other military vessels, and military air traffic. The operation room crew collect, gather, and processe information necessary to solve the tasks of the ship.

From the operation room, there is a ladder. Climbing this ladder leads one to the deck where the officers' mess is located. This is where meals are served. Next to the officers' mess is the commanding officer's cabin. The commanding officer is the only person on board with his own cabin. From the commander's cabin there is a short ladder going up to the bridge.

3.2 The bridge

Figure 3-1 gives an impression of the layout and the dimensions of the bridge and how the persons on the navigation team are placed relatively to each other. As can be seen in the figure, all persons except the plotter work with their face towards the direction in which the ship moves. The plotter is normally standing 90 degrees relative to the direction of speed.

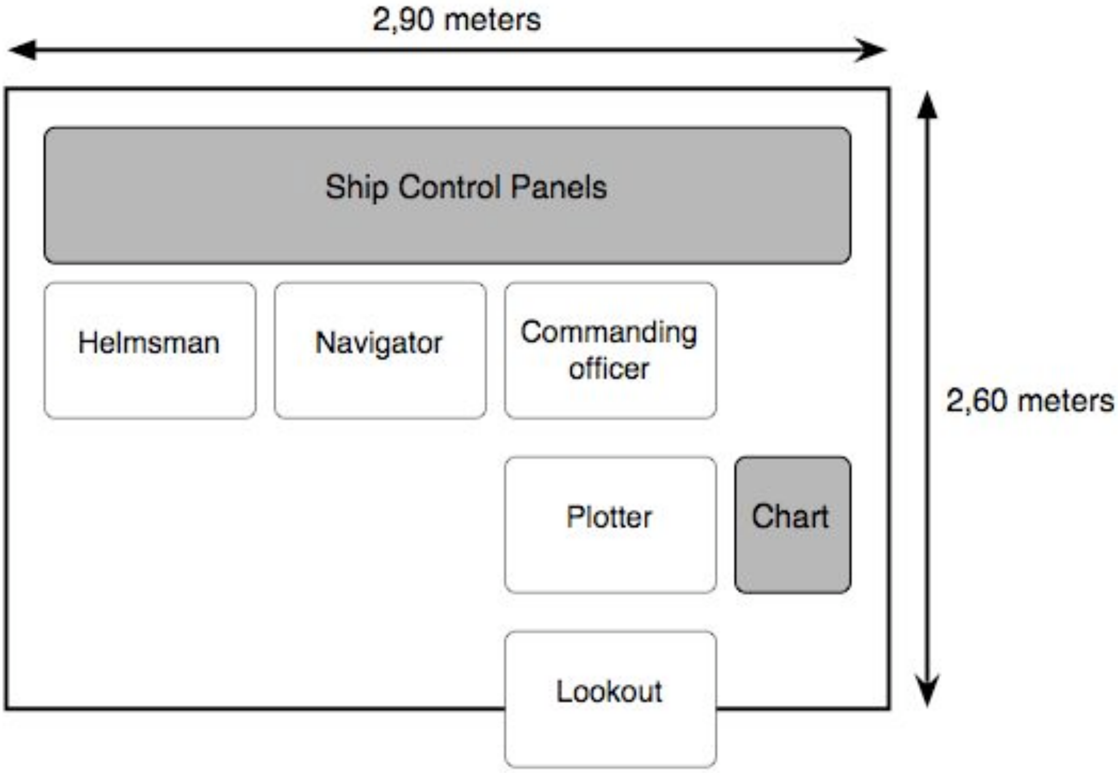


Figure 3-1: The bridge layout. Up on the figure is forward on the ship.

3.3 The Navigation crew

The navigation team consists of five persons, who jointly carry out the navigation tasks: A commanding officer, a navigation officer, a helmsman, a plotter, and a lookout. The first two are officers, the helmsman is normally an enlisted crewmember but can also be an officer. The plotter and lookout are enlisted crewmembers.

3.3.1 The commanding officer

The commanding officer holds the rank as Lieutenant or Lieutenant Commander. Age is usually from 25 to 35 years. Only male officers have to current date served as commanding officers on the fast patrol boats. The commanding officers have basic navigation training as cadets at the Royal Norwegian Naval Academy, followed by 4 to 10 years of navigation experience on the fast patrol boats. To qualify as a commanding officer one must have a minimum of four years of navigation experience on the type.

The commanding officer has the overall responsibility for the safety of the ship and he is also responsible for solving the tasks placed upon the ship. His work is to ensure that all crewmembers perform in order to make the ship fulfill its mission. The commanding officer must hence divide his attention between the navigation and the operations the ship is involved in. When the commanding officer is involved in the navigation he usually supervises the navigator.

3.3.2 The navigator

In this study the person that leads the navigation team is denoted *the navigator*. On the Hauk-class, the navigator would be either the navigation officer or the executive officer. After graduating from the Naval Academy, the first assignment for an officer on board a fast patrol boat will be as a navigation officer. After two years in this position, one can qualify as an executive officer. Then, after two years as executive officer, one can qualify as commanding officer. At the time the study was conducted one of twelve ships had a female navigator.

The navigator is the individual who controls the position of the ship and directs the ship’s movements in order to safely reach the destination. The navigator plans the navigation and executes this plan. When executing the plan, the navigator determines the ship's position, sets the speed and orders the course to be steered. The navigator is superior to and directs the plotter, helmsman, and lookout. The navigator's superior is the commanding officer.

3.3.3 The plotter

The *plotter's* function is usually performed by enlisted crewmembers. Two or three persons in a shift rotation share the function. Normally, the plotters are on duty for one hour. The plotters' age range from 19 to 22 years. In this study, one plotter was female, the remaining four were male. The function requires no previous experience or education, the crewmembers are trained on the job and have from 0 to 9 months of experience on the Hauk-class.

The plotter is the person who directly manipulates the chart. He or she plots the ship's position given to him by the navigator and informs the navigator how the ship's position correlates with the navigation plan. One of the most important responsibilities for the plotter is to operate the log, that is, to keep track of the distance to the point where the navigator must alter course.

3.3.4 The helmsman

The helmsman can be either enlisted or officer. This means that age range from 19 to 35 years. The level of experience range from 2 months to 10 years on board. Only male helmsmen were on board the ships included in this study. The helmsmen are trained on the job on board the ship. There are three to five persons in shift rotation sharing the function as a helmsman. Since the work can be physically demanding, the shift length depends on the job circumstances. In rough weather the helmsmen rotate several times per hour. If the ship navigates in confined waters, the navigator commonly prefers to have a trusted helmsman on watch. In such cases a shift can last for several hours.

The helmsman uses the wheel to steer the ship. The course to steer is ordered by the navigator. In front of him the helmsman has a gyro compass repeater where he reads the ship's course.

3.3.5 The lookout

The lookout is an enlisted person, with an age of 19 to 22 years. In this study only male lookouts were on board. The lookouts experience range from 0 to 9 months. The lookout is trained on the job and no previous experience is needed. The lookout is situated on the top bridge for optimal working conditions. The lookout reports to the navigator what he visually observes. According to procedure, the lookout reports what is deemed important for navigation safety, examples of such are other vessels, lighthouses and navigational marks.

3.4 Navigation tasks

For a fast patrol boat, navigation is a means to solve the missions that are assigned to the ship. However, navigation is a difficult and complex task and for that reason navigation training is also conducted isolated from other tasks. Basically, fast patrol boats are involved in two types of training tasks: Navigation exercises and tactical exercises. These tasks are described according to the type of exercise that was performed.

3.4.1 Navigation exercises

The aim of a navigational exercise is to train the navigator and the navigation team. This means that a particular route or area is selected to navigate in order to achieve pre-defined training objectives. The training objectives are defined by the navigation officer in cooperation with the commanding officer. As an example, during our study one of the fast patrol boat squadrons spent several hours of training in the extremely narrow “Folla” area where controlled high-speed maneuvering in narrow waters was a training objective. Other training objectives during the study were clearing traffic in narrow waters at high speed during night hours, accurate communication between plotter and navigator, and use of radar.

Figure 3-2: Three of the persons of the navigation team: The commanding officer (left), the navigator (middle), and the helmsman (right).

3.4.2 Tactical exercises

Tactical exercises have two objectives. The first is to obtain an updated picture of all vessels in the area. Second is to provide sufficient data for firing weapons at exercised hostile contacts. Tactical exercises train the operation room in their tasks, as well as the whole ship's ability to attack a target. During tactical exercises, navigation is used as a means for placing the ship in a favorable geographic position where sensors such as radar can be used. Navigation is also used as self-defense. Keeping the vessel close to shore means that it is harder to spot on enemy radar. Although navigation is important during tactical exercises, the training objectives are directed towards the ship's performance as a warship.

3.5 A quick guide to navigation

To provide a background for the following chapters, a quick guide to fast patrol boat navigation will be given. This guide will describe some of the particularities of fast patrol boat navigation, such as the importance of the chart, the navigation plan, how one finds the geographical position of the ship, and some of the heuristics that are used by the people on the navigation team.

A remarkable feature of fast patrol boat navigation is the speed at which it is performed. This means that the crew must adopt strategies for working effectively. Briefly, one can say that navigation methods are shaped to be used under time pressure. Fast patrol boat navigation is primarily carried out by using paper charts and visual observations to obtain and control the ship's position and proceeding. Hutchins (1995a) has thoroughly described how such methods are used on U.S. naval ships. Norwegian fast patrol boats use the same principles, but the execution is simplified according to the special context of high-speed inshore navigation.

Another feature of fast patrol boat navigation is that the ship's position is always calculated with reference to the chart. This points to a demarcation between *maneuvering* and *navigation*. Maneuvering is when one person directs the movements based on observations and knowledge of the sea area and routes (Norros 2004). While navigation involves the navigation team, maneuvering is carried out usually by the navigator alone. Maneuvering is more focused on the immediate movements of the ship, while navigation is focused on the position and proceeding of the ship for longer time. Commonly, maneuvering takes place for smaller periods or in limited areas. Examples are maneuvering to or from harbor or in narrow waters.

3.5.1 The chart and the plan

Fast patrol boats use commercially available paper charts issued by the Norwegian Hydrographic Office. Geographical information is represented in the chart, including shallow waters, land, and navigation marks. In the chart the navigator plans a route. Pencil lines drawn into the chart represent the route. Basically, the navigation route encompasses several consecutive lines joined together (see Figure 3-3). An individual line is denoted *the course* or *leg* and the entire collection of courses is denoted *the plan*. Where to place a course in the chart is dictated by the position of dangers such as land and shallow areas. The goal of the plan is to provide a tool for navigating safely from geographical dangers.

Each course is given a three digit number. The three digit number refers to the geographical direction of the course. The system refers to a 360 degree system where "000" and "360" degrees is directly northwards, "090" is eastwards. "180" means that the direction of the course is straight southwards. Figure 3-3 shows two courses "181" and "190" which means that the ship shall follow a course of 190 degrees, then 181 degrees. This brings us to the issue of where to change the course.

In addition to the three digit number the course has a defined length, measured in nautical miles. This distance expresses how long a distance course is to be followed. As an example; a simple plan can consist of the courses "190 - 2.0" and "181 – 3.2". This means that the ship will proceed with the course 190 degrees for 2 nautical miles, then change course to 181 degrees and proceed in that direction for 3.2 nautical miles.

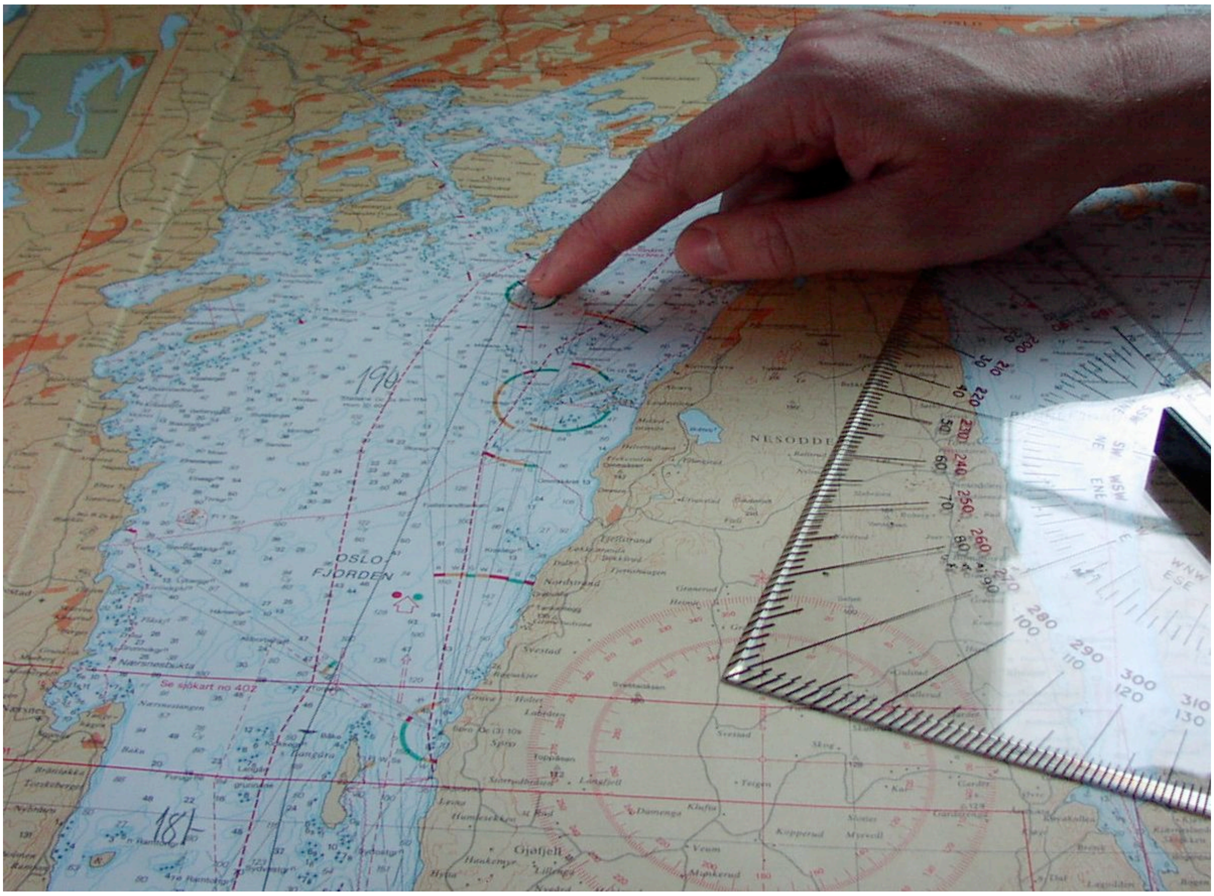


Figure 3-3: The navigation plan shown in a chart. The figures "190" and "181" refer to the compass course to steer.

When all the necessary courses have been drawn in the chart, the planning is finished. The ship is now ready to start navigating. A plan can consist of one or several courses. A plan can cover several hundred nautical miles or it can consist of one short course only. When the ship is underway the navigation plan is followed. To follow the plan, the navigation team must have knowledge concerning two issues. First, they must know the ship's position relative to the plan. The second issue is to know the remaining distance left until the course has to be changed.

3.5.2 Fixing the ship's position

Knowledge of the ship's position is obtained by *fixing the ship's position*. Fixing the ship's position refers to a representation of the position in the chart. One method is to take *cross-bearings*. This method is common on slower ships (Hutchins 1995). To take a cross-bearing, the navigator needs to identify two objects in the surrounding environment, objects that also are represented in the chart. Usually, navigation marks such as lighthouses are used. By using a bearing device, one measures the geographical bearing towards each object. These bearings are drawn in the chart, and the intersection between the bearings represents the ship's position. The advantage of this method is the accuracy of position. The disadvantage is that the method is time consuming, it requires time to measure bearings and to do the chart work. A trained team should be able to fix the position by this method in less than one minute. In one minute the ship will have traveled 0.5 nautical miles, which means that the position represents historical information rather than real time information.

The prevailing method of fixing the ship's position on fast patrol boats is to use the *four-point bearing* method (see Figure 3-4), where the ship's position is found by calculating bearing and distance from the one geographical object only. In this method, accuracy is traded in for effectiveness. The method requires that one geographical object is identified in the surrounding environment and in the chart (object C on figure). The object must be one that will be passed on a straight course. One measures the distance between two positions, the position where the object is in 45 degrees relative bearing of the ship (position A), and the position where the object is abeam (position B). Because ABC is an isosceles triangle, the distance run AB is equal to the bearing distance BC. When in point B, the navigator knows the distance to point C. The direction to the object is found by subtracting 90 degrees to the ship's course. In the Figure 3-4, the ship steers 090 degrees and the bearing to object C is 000 degrees.

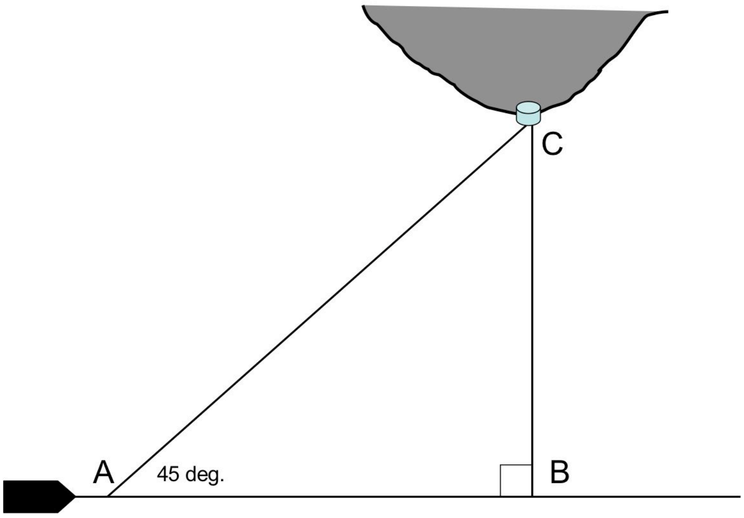


Figure 3-4: The four-point bearing method.

The method of four-point bearings has some advantages. A main advantage is that calculation of position takes little time, which means that the position is presented close to real time. The position of the ship is known nearly immediately when the ship passes the object. The method requires less chart work. The disadvantage of the method is the lack of accuracy, and for that reason the method is used to measure smaller distances than a half nautical mile. If the passing distance is larger than half a nautical mile (approximately 900 meters), cross-bearings are used.

3.5.3 Measuring distance

Independent of methods used to fix position, the distance from the ship's position to the point for where to change course is calculated . This means that measuring distance is important both for knowing where to change course, as well as for fixing position by four-point bearing method. Distance is measured by two methods which are carried out simultaneously.

The *log* is an instrument that measures the distance traveled through the water. There are two log displays, one for the navigator and one for the plotter. The displays can be used as a trip-log, with similar functionality as an odometer in a car. The other method for measureing distance is to convert time sailed into distance. This latter method is carried out by using a heuristic or a calculation rule of thumb. The rule is a chain of corresponding numbers;

30	24	20	18	15	12
12	15	18	20	24	30

In this chain there is a correspondence between speed in knots and time in seconds. As an example; top speed is regarded as 30 knots and correspond to 12 seconds per 0.1 nautical mile, 12 knots correspond to 30 seconds per 0.1 nautical mile. Because distance measurements are vital to navigation, and because heuristics are used, the fast patrol boats set speeds that match the heuristic. If a speed reduction from top speed is necessary, the speed is reduced to 24 knots. If further speed reduction is necessary 20, 18, 15 or 12 knots are chosen.

When changing course, the navigator does not only rely on distance measurements. To control the calculations, the navigator plans to change course when recognizable objects have a given position relative to the ship, usually abeam. In order to check the distance and time calculations, changing course is commonly combined with fixing the ship's position by four-point bearing method.

3.5.4 How to return to the plan

Although navigators aim to follow a plan it can be necessary to deviate from the plan in order to steer clear of other vessels. Wind and currents can also force the ship away from the planned track. Under such situations it will be necessary to know how to return to the planned track. Here another heuristic is used, known as the *six degrees method.* This heuristic describes a correspondence between change of course and sideways (lateral) movement:

If the ship's course is changed six degrees, the lateral movement will be 1/10 of the sailed distance (Figure 3-5). On the figure the lateral movement distance BC, will be 1/10 of the distance run AB. As an example; the original plan is to sail from A to B, a distance of one nautical mile. If the ship changes its course by six degrees at point A and sail one nautical mile to point C, it will at point C be 0.1 nautical mile beside the planned course. This heuristic is used both to plan evasive maneuvers and for the purpose of returning to the plan.

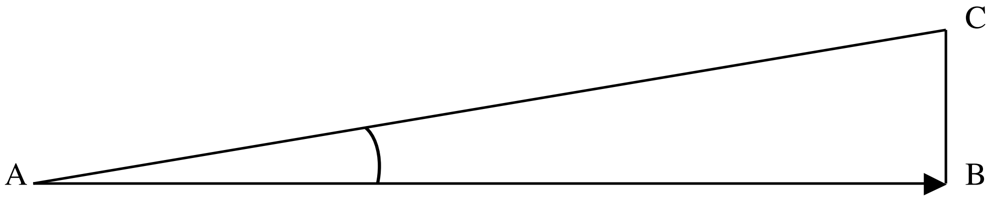


Figure 3-5: The six-degree rule.

This quick guide to fast patrol boat navigation has very briefly described the most salient features of navigation as it is practiced on these ships.

4 Task analysis of Hauk-class navigation

This chapter provides a formal description of how navigation is carried out on the Hauk-class fast patrol boat. Based on observations of navigation teams, tasks are represented in a structured manner using hierarchical task analysis (HTA) (Kirwan and Ainsworth 1992). Snyder (1991) describes task analysis as

> An ordered sequence of tasks and sub-tasks, which identifies the performer or user; the action, activities or operations; the environment; the starting state, the goal state; the requirements to complete the task such as hardware, software or information.

The resulting task description is hierarchical, which means that it states how work is organized in order to meet the system's goals. HTA produces a hierarchy of goals, tasks and operations. *Goals* are desired states of controlled systems e.g. navigate a ship to its destination. *Tasks* are the methods adopted to attain goals. *Operations* are any unit of goal directed behavior (Bridger 2003).

To establish the operations, information and communication necessary for navigation, a task analysis was carried out. The analysis focused on the goals the navigation team attain to, how tasks and operations are hierarchically structured, which persons use which artifact in order to attain a particular goal, and communication that occurs.

4.1 Data acquisition

The analysis is based on case studies that were conducted on board Norwegian fast patrol boats. Crews from the 21st and 22nd fast patrol boat squadrons in the Royal Norwegian Navy were studied. Two crews were studied during naval exercises in 2003 and 2004. The navigation teams were representative in terms of rank, training and experience. Direct and indirect observations were conducted; in total 120 hours of video was gathered. Semi-structured interviews with navigators were carried out. During the process of working out the task analysis, subject matter experts from the navy were consulted.

4.2 The crewmembers' workplaces

In the following, descriptions are provided about the crewmembers' workplaces. Each person has tools that are operated in order to perform his or her function.

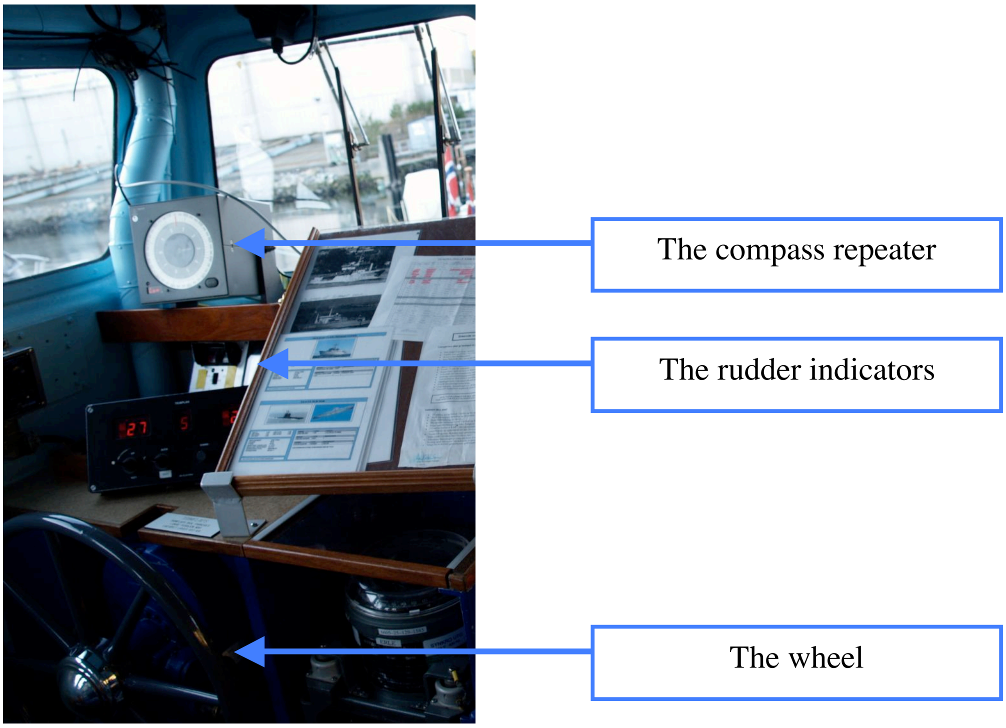


Figure 4-1: The helmsman's workplace.

4.2.1 The helmsman's workplace

The helmsman's workplace is shown on Figure 4-1. The helmsman operates the *wheel* in order to steer the ship on a course. The wheel is connected to the ship's rudders. To know the ship's course the helmsman monitors the *compass repeater* where the ship's course is represented. Because steering requires precision, the helmsman must also know the actual position of the rudders. In order to do this, the helmsman monitors the *rudder indicators,* which represent the actual position of the rudder.

4.2.2 The plotter's workplace

The plotter is the person who works hands on with the chart (Figure 4-2). This requires a pencil, an eraser, and special nautical rulers. The plotter also calculates the distance traveled and the distance remaining on each course. The plotter obtains knowledge of distance measurements from the *log*. The plotter is also the person who makes notes in the *log book*. The ship's position is at regular intervals (3-4 times per hour) noted in the log book.

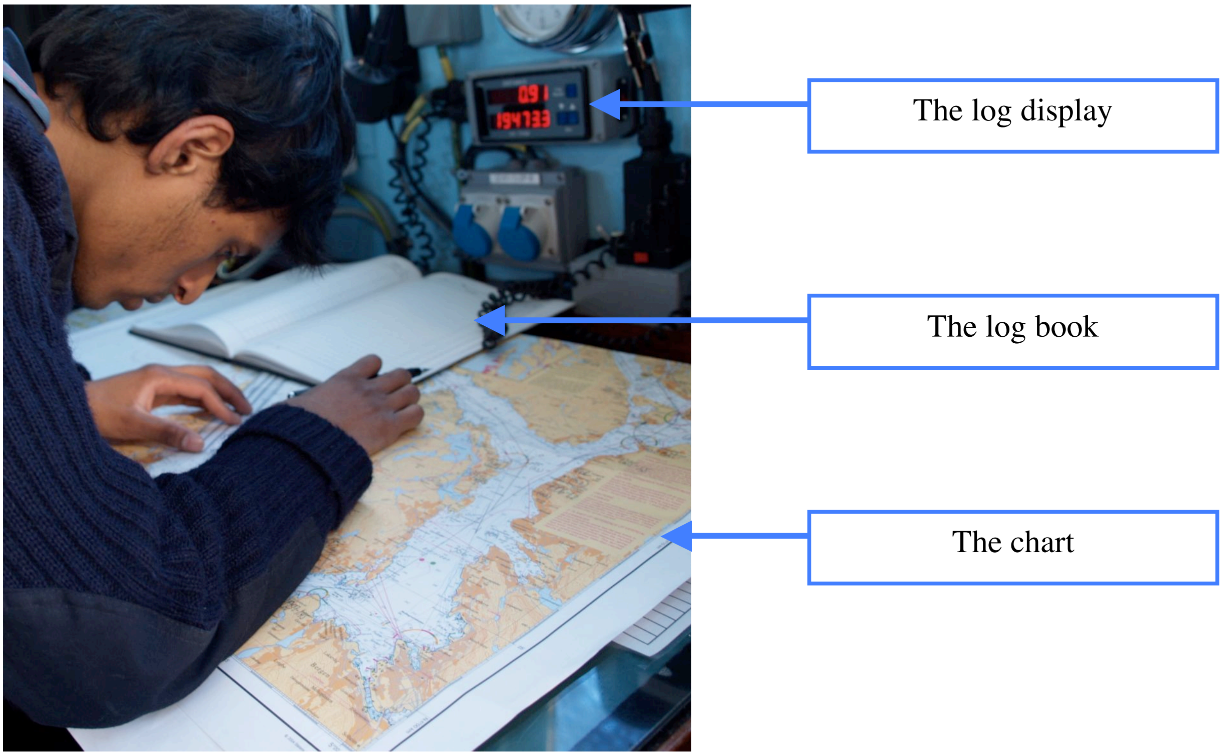


Figure 4-2: The plotter's workplace.

4.2.3 The navigator's workplace

The navigator is the person responsible for execution of the navigation plan, and his tasks include position fixing and distance measuring. The ship's position is fixed by taking bearings, by using the *optical bearing device* and *the bearing display*. The optical bearing device is directed towards the object one wants to measure bearing to, and the bearing can be read in the display. The display has two functions; it can display the direction of the bearing device or the course of the ship. Turning the *switch* changes what is represented on the bearing display.

The navigator has his own *log display* that measures distance traveled. This display also presents the ship's speed. The ship's speed is controlled by the *throttles*. The throttles regulate the engines' revolutions, which are presented on separate *dials*. An overview of the navigator's workplace is shown in Figure 4-3.

Figure 4-3: The workplace of the navigator and the commanding office.

4.2.4 The commanding officer’s workplace

The commanding officer’s workplace is situated directly to the right of the navigator (see Figure 4-3). Hence, the commanding officer has access to the same controls and displays as the navigator. Just in front of the commanding officer, the combined *electronic chart* and *radar* is located. These are presented on the same computer screen, and one must choose which one to present. The operator *interface* is located to the right of the radar and chart.

4.2.5 The lookout’s workplace

The lookout is situated outside the bridge. He visually observes the area in front of the vessel. The lookout uses binoculars; at night special night vision binoculars are used.

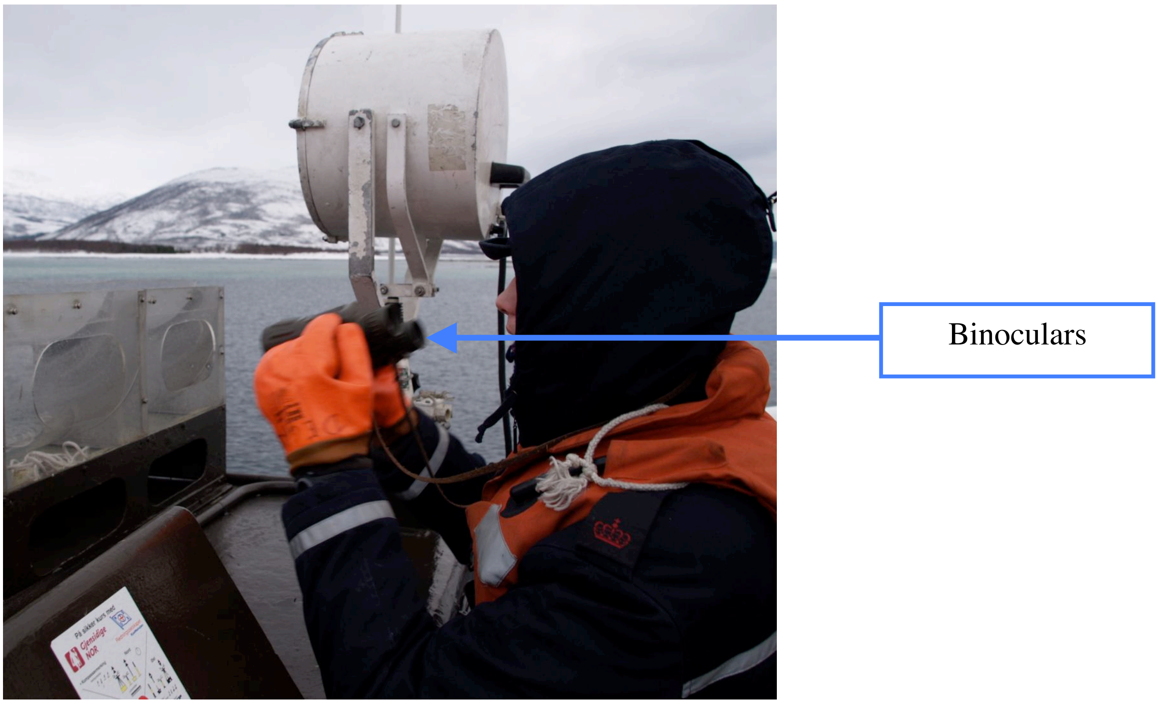


Figure 4-4: The lookout’s workplace.

4.3 Task analysis

A common set of instruments and information which the navigator needs to monitor at all times were identified. In good visibility conditions, the navigator observes the environment by visual means. The concurrent tasks carried out during good visibility are denoted SCAN. The navigator carries out these tasks.

Table 4-1: Concurrent tasks conducted by the navigator.

SCAN

- Check ship's course on bearing display
- Look out for vessels and observe navigation objects
- Evaluate course with reference to plan
- Evaluate performance of other persons on navigation team
- Monitor distance to turn by stop watch and log

4.3.1 Navigate to destination

The assignment *navigate to destination* is the highest level of navigator's work. This assignment includes planning and execution of the navigation plan. The assignment is given to the navigator from the commanding officer. The commanding officers usually gives directions such as where the destination is, which general leads to follow, if particular other tasks or exercises are to be conducted along the route, required time of arrival and other relevant issues. Based on these guidelines the navigator conducts the planning. The assignment can be divided into the following segments: Plan, start, monitor, change course, and arrive port. The segments are described in Table 4-2:

Table 4-2: Navigate to destination.

Super-ordinate	Task analysis Segments	Notes
0	NAVIGATE TO DESTINATION *Plan 0:* *Carry out 1 to 5 in order*	
	1. Plan	The planning phase.
	2. Start	The execution phase encompass task 2 to 5.
	3. Monitor	
	4. Change course	
	5. Arrive	This ends the execution of plan.

4.3.2 Plan

Planning is the first segment of the navigators assignment. The navigator plans the upcoming route, and upon completion he gets approval of the plan from the CO. Planning consists of seven main tasks, all carried out by the navigator (see Table 4-3).

The safety critical tasks during planning are the identification of hazards represented in the chart. To sail clear of hazards, corresponding aids for navigation are identified. Aids can be external, such as lighthouses or internal such as use of radar. Based on the identification of hazards and aids, the course is plotted in the chart. This sequence is repeated for each course of the plan. Before the plan is executed, the commanding officer will approve the plan. If any comments, courses are edited as necessary.

Table 4-3: Plan.

Super-ordinate	Task analysis Tasks	Notes
1	PLAN *Plan 1:* *Carry out 1,* *Do 2-5 in sequence, and repeat for each course* *Do 6 as necessary* *When last leg on route is plotted do 7*	
	1. Choose general route	Based on guidelines from the commanding officer
	2. Identify hazards	
	3. Find aids	
	4. Plot course in chart	
	5. Choose next leg	
	6. Edit course	
	7. Approval by commanding officer	

4.3.3 Start

Start of sailing includes the tasks necessary to get the ship ready for departure, and to start the execution of the navigation plan. This segment consists of four main tasks: Personnel on watch, brief personnel, maneuver from jetty, and start first course.

People are called on watch by announcing departure over the public announcement system. When the navigation crew is on the bridge, the navigator briefs the bridge personnel. If circumstances dictate, a particular helmsman may be preferred. The lookout is briefed if particular issues are to be observed. The plotter is briefed about where to start distance calculations and where to note first position. The navigator further describes the navigation plan and his intentions to the plotter, and what special information that will be needed. The plotter is given a broad description of the plan, such as a description of the demanding areas.

When the ship starts on the first leg of the navigation plan, the navigator SCAN and uses the optical bearing device to check heading towards geographical objects. The navigator and plotter communicate to confirm navigator's observations with the plan in the chart.

4.3.4 Monitor

It is essential for the navigator to keep track of the ship's progress and its deviation from planned course. This is done through the monitor tasks, described in detail in Table 4-5. Monitoring the plan consists of four tasks: Check heading and distance traveled, take positions, alter course, and adjust ship's speed. The navigator is the person who initiates and coordinates these tasks.

4.3.5 Change course

Change of course relates to the distance traveled. When the ship has sailed the distance corresponding to the course, the navigator must bring the ship onto the next planned course. This segment consists of four task; find next course, check next course, identify turning object, and order new course. Table 4-6 describes these operations.

4.3.6 Arrive

When the ship arrives at the destination several tasks are carried out: Maneuver to jetty, debrief personnel, and go off watch. These tasks are described in Table 4-7. When the crew goes off watch, the assignment has been completed.

Table 4-4: Start.

Super-ordinate			Task analysis Tasks/ operations	Notes
2			START *Plan 2:* *Carry out 1 to 4 in sequence*	
			1. Navigation team on watch	Navigator calls personnel to stations
			2. Brief navigation team	Navigator briefs the team
			3. Maneuver to starting point	Navigator carries out the maneuvering of the ship
			4. Start first course of navigation plan	SCAN
	2.2		BRIEF NAVIGATION TEAM *Plan 2.2:* *Carry out 1*	Navigation team is given general information, the plotter is briefed specifically
			1. Navigator briefs plotter	
	2.3		MANEUVER TO START POINT *Plan 2.3:* *Carry out 1 and 2 in sequence*	
			1. Find reference point	Navigator identifies objects in the world and communicates with plotter.
			2. Update plot	Plotter starts calculations
	2.4		START FIRST COURSE *Plan 2.4:* *Carry out 1*	
			1. Check heading	SCAN
		2.2.1	NAVIGATOR BRIEFS PLOTTER *Plan 2.2.1* Carry out 1 and 2 in sequence	
			1. Describes plan	Uses chart as a common frame for explanation.
			2. Describes where to update log after departure	Plotter often makes notes in chart
		2.4.1	CHECK HEADING *Plan 2.4.1* *Carry out 1 to 3*	
			1. Check repeater	Done by the navigator
			2. Check optical bearing device	Done by the navigator
			3. Verify with plot	Communication navigator - plotter

Table 4-5: Monitor.

Super-ordinate	Task analysis Tasks/ operations	Notes
3	MONITOR	
	Plan 3: *Carry out 1-3 in sequence* *Carry out 4 if applicable*	1,2, and 3 might be carried out in any sequence as they are independent.
	1. Check distance traveled and heading	
	2. Take position	
	3. Alter course	
	4. Reduce speed	If applicable
3.1	CHECK DISTANCE TRAVELED AND HEADING	
	Plan 3.1: *Carry out 1-3 in sequence*	1,2, and 3 might be carried out in any sequence as they are independent.
	1. Obtain information on course and distance	
	2. Obtain distance to turn	
	3. Check heading	
3.2	TAKE POSITION	
	Plan 3.2: *Do 1 or 2*	
	1. Take cross-bearing	
	2. Take four-point bearing	
3.3	ALTER COURSE	
	Plan 3.3: *Do 1-4 in sequence*	
	1. Decide on corrective course	Heuristics normally used
	2. Calculate distance to enter planned track	
	3. Order new course to helmsman	
	4. Start watch to control distance	Navigators stop watch
3.4	ADJUST SPEED	
	Plan 3.4:	
	1. Decide on new speed	Heuristics normally used
	2. Set throttles	
3.1.1	OBTAIN INFORMATION ON COURSE AND DISTANCE	
	Plan 3.1.1: *Do 1-3 in sequence*	Communication between navigator and plotter
	1. Plotter reads chart	
	2. Plotter announces distance and course	
	3. Navigator acknowledges	

3.1.2 OBTAIN DISTANCE TO TURN

Plan 3.1.2:
Do 1-6 in sequence

1. Plotter reads log
2. Plotter compares reading to distance at leg start
3. Plotter subtracts elapsed distance from total distance
4. Plotter announces remaining distance
5. Navigator acknowledges
6. Plotter marks distance in chart

3.1.3 CHECK HEADING

Plan 3.1.3:
Do 1-3 in sequence

All done by navigator

1. Find reference point
2. Take bearing with optical bearing device
3. Compare bearing with planned course

3.2.1 TAKE CROSS-BEARING

Plan 3.2.1:
Do 1-3 in sequence

1. Identify two objects	Done by navigator
2. Take bearing	Done by navigator
3. Chart work	Done by plotter

3.2.2 TAKE FOUR-POINT BEARING

Plan 3.2.2:
Do 1-3 in sequence

1. Identify one object	Done by navigator
2. Measure bearing and distance	Done by navigator
3. Chart work	Done by plotter

3.2.1.1 IDENTIFY TWO OBJECTS

Plan 3.2.1.1:
Do 1-4 in sequence

All tasks done by navigator. Task 2 requires shared understanding with plotter.

1. Observe object visually
2. Identify from chart
3. Verify with personal sense
4. Communicate object to plotter

3.2.1.2 TAKE BEARING

Plan 3.2.1.2:
Do 1-3 in sequence

1. Use optical bearing device	Done by navigator
2. Report bearings to plotter	Done by navigator

	3. Plotter notes log	
3.2.1.3	CHART WORK *Plan 3.2.1.3:* *Do 1-7 in sequence* 1. Marks lines of bearings in chart 2. Obtains intersection 3. Notes log in chart 4. Compares position with plan 5. Reports relation between plan and intersection 6. Navigator acknowledges 7. Notes position in log	All tasks except 6 carried out by plotter
3.2.2.1	IDENTIFY ONE OBJECT *Plan 3.2.2.1:* *Do 1-4 in sequence* 1. Observe object visually 2. Identify from chart 3. Verify with personal sense 4. Communicate object to plotter	All tasks done by navigator. 2 requires shared understanding with plotter.
3.2.2.2	MEASURE BEARING AND DISTANCE *Plan 3.2.2.2:* *Do 1-7 in sequence* 1. Direct bearing device 45 degrees relative to course 2. Start watch when object in bearing 3. Report planned passing distance to object 4. Stop watch when object 90 degrees relative to course 5. Calculate distance 6. Calculate bearing 7. Report distance and bearing to plotter	All tasks done by navigator.
3.2.2.3	CHART WORK *Plan 3.2.2.3:* *Do 1,2 in sequence* 1. Plotter notes log in chart 2. Plotter notes position in log book	All tasks done by plotter

Table 4-6: Change course.

Super-ordinate	Task analysis Tasks/ operations	Notes
4	CHANGE COURSE *Plan 4:* *Do 1-4 in sequence. 3 can be done at any time*	
	1. Find next course 2. Check next course 3. Identify turning object 4. Order new course	
4.1	FIND NEXT COURSE *Plan 4.1:* *Do 1,2 in sequence*	This task might be carried out several times to verify plan
	1. Plotter reads distance and course in chart 2. Navigator acknowledges	
4.2	CHECK NEXT COURSE *Plan 4.2:* *Do 1-4 in sequence*	Carried out by navigator
	1. Choose display on knob 2. Direct bearing device to next course 3. Read display 4. Reset knob	
4.4	ORDER NEW COURSE *Plan 4.4:* *Do 1-3 in sequence*	Carried out by navigator
	1. Object in 90 degrees relative bearing 2. Decide on turn 3. Orders to helmsman	
4.4.3	ORDERS TO HELMSMAN *Plan 4.4.3:* *Do one of 1,2, or 3*	Depends on the amount of degrees of course change.
	1. Positive control turn	Navigator orders rudder angle
	2. Less than 10 degrees course change	Navigator orders new course
	3. More than 10 degrees course change	Navigator orders rudder angle and course

Table 4-7: Arrive.

Super-ordinate	Task analysis Tasks/ operations	Notes
5	ARRIVE *Plan 5:* *Do 1-4 in sequence*	
	1. Maneuver to end point	
	2. Approach jetty	
	3. Debrief navigation team	Plotter is usually given own debrief by navigator
	4. Off watch	Navigator starts making new navigation plans.
5.1	MANEUVER TO END POINT *Plan 5.1:* *Do 1-4 in sequence*	All tasks carried out by navigator.
	1. Alert personnel	
	2. Brief personnel	About plan for securing
	3. Plan approach	In cooperation with commanding officer
	4. Order mooring stations	

4.4 Discussion

Task analysis is a means for obtaining a sound understanding of interactive systems before design work is started. The method provides a detailed description of assignments in a system-specific context. The method has also a defined start and stop point. The start point is the overarching assignment of the work. The stop point is the description of detailed operations that are carried out.

There is, however, one limitation connected to task analysis that should be noted. Using the method usually requires that a prototypical task can be defined (Rasmussen and Rouse 1981) or that worker follow normative prescriptions (Vicente 1999). Authors (e.g. Sheridan 1998, Vicente 1999) claim that this is an unrealistic assumption about human work. Several authors have claimed that worker do not follow normative prescriptions (e.g Hutchins 1995a, Nardi 1996a, Dekker 2002, Lützhöft 2004, Norros 2004).

The following chapters will elaborate on the work of fast patrol boat navigation teams and use other frameworks in order to describe their work.

5 Usability study

The previous chapters have introduced the Hauk-class fast patrol boat and described how these ships are navigated (Chapter 3) and provided a detailed task analysis of the work of the navigation team (Chapter 4). To gather knowledge about the artifacts that are currently used on the bridge of the Hauk-class, a usability study was carried out. The central aspect of this study was to investigate to which extent modern navigation equipment corresponds with established human factors guidelines.

Usability studies explore the artifacts from the users' point of view. The users are those who work with the equipment on a daily basis. The users possess knowledge about the use of a system. However, being an expert at the job is different from being an expert at how to organize or invent artifacts that can improve the work. Users cannot be expected to provide directly all the knowledge necessary for job improvements, or to know which human factors guidelines exist in the field (Nielsen 1993, Faulkner 2000). To say anything about artifacts functions with regards to human factors principles, there is also need for human factors knowledge.

This study used design heuristics for the evaluation of usability issues. In general, heuristics are principles believed to improve a system's safety and effectiveness. Heuristics are widely used within human-computer interaction in the design of display interfaces (e.g. Nielsen 1993, Shneiderman 1998). However, heuristics can also have a broader scope of use, and treat more general aspects of design (e.g. Norman 1988).

In this usability study, expert users and human factors experts cooperated in order to reveal the function of the system as well as human factors related issues. The equipment in question was the systems that had been fitted to the ship in a technology upgrading. This upgrading had been completed six months prior to the investigation. The systems were the radar, the communication system and ship automation.

The radar is the ship's primary means for detecting other ships and land under low visibility conditions. The radar interface (Figure 5-1) consists of one screen and the operator panel. On the screen, the radar picture is displayed. The screen can also display an electronic chart. There are several functions related to the presentation of the radar picture or the chart. These functions are displayed in menus on the left part of the screen and are controlled by use of the operator panel. The operator panel is a variation of a computer mouse, using a tracker ball and controls for right, middle and left click.

Figure 5-1: The radar screen (left) and the operator panel with tracker ball (to the right).

The communication system interface at the commanding officer's position (Figure 5-2) consists of two boxes and one headset. Identical interfaces are also found at other working positions on the ship. The boxes are used to choose whom to communicate with, e.g. with other crewmembers on the ship or external communication with other ships. The headset is used to send or receive voice communication.

Figure 5-2: The communication system at the commanding officer's position. The system includes the two boxes and the headset.

The ship automation system (Figure 5-3) is the interface the navigator operates in order to control the ship's speed. The navigator sets the speed by positioning two throttles that correspond to the desired engines' rotational speed. The navigator can achieve desired rotational speed at a minimum of time by using *manual mode*. The manual mode leads to serious stress on the engines, and this mode is primarily used in emergency situations. In *automatic mode*, the automation system will increase or decrease rotational speed in accordance with a predefined program. The engines' present rotational speeds are displayed on two dials on the upper part of the interface. Buttons for choosing the mode are located on each side of the throttles. On the interface there are several indicators showing engine status. There are also audio alarms connected to the automation system.

Figure 5-3: The automation interface. The throttles are in the centre, buttons for changing mode are located beside the throttles. Dials representing the engines' rotational speeds are on the upper part of the figure.

5.1 Method

The usability study used a *cognitive walkthrough* (Faulkner 2002). A cognitive walkthrough is a formal technique which utilizes users and human factors experts. The expert user informs the human factors expert about the application and use of the equipment. The human factors expert pretends to be the user but at the same time has an expert appreciation of the usability issues. In this study the expert users was one experienced fast patrol boat navigator with 4 years of experience on the Hauk-class. Two evaluators evaluated the navigation equipment in accordance with an agreed framework from different design heuristics. The two evaluators performed their evaluations separately, so that their opinion was not biased by the other's opinions. The agreed framework for this study was design heuristics derived from Norman (1988) and Hoff (2002). The principles from Norman (1988) were:

Gulf of execution. The difference between the user's intentions and the allowable actions is the gulf of execution. The actions provided by the system can be awkward to use, or in worst cases the system may not provide possibilities for the user to carry out the intentions.

Gulf of evaluation. This aspect refers to whether the system provides a physical representation that can be directly perceived and that is directly interpretable in terms of the intentions and expectations of the user. System feedback about ongoing changes should be directly perceivable in order not create a gulf of evaluation.

Mapping. This refers to the relationship between the configuration of the interface and the spatial location of the represented elements. Mapping is about how the representations on the interface are spatially located.

The Ecological Interaction Properties are elements that describe the user experience of a tool used in a particular context (Hoff 2002). The following properties were used:

Motoric scaling. This refers to the physical size of the interface in relation to the anthropometric and biomechanical properties of the user. According to Hoff (ibid.) modern products are commonly small and light considering their use, examples are wrist watch calculators and mobile telephone joy sticks.

Perceptual scaling. This refers to how presentation of information is fitted to the user's perceptual system, e.g. how information is represented visually, by sounds, or tactile. This heuristic is commonly violated with regard to use of lights in interfaces (ibid.).

Perceptual Richness. An interface can engage many or few of the users perceptual senses. The interface can inform the user through visual inputs, tactile feedback, sounds, smell and so on. A perceptually rich interface is an interface that uses several of the user's senses in interaction.

Specific – Generic. The dimension refers to the relationship between controls and the functions that are operated. As an example; an iPod controls a large amount of functions from four touch buttons and a touch wheel. This is an example of a generic interface. On the opposite, on a specific interface one control is connected to one function. An example is old TV sets, where on/off, each channels and light, contrast on so on had dedicated buttons.

5.2 Results

The cognitive walkthrough revealed in total 30 issues related to the equipment in question. These are presented in tables (Table 5-1 to Table 5-3). Each usability issue is presented along with its corresponding design heuristics.

Table 5-1: Radar interface findings.

No:	Usability issues	Heuristic
1	The operator interface is hard to access from the navigator's primary working position.	Gulf of execution
2	The buttons on the operator panels lack tactile feedback.	Motoric scaling
3	The radar screen displays too much light during the dark hours. The crew has made a foam modification that reduces light. However, this modification means that the navigator cannot access the radar from the normal working position.	Perceptual scaling Gulf of evaluation
4	Buttons on the operator panel is marked A, B, and C. Their function must be inferred from prior knowledge.	Gulf of evaluation
5	The operator panel controls several functions by tracker ball and menu operations. The functions are not structured according to criticality or user relevance. E.g. function to mark the man over board position is not easy accessible.	Gulf of execution Specific-generic
6	Switching between chart and radar functions sometimes makes the system stop. System status and progress are not clearly represented.	Gulf of evaluation

Table 5-2: Communication system findings.

No:	Usability issues	Heuristic
7	Buttons on communication units are located too close for operation when the ship is heaving.	Motoric scaling
8	Buttons lack tactile feedback. Users need to see the interface in order to select the right button, and to evaluate if the right command were given.	Motoric scaling Gulf of evaluation
9	It is not easy to determine which functions correspond to each button.	Gulf of execution Gulf of evaluation
10	All buttons are of identical form and shape. It is not easy to determine their primary functions.	Perceptual scaling Motoric scaling
11	There is no correspondence between the layout of the interface and the system's functions. Buttons with related functions are not located together.	Mapping Gulf of evaluation
12	The headsets have no determined place when not in use. In the dark the headsets are hard to find.	Mapping Specific-generic
13	There are no dedicated communication channels from the navigator to the lookout. Knocking signals are used.	Gulf of execution
14	The communication system has many sub-menus. To find a given function requires time and cognitive effort.	Specific-generic
15	The communication frequency monitored is not represented to the user. This must be inferred based on the content in the radio transmission.	Gulf of evaluation Mapping
16	In some functions different boxes are used for communication input and output.	Gulf of execution Gulf of evaluation
17	The interface provides much light during dark hours. To reduce light the interface is covered. This also reduces access to the interface for operation.	Perceptual scaling

Table 5-3: Automation system findings.

No:	Usability issues	Heuristic
18	Buttons for choosing manual or automatic change of engine rotational speed is located under covers. This reduces the risk of unintentional activation, but makes vital functions hard to access.	Gulf of execution
19	The automation lacks feedback of what mode of engine control is active.	Gulf of evaluation
20	In order to perform an emergency stop, the maneuver handles can be pulled hard backwards to activate manual control. It is not clearly represented when manual control is active.	Gulf of evaluation
21	Users describe maneuver handles as too sensitive to small adjustments.	Motoric scaling
22	The maneuver handles have a small tactile feedback that represents neutral position. This feedback is hard to feel.	Motoric scaling Perceptual richness
23	Many buttons have little tactile feedback. Some are hard to separate from the consol surface.	Motoric scaling Perceptual richness
24	One switch refers to the choice of representation on the display located on the starboard side of the bridge.	Gulf of evaluation Mapping
25	One switch has options that relate to functions that are no longer available.	Gulf of evaluation
26	The functions are grouped according to which technical system parts they belong to. The functions are not grouped together based on importance and relevance for user or tasks.	Physical-inferential Mapping
27	The location of window wiper switches do not correspond to the spatial location of the wipers.	Mapping
28	The alarm indicators are identical to the buttons for controlling engine mode. The operator must infer feedback and function.	Gulf of evaluation
29	The interface provides much light during dark hours. To reduce light the interface is covered. This also reduce access to the interface for operation.	Perceptual scaling
30	To perceive buttons visually in the dark, black buttons with white text are better than vice versa.	Perceptual scaling

5.3 Discussion

The usability evaluation of one Hauk-class bridge provided findings that can be related to central aspects of man-machine interaction in a complex technological system. The findings indicate that there is a discrepancy between the solutions provided by the manufacturers and the solutions preferred by the actual users. The solutions provided by manufacturers are in some cases not in line with established human factors principles. An important issue here is to what extent the users compensate for the discrepancy between what is provided and what is preferred. There is a risk that such compensation will degrade safety, effectiveness, and health. This report suggests two main methods of user compensation:

(1) The users compensate by expanding their actions and sequences of actions, so called *workarounds*. The users increase the amount of actions required, and also increase the complexity of the actions when operating the system interface or controller functions. For instance, this is found in the use of the radar interface; the interface buttons provide little information about function and the user must add more steps in order to perform the relevant tasks. These steps are about controlling and verifying that one really carries out what one had planned to do. If the interface had provided more rich feedback, such steps would not be needed. Workarounds have a mental component related to memory and inference, and workarounds can increase the workload.

(2) The users modify the equipment and make their own design, so called *system tailoring*. In such cases the users change the physical properties of the exterior or the interface. Examples are the use of covers to reduce light from radar, communication system, and control panels. On the communication system small pieces of tape were used to mark essential functions by adding texture to a specific button. This improved the operation of the system. On the other hand, the covers made for the automation

control console covered functions for changing the engines' rotational speed. This example of system tailoring could reduce safety.

This usability study is based on a vessel that is currently in service and where procedures and practice are established. To this established organization, new and modern equipment is introduced. The findings indicate that the new systems on this ship are not in accordance with general design heuristics. The findings also suggest that there is a need for the user to modify the equipment in order to improve usability. Compensation and user adaptation to advanced technology is common, and such findings are also found in other industry domains, e.g. at nuclear power plants (Vicente 1999), in electrical power controls (Hoff 2002), operating rooms (Cook and Woods 1996), and in aircraft cockpits (Hutchins 1995b). That such findings are made on the bridge of the Hauk-class comes as no surprise. The findings do not necessarily represent safety-critical issues. A main point here is how to understand this user adaptation, and the impact on safety. In order to say anything about the impact on safety, the users' compensations should be evaluated. User compensations may function satisfactorily in normal situations. However, such an evaluation should investigate whether the users' compensation can lead to degraded safety in special or abnormal situations.

Design heuristics is a low-cost means to improve design. However, in order to conduct a heuristic evaluation there must exist a product to investigate. In order to include human factors at an early stage of product development, the knowledge of user and system use can form a basis for design of an initial product solution. In the following chapters the everyday work of the navigation teams will be investigated and the knowledge obtained will form a basis in design of prototypes of navigation equipment.

6 Distributed cognition findings

In order to gather knowledge of how high-speed navigation on fast patrol boats the distributed cognition approach was used to describe the tasks performed by the navigation team. A description of the framework of distributed cognition was given in chapter 2. In short, distributed cognition is a descriptive framework that provides a means for structuring what people really do in their field of work (Nardi 1996b, Halverson 2002). Distributed cognition is a perspective on cognition rather than a type of cognition (Hollan et al. 2000). It reflects how cognitive activities are interactions between functionally related persons and artifacts. Such functional relationships can configure themselves to bring sub-systems into work in order to solve problems and carry out tasks. A tenet of distributed cognition is how information follows trajectories within the functional relationship. The focus of the investigation was on how the work of the navigation team involves interaction between crewmembers and artifacts.

The analysis is based on field studies that were conducted on board Norwegian fast patrol boats. Crews from the 21st and 22nd fast patrol boat squadrons in the Royal Norwegian Navy were studied. Two crews were studied during naval exercises in 2003 and 2004. The navigation teams were representative in terms of rank, training and experience. Direct and indirect observation was conducted, in total 120 hours of video was gathered. Semi-structured interviews with navigators were carried out.

The study identified some central cognitive processes in the navigation team, processes that were related to planning navigation, and execution of the navigation plan. In these processes both crewmembers and the artifacts they used were necessary agents. Further, the relationship between the agents were investigated, especially how relationships varied during navigation.

6.1 Cognitive processes

In the work of the navigation team, two main groups of cognitive tasks were identified; the tasks relating to the planning of the navigation, and the tasks relating to the execution of the navigation plan. Navigation is always planned, and planning is regarded as a task of its own. When the ship departs, the navigation plan is executed. Here, two major cognitive tasks were identified; memorizing the plan, and calculation of the ship's position. Memorizing is about how the knowledge obtained during planning is recalled and made available to the navigator. Calculation of the ship's position is about obtaining knowledge of the ship's geographical position. In the following these cognitive processes are elaborated on.

6.1.1 Planning

The navigator receives his assignment from the commanding officer. When the navigator has received information of which general geographical route will be navigated, the navigator plans the navigation in more detail prior to departure. The equipment that is used is: The chart, a ruler, pencils, and eraser. Planning is about choosing a track that the ship should follow. The result of the planning is a series of consecutive lines drawn in the chart, denoted *the plan*. An individual line is denoted the *course*. The plan represents the track the navigator will follow during the navigation. Each course is planned based on the information the navigator obtains from the chart.

During planning the navigator works on representations of the real world. The chart represents the positions of land, sea, and objects relevant for navigation. The courses that are drawn in the chart represent the track that will make the vessel progress safely. During planning, the navigator draws courses that are clear of the representations of shallow area, small islets, and other objects. However, the navigator is not only concerned with planning the course clear of dangerous areas.

The navigator also takes into account that the course should be easy to follow during execution of the navigation plan. Hence, the planning focuses on both the representations of the geographical dangers along the route, as well as the representations of objects that will support the navigator in following the planned track. This is expressed in a planning strategy, the strategy of *identifying dangers and means*. This strategy includes two steps. First, the navigator should identify the chart representations of dangers relevant to each course. Dangers are whatever objects the vessel might collide with, and examples of such dangers are shallow areas and land. In the chart, the navigator marks dangers by use of a pencil. Second, the means for safe navigation is identified. Such means are objects that support the navigator in turning the course in the chart into a trajectory in the world. A lighthouse can be a means; when a course[4] is planned with a heading towards a lighthouse, the lighthouse is the reference object that supports turning the plan into a trajectory in the real world.

During the planning process the charts are enriched. A plain chart represents a basis of information available. During planning the information relevant to the fast patrol boats navigation is extracted and highlighted. Hutchins (2004) suggests that there should be a clear mapping between the operator's salient conceptual relations and salient perceptual properties on the artifact's interface. During the planning process the navigator improves the chart so the interface (chart) reflects the specific plan that is to be carried out. Thus, the planning process does not only result in a series of consecutive courses that should be followed, the planning also results in an enriched chart that is the frame of reference for the other cognitive tasks; how information is retrieved from the chart, and how the ship's position is calculated. Figure 6-1 is an example of a chart prepared for navigation.

---

[4] A note on the terminology: *course* as it is used on board naval ships can mean both the representation in the chart as well as it can mean the trajectory in the real world.

Figure 6-1: Chart prepared for navigation.

6.1.2 Memory

After planning, the navigator rehearses the plan until he has a mental representation of the plan. However, memory is known to be a limited resource (Miller 1956, Reason 1990). The navigator cannot remember all relevant details of the navigation plan that were highlighted during the planning. The navigator needs to have some sort of system that can hold and provide information. This system is found in the functional relationship between the chart, the plotter, and the navigator. In this system the chart functions as external memory. The plotter reads the chart and the information is communicated between the plotter and the navigator. The frame of reference for this communication is what has been highlighted in the chart during planning. The following example gives an example of the communication between plotter and navigator.

Example 6-1: Communication between navigator and plotter.

Time is 01.13 a.m., it is dark and snowing. The navigator is using the radar, then looking out. Simultaneously he is communicating with the plotter.

Navigator: Repeat distance on this course. (*The navigator is looking into the radar while talking.)*

Plotter: Six point fifteen.

Navigator: Roger, next course.

Plotter: Zero Five Six.

Navigator: Roger. (*The navigator is looking into the radar, then he is turning towards the plotter and looking into the chart.)*

The communication between the plotter and the navigator is not limited to what has been planned. Meeting vessels cannot be planned beforehand. Commonly, meeting a vessel necessitates a deviation from the plan, which again requires information particular to this deviation. An example of ad-hoc communication is the following example:

Example 6-2: Meeting a vessel.

Time: 0123 am to 0124 am (local)

Lookout: Vessel ahead!

Navigator: Go to three three six degrees.

Helmsman: To three three six degrees.

Plotter: No dangers on this course, some shallow water on port.

Example 6-2 demonstrates how the plotter understands that a change of course makes the navigator demand additional knowledge of the waters. The plotter informs the navigator that there are no dangers relating to this course. This example also shows how an experienced plotter extracts information from the chart and makes this available to the navigator.

In addition to the chart, some other artifacts are used to augment the navigator's memory. In Example 6-1 the navigator operated the radar. On the radar there is an electronic bearing marker, that is a line representation that can be adjusted to point in all directions on the radar screen. The marker is adjusted in order to find the bearing in degrees relative to contacts observed on the radar screen. The measurement can be read on a display on the radar. When the plotter reads the next course, the navigator commonly directs the marker in the same bearing as the upcoming course. In this way the navigator does not need to remember the next course, the course can be read in the measurement display. When navigating visually, the optical bearing device (Figure 6-2) can be used to augment memory in a similar way as the radar bearing marker. In this case, the navigator directs the optical bearing device in the same compass direction as the next course, and the direction of the device is displayed in a separate display (see Figure 4-3).

The memory function of the electronic bearing marker and the optical bearing device is to hold information over a limited time. These artifacts can be tuned to function as memory. However, their primary function is however connected to measurements of bearings. The chart provides a more stable representation of information. This information is available for longer periods of time. The primary function of the chart is to provide the navigator with what is necessary to know in order to navigate safely. Although the chart provides relevant information, the navigator also uses other artifacts to offload cognitive effort.

6.1.3 Obtaining the ship's position

The two previously described cognitive processes were about planning and memorizing the knowledge that was obtained during planning. In order to control the progress when the ship is sailing, the navigator must have knowledge of the ship's position. The navigator controls the ship's progress relative to the navigation plan. The technique of directing the optical bearing device in the direction of the next course is not only about augmenting memory. The directing also helps the navigator to obtain a spatial sense of the environment. Based on this spatial sense, the reference objects in the navigation plan are identified and used to obtain knowledge of the ship's position. Basically, there are two ways of obtaining the ship's position when navigating visually, that is by using cross-bearing or four-point bearing method.

When the ship's position is to be found by cross-bearings the navigator measures bearings to two known objects by using the optical bearing device. A known object is an object that is identified both in the environment and as the corresponding representation in the chart. Examples of such objects are lighthouses, iron perches, and small islets. The bearings are measured by the use of the optical bearing device and its display, and are then communicated to the plotter. The plotter draws these bearings in the chart. The bearings are now represented as lines in the chart. The ship's position is represented in the chart by the intersection (cross) of the bearings, hence the name cross-bearings. The plotter then communicates back to the navigator how the ship's represented position corresponds to the plan. Upon receiving information about the position relative to the plan, the navigator decides what courses to steer.

Fixing the position by use of cross-bearing is accurate, however the method is time-consuming. On fast patrol boats the prevailing method of position fixing is the use of four-point bearings. This method is less time-consuming, but also less accurate. More descriptions of the position fixing methods can be found in chapter 3. Here we will focus one issues of the four-point bearing method; how to make a bearing 45 degrees relative to the ship's steered course. There are basically three ways of aligning the optical bearing device 45 degrees relative to the ship's course:

1) Take the ship's course and add or subtract 45 degrees and then align the bearing device to the calculated direction. While aligning, it is necessary to monitor the display to read the device's direction.
2) The bearing device has a small scale that can be used for alignment (see Figure 6-2). This requires the navigator to lean forward to get a close look. At night a torch must be used to read this scale.
3) Some bearing devices have small pins screwed into the body of the device. By touching and perceiving how two pins align the device can be aligned correctly.

Figure 6-2: The optical bearing device. The three alignment pins and the scale can been seen on the close-up picture to the left.

On one fast patrol boat, the optical bearing device was not equipped with pins. The navigator, however, was used to operating a device equipped with pins. The navigator then had to abandon his preferred method of taking 45 degrees relative bearings. At night, the navigator found it inconvenient to use a torch. He was then left with one option; he had to make calculations. He experienced that the lack of pins led to an increased workload.

These examples of different ways to align the optical bearing device illustrate how one can use different types of knowledge to reach the same result. The knowledge needed to align the pins is different from the knowledge needed for making calculations. The example also describes how the operators experience a difference in operating the artifact.

6.2 Dynamical configuration

The examples of how the navigation team obtains the ship's position demonstrate that cognitive processes are shaped by the context of high-speed navigation. The navigation team makes opportunistic use of the functional relationships and information trajectories in their work. Opportunistic use is when people use what is deemed good enough to reach their goals, and not necessarily what is perfect or according to procedures. Hollnagel (2004) has coined the term Efficiency Thoroughness Trade-Off (ETTO) that describes how people balance the needs for efficiency against the need for thoroughness.

Opportunistic activation or deactivation of information trajectories and functional relationships can increase team performance. On the other hand, it can also diminish safety. In the following, examples of activation and deactivation of functional relationships are presented, as well as examples that demonstrate how dynamic configurations affect team performance and safety. The first example demonstrates how an established information trajectory is deactivated, which leads to a change in the functional relationship.

Example 6-3: Deactivation of information trajectory.

A ship had two plotters, one experienced and one novice. The latter was not able to work fast enough to give the navigator necessary information. When the novice plotter was on watch, the navigator had to compensate the lack of information by using the radar, and by looking more into the chart, and even doing some work on the chart himself. When the novice plotter was on duty the normal information trajectory between the navigator and the plotter was deactivated.

The next example shows how a new functional relationship is activated opportunistically.

Example 6-4: Opportunistic activation of information trajectory.

One ship had a test version of an electronic chart system. This chart system was mounted between the navigator and the commanding officer. The chart system was supposed to be used only to verify the positions found by the ordinary manual chart work. At night, there are fewer objects to observe for position fixing, and the navigator uses lighthouses and lighted marks to obtain the ship's position. For the plotter this means a longer interval between receiving position information from the navigator. If a too long interval elapses, the chart will not provide useful information for the navigator. In such situations the navigator usually uses the radar to obtain additional bearing so the plotter is informed frequently. In this case, however, the electronic chart (and satellite navigation system) provided the navigator with information about the ship's position. This information was available to the navigator and with less cognitive effort than the normal cooperation with the plotter. In this context the electronic chart system was taken into use as the preferred means for navigation. A functional relationship and information trajectory were here opportunistically activated.

Dynamic configuration of the functional relationship can influence the team's performance. In one situation dynamic configuration was found to form a barrier against erroneous actions. This is described in the following example:

Example 6-5: Barrier against erroneous actions.

In very confined waters the helmsman gives port wheel instead of starboard wheel as ordered. An officer that was not on duty, but was present on the bridge, became quickly aware of the error. This officer grabbed the helmsman instantly and corrected him. Thereby this officer became a part of a functional relationship. A second later the navigator ordered the wheel amidships and then gave new orders to bring the ship back on track. A few seconds later, the commanding officer said; "that's just fine, helmsman. Don't you think of it, just start again". Then the team went back to normal operations.

In Example 6-5 the system configured itself to solve the situation and then re-configured back to normal operations in less than ten seconds. Similar errors by helmsmen were also observed in open waters. In these cases the navigator has calmly corrected the helmsman, and there has not been any change in information trajectories or functional relationships. In narrow waters, the error made by a helmsman could lead to serious consequences, while there are no consequences in open waters. The configuration of the functional system seems to be connected to the consequences of the activity. Dynamic configuration seems to be context sensitive, in this example it is sensitive to the waters.

In the next example tasks develop from the context, and information trajectories are changed in the attempt to find necessary information.

Example 6-6: Entropy.

A situation occurred during dark hours where the navigator became unsure about the ship's position. The log was inaccurately updated and there was doubt about when the ship should change course. When reaching the point that was estimated as where to change course, the new lighthouse the ship should head towards was not visible to the crew. At this point, the navigator was also distracted by an engine alarm sounding on the bridge. The helmsman as well as the plotter started to look for the lighthouse, a task well beyond their responsibility. Eventually the light was seen and reported by the helmsman to the navigator. When the light was observed the ship's position was determined.

These previous examples show that functional relationships are dynamic but have a centre of gravity; the navigator holds the relationship together. As long as the navigator controls that each on the team carry out their job, the information trajectories are stable. When the navigator does not, as in Example 6-6, the result is entropy and the established information trajectories change. Although the situation did not develop into danger, the team for a period of time did not work as a team.

These four examples suggest that there are several ways a system can configure itself. On the one hand this configuration can provide redundancy and layers against failure, but the dynamic nature can also lead to decreased performance. Dynamic configuration can directly be executed by a person, but configuration can also develop from context and tasks.

6.3 Elaborating on information trajectories

Information trajectories can be observed and found in established practices. The trajectories that have been described so far are based in the everyday work of the navigation team. However, there are also more subtle information trajectories within the functional relationships on the bridge. An example is found in the interaction between the navigator, the helmsman and the wheel.

Figure 6-3: Cut working table in order to get access to indicator.

To steer the ship, the navigator directs orders to the helmsman on what course to steer. When the navigator orders the degrees to port or starboard, the helmsman uses the rudder indicator to control that the wheel's steering input results in the required position of the rudder. However, mixing port and starboard is not an unusual error to make. Especially in very narrow waters there is no room for making mistakes. The navigator can control the helmsman's operations by looking at the wheel and observing the turning direction, but this is not possible during dark hours. The rudder indicator is hidden from the view of the navigator, because there is a working table situated between the helmsman and the navigator. On one ship this working table had been modified. A piece of the table was cut out to give the navigator access to reading the rudder indicator (Figure 6-3).

Another way of controlling the helmsman is to obtain information from other senses. One navigator described how he in narrow waters puts his hand slightly in touch with the wheel to feel the rotation direction of the wheel, just to be sure the wheel is turned the correct way. The navigator would then discover an error earlier than watching the rudder indicator. The navigator could also grasp the wheel to prevent an error at an early phase and thereby avoid serious consequences.

The artifacts described so far are operated directly by the crewmembers. However, some artifacts have a very different use. For instance, electronic charts and satellite navigation systems can be described as black boxes, where information is processed inside the box and the operator works on the interface. On the interface, a selection of information is represented. In our study, one ship was equipped with both electronic and paper charts. When regarding these two types of charts from a distributed cognition perspective different qualities were discovered.

When investigating the information trajectories connected with the paper chart, one can quite easily follow the trajectories between the agents. How the ship's position is found can be used as an example: The bearings are measured by the navigators working with the optical bearing device, the bearings are represented on a display, then they are communicated from the navigator to the plotter, and then the bearings are drawn on the chart. This process leads to a representation of the ship's position. The process is observable and transparent. This transparency is contrasted by the hidden information trajectories of the electronic chart system. Here the ship's position is automatically represented by a symbol. The position of this symbol in the electronic chart is based on measurements from the satellite navigation system. The process can be described as using a black box. The output from the black box is a representation of own position, but what is going on inside the box, the navigator cannot know anything about.

Traditionally, navigators evaluate the processes that lead to a representation of the ship's position. The navigator mentally considers questions such as; was the ship moving heavily when I took the bearings? Is the plotter experienced? Did I read the bearings right? Did I bear towards the right lighthouse? In the electronic chart system, the process of determining the ship's position cannot be evaluated effectively by such a strategy. Concerning information trajectories, it seems that the electronic chart represents little information connected to the performance of the system.

6.4 Discussion

The framework of distributed cognition is in this study used to identify implications for design of navigation equipment. The discussion treats general issues that are believed to be relevant in design.

Using the framework of distributed cognition brings into focus the work of the system rather than the work of the individuals. The system includes both people and artifacts, and how these are functionally related. Distributed cognition investigates how functionally related agents form a cognitive system where information is obtained, shared, and exchanged. In the system's cognitive processes, information is described as following trajectories between agents. A distributed cognitive system is dynamic in the sense that functional relationships and information trajectories are activated or de-activated.

Distributed cognition indicates that artifacts can have qualities beyond the initial assumptions of what the artifact was supposed to do. The optical bearing device is such an example. It was designed to measure bearings. However, it is used both to take bearings, augment the navigator's memory, and to support the navigator's spatial sense of the environment. For designers it is not enough to have knowledge of the technical and formal use of an isolated artifact. The relationship with other agents should be discovered.

A design challenge is to make artifacts that are relevant in a variety of relationships and contexts. A directly operated artifact, such as the bearing device can improve its contextual relevance by changing the physical properties of the artifact itself. By mounting pins on the device, it became more usable in the dark. By this improvement the navigator could use other senses to operate the device. The term perceptually rich (Hoff 2002) refers to an interface that gives inputs to the operator by several senses e.g. by the use of haptics (force feedback), tactility, lighting or sound. Regarding directly operated artifacts, perceptual richness seems to make the artifact relevant in more different functional relationships.

This chapter's findings show that pieces of information can be shared in rather subtle ways such as the navigator that touches the wheel to feel in which direction it is turned. That information is perceived in several ways can indicate that a perceptually rich artifact will afford sharing of information. As an example: In order to improve the navigator's control ability towards the helmsman, one could design a wheel that makes one sound when turned to starboard, and another sound when the wheel is turned to port. The specific solution here is to represent the wheel's movements in terms of sound, the general implication is to make artifacts perceptually rich for easier sharing of information. To equip the optical bearing device with pins is another example of how to make the artifact more perceptually rich. When the artifact can be physically manipulated instead of mentally calculated, the result is presumably a changed workload. Distributed cognition suggests that problems and their solutions can be represented in several ways.

According to Hutchins (2004) there should be a clear mapping between the operator's salient conceptual relations, and salient perceptual properties on the artifact's interface. Such a mapping can be found in the paper chart where the navigator during planning marks out the objects that are particularly important to the navigation process. These objects are elements of the navigator's mental model of the navigation plan. Electronic charts do not have a similar possibility to mark out the salient conceptual objects or relations.

That the electronic chart offers limited possibility to map conceptual relations and perceptual properties is made even worse during dark hours. To preserve night vision, the navigation team uses very little light on the bridge. It is then harder to use representations such as the chart and the radar to share information. To improve usability, the conceptual relations of the electronic chart should probably have more salient perceptual properties.

On black box type artifacts, functionality is also connected to how the operator can evaluate the performance of the system. As an example, the satellite navigation system represents the ship's position in the chart automatically. However, there are calculations done inside the system where the outcome could describe the quality of the ship's position (Røed 2001). Usually, the results of these calculations are not represented to the user. To improve transparency and functionality on black box type artifacts, distributed cognition can suggest which information is needed by the user.

7 Activity theory findings

Activity theory is a descriptive framework that offers terminology and concepts for describing what people do in their everyday situations. Activity theory looks at how people interact with other persons and work with the tools they use in their activity. Activity is defined as what persons do in their everyday life. In an activity people relate to their goals, their tools, their social context, and to environmental constraints. The theoretical foundation of activity theory was earlier described in section 2.2. In this chapter the theoretical framework will be used for describing the work of the navigation team on fast patrol boats.

The analysis is based on field studies conducted on board Norwegian fast patrol boats. Crews from the 21st and 22nd fast patrol boat squadrons in the Royal Norwegian Navy were studied. Two crews were studied during naval exercises in 2003 and 2004. The navigation teams were representative in terms of rank, training and experience. Direct and indirect observation was conducted, in total 120 hours of video was gathered. Semi-structured interviews with navigators were carried out.

7.1 The structure of navigation as activity

The tasks of the fast patrol boat require several activities to be conducted simultaneously while the ship is at sea. Different crewmembers are involved in different activities, e.g. the cook is involved in the activity of cooking, the communication operator is involved in another activity, and so forth. This study focuses on the activity of navigation, which is the unit of analysis. This activity is the work of the navigation team as it is carried out on the bridge of the ship during sailing. The navigation team consists of five persons, and the most central person is the navigator. The other persons on the navigation team will be understood in terms of role as support to the navigator.

In the study, activity is regarded as situated actions that take place over short periods of time. A model of activity as situated action was presented in chapter 2. The structure of navigation as activity can be described as the relationships between the subject, object, tools, constraints and the outcome of activity (Norros 2004).

The five persons navigation team is the subject in the study. The team's activity is directed towards an object.

Figure 7-1 shows the layers corresponding to the hierarchy of the activity The motive of the activity is to sail the ship safely and efficiently. The term *efficient* denotes that there is a need to carry out tasks within a given timeframe. It is not enough for the ship to reach its destination, the team should also accomplish this task within a certain time frame. The most prominent actions carried out are to direct the heading of the ship, control the speed, and fix the ship's positions. These actions are directed towards the goal of following the navigation plan. The actions are carried out by operations, which are done through the use of navigation artifacts. These operations correspond to the working conditions applicable to each artifact.

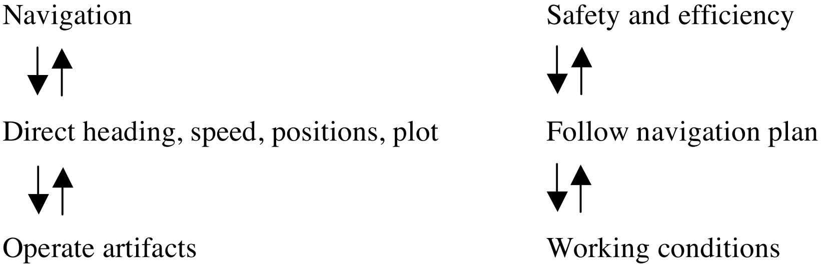


Figure 7-1: The object of the activity corresponding to the hierarchy of the activity.

The crewmembers use tools to mediate their actions. The navigator mediates the activity through a plan represented in the chart and by navigation artifacts such as the optical bearing device and the radar. The navigation team directs their work to transform the object into an outcome. The outcome of the activity is the trajectory of the ship. The structure in which navigation as activity takes place can be represented by the following figure:

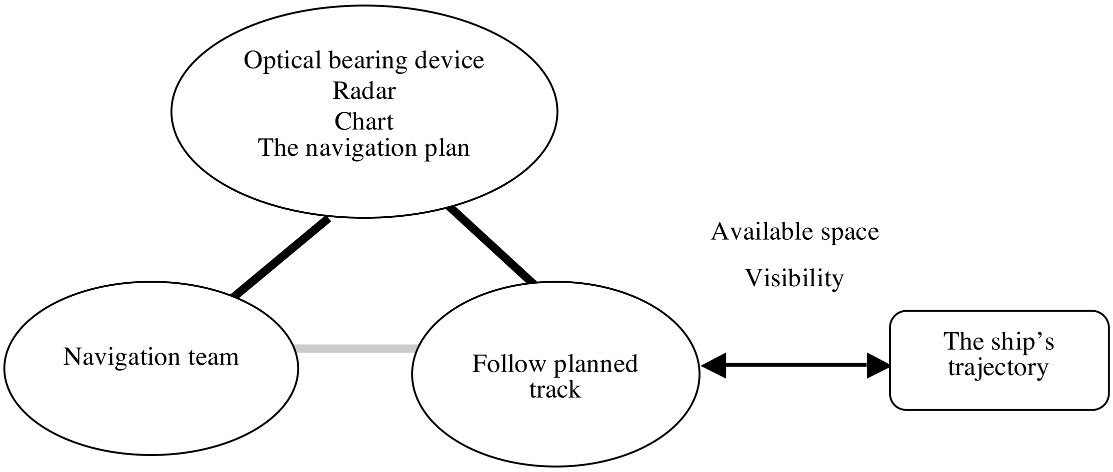


Figure 7-2: The structure of navigation as activity.

Figure 7-2 denotes the relationship between crewmembers, their tools and goals. Actions are considered within a limited timeframe, and cultural and historical relationships to the activity are not taken into account. The black lines on the figure represent mediated relationships. In the following the structure represented on Figure 7-2 will be the frame of reference for describing the activity of the navigation team. The focus will be on the relationships between the elements of the model as well as the tensions within the model.

7.2 Two phases of navigation

Navigation contains two distinct phases, the planning phase and the execution phase. Planning is carried out before the ship leaves harbor. In this phase the navigator shapes the tools that will be used later. The process of internalization-externalization is central here. A navigation plan is externalized in the chart by the navigator. The navigator draws lines in the chart representing the course to steer and for how long a distance the course should be steered. Other information relevant to navigation is noted as well, such as areas with shallow waters, navigation lights to use on particular courses, passing distance to land and more. In this way the chart is enriched in the sense that information is integrated and made more available for the navigator and the plotter. The navigator externalizes his plan in the chart according to his personal sense of what will be important when sailing the route. However, some pieces of information have to be memorized, and this is internalized in order to be able to follow the plan without continuously looking at the chart. Gautherau and Hollnagel (2005) describe planning as a resource for actions. On the fast patrol boats the plan is a resource for the whole team and not only for the navigator.

When the ship departs the navigation activity enters a new phase, the execution phase. The navigator now directs the ship’s heading and speed based on the navigation plan. In this work, the course and distance to sail is communicated between the navigator and the plotter. When the navigator has received and understood the information given to him by the plotter, he acknowledges. If the navigator is in doubt about the meaning of the information, he asks the plotter to repeat or verify. Sometimes the navigator turns to look into the chart and discuss upcoming parts of the voyage. Here, the chart serves as a common frame of reference for the navigator and plotter.

During the execution phase, the externalized plan represented in the chart is negotiated with the real world. The navigator needs to have a personal sense of the chart as well as the relative position of other vessels. In order to achieve and hold a internal representation of the environment, the plan is continuously communicated. By communicating with the plotter and the lookout, the navigator internalized the plan for the near future of the voyage. An example of this is as follows:

Example 7-1: Internalization of navigation plan.

Time : 0113 am to 0115 am (local):

The navigator is using the radar, then looking out. Simultaneously he is communicating with the plotter.

Navigator: Repeat distance on this course. *The navigator is looking into the radar while talking.*

Plotter: Six point fifteen.

Navigator: Roger, next course.

Plotter: Zero Five Six.

Navigator: Roger. *The navigator is looking into the radar, then turns towards the plotter and looks into the chart.*

Lookout: Vessel in Green 30.

Navigator: (*Talking a bit low*) Green 30, yes, that is roger. *The navigator is still looking into the chart.*

Lookout: Vessel in Green 30.

Navigator: Roger! *The navigator is turning towards the radar.*

This example demonstrates the cooperation between the navigator, the plotter and the lookout. The crewmembers use certain artifacts to mediate the activity. The navigation plan is the centre of the internalization-externalization process, where the next course and distance to sail is communicated and internalized. When the navigator has received and understood the information given to him, he replies using the word “roger”. When the navigator wants to verify information, he asks the plotter to verify; “repeat the distance...”. The word “roger” then indicates that internalization has taken place.

7.3 Mediation

As the previous examples have described, the navigation team uses tools to mediate the actions. The tools are neither the actions or operations themselves (Kuutti 1996), but the tools mediate the operations. Nor are the tools the artifact itself. Beguin and Rabardel (2000) describe how a tool is a composite entity of the artifact and a mental scheme of how to use the artifact. Rabardel and Beguin (2005) have elaborated on the concept of mediation, and argue that subjects use tools in a form of *instrumental mediation*. Here, *reflexive mediation* refers to creating relations between the tools and the subject, and how the subject uses tools for support. *Inter-personal mediation* concerns mediated relationships to others. This section makes a closer investigation of mediation and describes how the chart and the optical bearing device are used to mediate activity. The formal function of the equipment on the bridge has been described earlier in chapter 4.

7.3.1 The chart

The previous chapter on distributed cognition showed how a paper chart supported psychological features such as calculation and memory. Here, it is emphasized how the paper chart serves communicative purposes in the coordination and synchronization of the actions of the navigator and the plotter. The navigation plan, externalized in the paper chart, is a tool used for inter-personal mediation, where the plotter elaborates on the navigator's previous work. The paper chart represents a 'journey-dependent' interpretation of safe and efficient movement of the ship. Given that the tasks of operating the ship are distributed between several crewmembers, the controlled proceeding of the ship in accordance with the planned track demands the coordinated actions of each involved subject.

On the fast patrol boats, the navigator used the paper chart in combination with verbal and physical communicative gestures in the interaction with the plotter. The navigator made himself understood to the plotter by physically pointing in the paper chart as well as verbally referring to features of the enriched information. For example, when uncertainties regarding the nature of navigational objects occurred, the navigator turned over to the plotter and the chart, and pointed out spatial relationships and verbally elaborated his understanding. The discussion of navigational operations was heavily based in the joint perception and understanding of the chart. Further, the anticipation of the upcoming courses was based in communication over the paper chart. The navigator just asked for ‘the next course’, and the plotter replied on basis of the enriched paper chart. This allowed for an economized and efficient dialogue.

In order gather knowledge of electronic chart navigation in the fast patrol boat community, the squadron had borrowed a prototype of an electronic chart. This system was temporarily mounted on one of the ships observed. The system interface consisted of a small 20 cm x 20 cm screen, and an external interface panel. The system was mounted right in front of the commanding officer and easily accessible to him in the right corner of the ship bridge (Figure 4-3). In its formal function, the system was equivalent to the traditional paper charts used. They both contained geographic information of the displayed area and included the planned courses to sail with headings and distances. However, the electronic chart system was used in a quite different manner. First, the fixed spatial location of the electronic chart made it difficult to physically access for both the plotter and the navigator. The plotter and the navigator had to leave their normal working position if they tried to use the electronic chart as communicative tool. Secondly, the interface made it possible for only one person to manipulate the electronic chart at any give time. Considering the interface and spatial location, the communicative mediation was changed. The dialogue of navigational issues became cumbersome, as the common reference for statements was more difficult to establish.

7.3.2 The optical bearing device

The operation of the optical bearing device during sailing can be described by the terms reflexive mediation and inter-personal mediation. The device was used not only for taking bearings of navigational objects in the surroundings (e.g. sea marks), but also used for offloading cognitive activity (e.g. memory). When the plotter informed the navigator of the next upcoming course to steer, the navigator often directed the optical bearing device in the same compass direction as this next course. The advantage was that the navigator did not have to remember the next course as he could just read the course on the bearing device's display in the 'next course' position. This means that instead of remembering the next course as a three-digit number, he could let the tools support him. First, he could get a general notion of the next course by perceiving roughly the angle of the optical bearing device. Secondly, he could read the exact course by viewing the display. The information of the next course is not just externalized from the short time memory, but also given a representation as the actual position of the bearing device. Just as the chart, this tool serves the offloading of memory of detailed information, but also carries with it a forecast of activities to come. The chart forecasts in longer timeframes (e.g. the whole journey), whereas the optical bearing device foresees in shorter timeframes. (e.g. next course or next navigation object to be used).

7.3.3 Remarks about mediation

The previous sections described how the subjects relate to the objects through the instrumental mediation of navigational tools. Several features have been exemplified, ranging from relativity simple offloading features (e.g. memory) to more complex features as forecasting and anticipation of actions. It has also been exemplified how the coordination of joint actions among crewmembers are affected by tools, e.g. paper chart versus electronic charts. This suggests that actions and operation are shaped by the tools that are used in the activity.

However, the transformation of object into outcome is not only tied to the use of tools. The activity system must also be attuned to the conditions of the context outside the crewmembers and their tools. The surrounding world is constantly changing and offers disturbances and variance that must be handled. Winds, currents, tidewaters are examples of this. It is, after all, how the system “finds itself in the world” that decides whether the object is transformed into a desired outcome. It is therefore necessary to supplement the description of tools and mediation with description of the surroundings in order to shed light on the condition of navigation in high-speed craft.

7.4 Constraints

In the operation of fast patrol boats the crew must relate to constraints. Constraints are system-dependent and correspond to the fast patrol boat’s capabilities and dynamics. In the navigation study, two major types of constraints were identified.

7.4.1 Functional space

In order to navigate safely and efficiently, the ship must not touch other solid objects, for example land or rocks. However, ‘land’ can have different meanings. Land can be the terrain above the sea surface, but it can also be shallow waters, sunken rocks, or reefs. Shallow waters for a fast patrol boat means a depth less than three meters, and is equivalent to land – it is not sailable. In addition to the static objects there is the issue of moving objects. Other ships also represent restrictions in terms of where to sail. Areas with much traffic are also considered functionally confined. However, this feature will not be commented upon in this study.

Functional space relates to what extent navigation and maneuvering takes place in open or confined waters. Open waters are characterized by the absence of dangers (rocks, land, shallow water), whereas confined waters are highly constrained by such dangers. In open waters, the ship moves in a non-constrained functional space. The absence of conflicting objects offers the possibility to sail in any chosen direction and sufficient time to operate. Opposite, confined waters are highly constrained by the presence of land, rocks, vessels and/or shallow water. The ship has restricted options of which directions to sail, and a significant time pressure for operation and higher demands for precision (see Figure 7-3).

Figure 7-3: Confined waters at high speeds require precision.

The presence of dangers varies along the coastline, and the distinction between open and confined waters is thus not a categorical one. The distinction serves more as a continuum describing the demand for controlling the position of the ship. The ship never moves in the *exact* course line, but as close as possible with the explicit knowledge of to what extent the ship deviates from the planned course. Open waters allow deviation from planned course lines without risking the safety of the ship. The navigator is still obliged to know the exact deviation, but may postpone the correction without any consequences. Opposite, the demands for precision are considerable in confined waters. Any deviation from the planned course must be corrected immediately, and there is little or no error tolerance in the positioning of the ship.

Functional space concerns the tolerance of deviations from ideal system states. The controlled movement of the ship is always subject to variance, and the ship always operates with small disturbances and variance in its performance. Disturbances originate from the effects from and interaction between contextual factors, e.g. sea currents, wind, water depth and activity system factors such as crew performance, and functioning technical systems. The change in functional space during a journey is thus a highly salient feature of the relationship in the object-outcome transformation.

7.4.2 Visibility

Optical navigation is rooted in the visual access to the context. It lies in the very definition of this type of navigation that the determination of position rests on the observation of the relationship between the ship and geographical objects. The Royal Norwegian Navy has defined three navigation modes reflecting the how visibility conditions may stage navigation; (a) navigation by using optical bearings, (b) optical bearing supported by radar or (c) by radar alone (Øi 1985). These three modes of navigation are tied to the level of visibility: Good visibility suggests using unaided visual inspection of optical bearings, whereas poor visibility suggests use of radar as support or radar alone.

When the vessel sails under good visibility conditions, the team can easily perceive visual objects such as landmarks and navigation marks. Two tools used in visual navigation are binoculars and the optical bearing device. When the visibility is low (e.g. thick fog, rain, snow, or during nighttimes) objects relevant for determining the position cannot be perceived directly, and the navigator must use other means to manage the task.

As visibility conditions change, so does the functionality of the tools used in navigation. Going from good to poor visibility implies that binoculars are not an effective tool for observation. The radar is then used to assist visual observation. However, the tools do not simply replace each other in the achievement of specific tasks and goals. The tools also change how the subject interacts, and the nature of task as such. Position determination takes more time and is tied to more uncertainty as visibility decreases.

7.4.3 The constraint matrix

The two constraints can be represented in a matrix. The two dimensions of work domain constraints are illustrated in Table 7-1:

Table 7-1: work domain constraints matrix

Open waters	Little constrained	Partly constrained
Confined Waters	Constrained	Constrained
	High Visibility	**Low Visibility**

The vertical axis refers to the functional time/space constraints; whereas the horizontal axis denotes high or low visibility. The figure illustrates that navigation in confined waters in combination with low visibility is most constrained, while navigation in open waters in good visibility is little constrained.

7.5 Contradictions of navigation

An activity is virtually always in the process of dealing with contradictions. On fast patrol boats internal and external factors can develop and lead to contradictions. This can create a sequence where the activity is "goes sour", which means that minor and unproblematic contradictions come together and form a breakdown. As contradictions occur they may lead to a shift of focus, or a more serious breakdown of the activity. The contradictions found in this field developed from both internal and external factors. The factors that will be focused on are how the navigation team interacted with their plan, other ships in the vicinity and own ship's technical status. We will take a closer look at three different contradictions, varying from minor to significant impact on the activity.

The first contradiction in our study occurred because of uncertainty about the ship's position. At one point, the navigator updated the log, recalculated the distance from the ship's position and where to alter the course. However, the ship's position was not as accurately determined. The navigator realized this, but decided it was good enough to continue the navigation. Within the next five minutes, this led to a breakdown. When the log indicated that the ship had reached the point where it should alter its course, the next lighthouse to head onto had not yet turned up. Example 7-2 describes this situation:

Example 7-2: Navigation mark is not observed.

Time: 0121 am to 0122 am (local)

The navigator uses his binoculars to look.

Navigator: Can't see the light. (*Waits*). Repeat the course.

Plotter: Next course: three three six.

Navigator: Roger. *The navigator uses his binoculars, then turns towards the radar.*

This breakdown has posed questions to the navigator such as; how inaccurate is the log and how far can I proceed on this course? If the navigator overshoots the planned on distance the consequence can be grounding. In this case the navigator had planned using the next lighthouse to determine the ship's position. When the light did not show, he believed he could continue a few more seconds on the present course without heading into danger. The navigator believed the inaccuracy in position meant that he had not yet reached the position the log indicated. The light turned up eventually, but the last minutes before changing the course involved communication between the navigator and the plotter. The navigator repeatedly wanted the plotter to confirm the next planned course, as well as the distance on the present course.

This situation occurred because of inaccuracy in the operation of updating the log, which led to a change in the conditions. As this contradiction developed, eventually the navigator could not rely on performing normal operations, that is, use the log and navigation lights. The new conditions meant that he had to realize his goal by other operations. The navigator continued sailing, assuming the light would turn up. At the same time as this contradiction occurred another external factor came into play; the presence of another ship in the vicinity.

The second contradiction occurred just after the ship was established on the new course, heading for the light that eventually turned up. Then the lookout then reported a ship ahead. A ship on the opposite course demanded the navigator to take precautions. The navigator needed to be aware of where there are deep enough waters, in case of needing to use maneuvers to avoid the other ship. The situation developed as in Example 7-3:

Example 7-3: Vessel ahead.

Time: 0123 am to 0124 am (local)

The navigator is communicating with the engine control room on the intercom.

Lookout: Vessel ahead!

Navigator: Go to three three six degrees.

Helmsman: To three three six degrees.

Plotter: No dangers on this course, some shallow water on port.

Navigator: Port, you said?

Plotter: Yes.

In this situation the plotter immediately informed the navigator that there was only one potential danger in the area, an area with shallow water on their port side. This information was important to the navigator. This episode with the meeting ship resulted in a focus shift. Since the plotter understood the situation and what the navigator needed to internalize, this episode was maintained at the operation level. The episode developed fast by external factors, but it was also solved fast by the navigation organization.

The third contradiction, which also occurred simultaneously with the two others, is connected to the technical status of the ship. During the last weeks, the ship had experienced several false alarms in connection with the auxiliary machinery[5]. The alarm was categorized as critical. However, for navigation purposes there was nothing critical about it. The alarm was first triggered when the navigator realized that the log was inaccurate and he wanted to confirm the distance to the point where to alter course. This situation developed as follows:

---

[5] The auxiliary machinery produces electricity. This electricity is not immediately important for the navigation equipment since this equipment has a battery backup in case of a power failure.

Example 7-4: False alarms.

Time: 0120 am to 0121 am (local)

The navigator and the plotter are communicating about the distance to the new course. The alarm sounds, the plotter continues talking.

Navigator: *Removes cover to reset alarm, then addresses the plotter:* Roger [about the distance]. *Navigator then twice calls the engine control room on the intercom, then puts away the intercom set and looks into the radar.*

Plotter: You want to call down [to the engine control room]?

Navigator: No, it's fine. *He is looking into the radar.* Two point nine was that the distance?

Plotter: Two point ninety five

Navigator: ...ninety five.

Plotter: You will se the light at two point eight, approximately.

The navigator is then interrupted by a call from the command and information room.

In this example the navigator deals with several tasks. He must access and reset the alarm. This task requires him to call the engine control room. Simultaneously, he keeps track of the sailed distance and operates the radar. He experiences a shift of focus in connection with the alarm, but redirects his focus to the navigation. However, the alarm is trigged again a few minutes later.

These three contradictions caused by the inaccurate log, the ship ahead, and the alarm, simultaneously influenced the activity by changing the conditions. Minutes after the first alarm went off, the alarm sounded again. This was at the point when the navigator was preparing to alter the course. Just after the course was altered, a ship ahead was reported by the lookout. The whole situation developed as follows:

Example 7-5: A going sour situation.

Time: 0122 am to 0124 am (local):

The navigator has started to reduce the speed. He has not yet seen the light to head on the next course and communicates with the plotter to double check the plan. Then, the alarm sounds again.

Navigator: Call the engine control room. Port three.

Helmsman: Port three.

Plotter: The light is seen.

Navigator: Roger. Amidships.

Helmsman: Amidships.

Navigator: Steady so.

Helmsman: Steady so on one five zero degrees.. no.. zero zero five zero degrees.

Plotter: You said call the engine control room?

Navigator: Yes.. Update[the log].. Port three.

Plotter: Updated

Helmsman: Port three.

Navigator: Port five.

Plotter: *Talks to the engine control and hands the phone to the navigator.*

Navigator: *To engine control room*: There is a critical alarm on port [auxiliary engine] all the time. *Simultaneously as the he speaks to the engine control room he uses the binoculars searching the area ahead of the ship. The alarm sounds again*

Lookout: Vessel ahead

Navigator: *To the helmsman:* Go to three three six degrees.. *In phone:* Yes.. OK. *To lookout:* Roger. *Navigator puts away the phone and then takes up the binoculars.*

Helmsman: Three three six on.

Navigator: Roger.

Plotter: No dangers on this course, some shallow water on port.

Navigator: Port, you said?

Plotter: Yes.

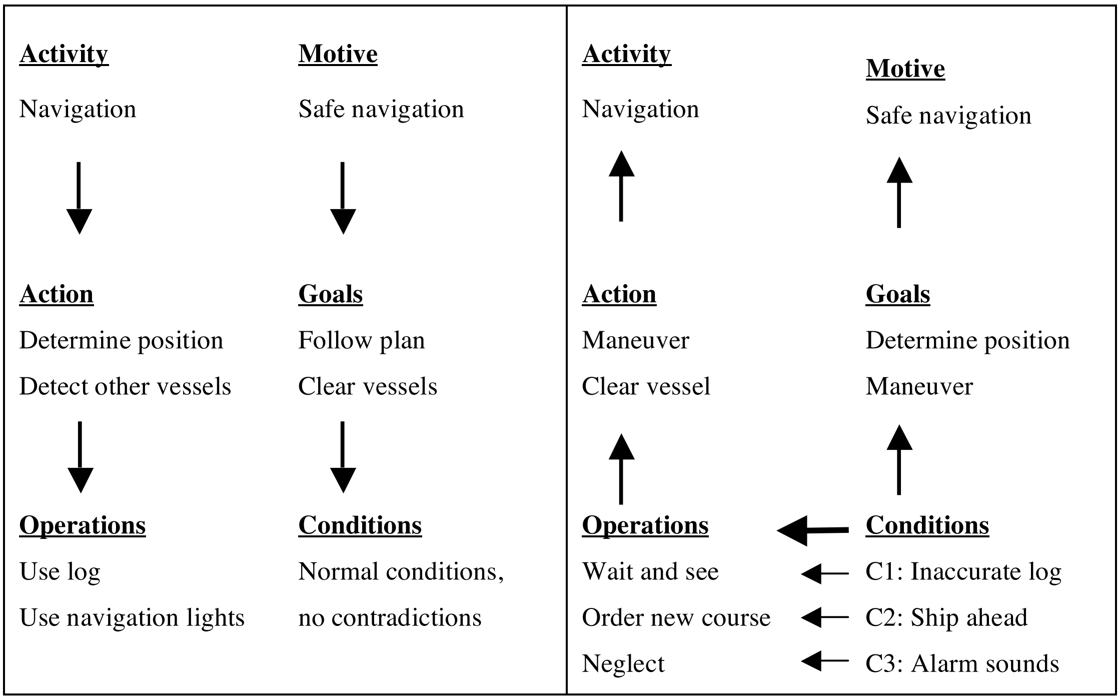
The commanding officer enters the bridge and the navigator gives him a short situation report of the alarms sounding.

During the episode described in Example 7-5 the navigator works really hard to keep the activity directed towards the plan and the motive. The activity is close to collapsing into a situation where the motive of safe and effective navigation is no longer reachable. The navigator has to administrate the operations to be carried out. He cannot carry out all operations demanded by the context, he must then prioritize and execute the most important tasks. The activity's clash with reality has led the activity into a state where the activity has turned unstable, that is, the outcome of the activity is uncertain.

In order to sum up, we will now return to the framework of activity theory. Navigation under normal conditions and major contradictions are put together in Table 7-2:

Table 7-2: Propagation of contradictions.

Normal conditions: Major contradictions:



In the columns to the right, operations are deduced from the actions and actions are as well deduced from the activity itself. When no contradictions are involved, there is a deduction of levels downwards in the hierarchy. In the columns to the left contradictions interact. The three contradictions are denoted C1, C2 and C3. Each of these contradictions shape the correlating operations carried out by the navigator. Two of the contradictions did not lead to a change at the action-goal level. The ship ahead (C2) led to an operation where the navigator maneuvered to clear the meeting ship. The alarm (C3) was solved by crewmembers in the engine control. However, the contradiction connected to the inaccurate log (C1) led to new goals and hence propagated upward the hierarchy. This contradiction shaped the actions and goals of the navigator. There was as well a risk that the contradiction C1 could propagate further and influence the motive for the navigation. However, as the light turned up, the ship's position could be established and the contradiction was sorted out.

7.6 Discussion

The framework of activity theory used to study fast patrol boats has provided descriptions of the relationships between the navigation team and the tools they use at work. These tools are material tools such as bearing devices and charts, and there are immaterial tools such as plans and goals. Activity theory also described how environmental constraints influenced the work of the navigation team. The framework described how navigation as an activity is shaped by the interaction between the crew, their tools, and their goal. The framework also describes different levels of their work according to changes of goals to be achieved. Goals are not static, and variation depends on changing constraints within the relationships between the crew, their tools and goals.

From this study of navigation as activity, the description brings into focus some aspects that can be valuable inputs in a design process of navigation equipment. First, the framework describes the context of the work of the navigation team. Second, the framework describes how the tools that are used shape activity. Third, the description of contradictions brings into focus the driving forces that can say something about the future of the activity.

7.6.1 Describing the context

Several design approaches describe the need for knowledge of context (e.g. Beyer and Holzblatt 1998, Faulkner 2000, ISO 13407), However, these approaches commonly describe ways to identify and organize steps in a design process, rather than provide research-based theoretical frameworks that guide in how to describe context of use. This study suggests that activity theory may augment design approaches by providing a means for understanding the meaning and implication of the context. Two constraints in the activity were described, relating to the functional space and the visibility in which the ship navigated. The influence of these constraints shaped the conditions under which the activity developed. In a design process, a description of the relevant constraints is important input. The end product should be usable under the conditions that can be expected. In the study of fast patrol boat navigation, the constraints have more of an indirect implication in the sense that the constraints suggest that the users under constrained conditions has limited time to operate artifacts. In addition to describing the constraints of the activity, activity theory describes variances in the constraints. Over time, an activity is subject to changes in context and constraints.

7.6.2 Tools shape the activity

As previously described constraints shape the activity of the navigation team. But activity is also shaped by other factors such as the crew’s tools. Beguin and Rabardel (2000) describe how a tool can be regarded as a composite entity of the artifact itself and a mental scheme of how to use the artifact. The tools used by the fast patrol boat navigation team has on the one hand the formal technical functions, on the other hand the crewmembers have a mental sense of the use. The actual use of the artifacts often exceeds the technical specifications. An example was the optical bearing device, where the formal function was to measure bearings. However, the device was also used as memory augmentation and to get a spatial sense of the location of geographical objects relative to the ship. On the ship that was equipped with both electronic and paper charts, it was found that both these tools had similar technical functions. However, the two systems influenced communication and collaboration differently.

7.6.3 Contradictions

Activity theory describes how contradictions are found within activity. These drive the development of the activity. The work of the navigation team was also about solving the developing contradictions in the activity in order to keep the activity directed towards the overarching goal of safe and efficient navigation. To solve the contradictions, crewmembers prepared their tools prior to the start of the navigation. The paper chart was manipulated and enriched in order to support communication and thinking about upcoming events. The bearing device was pointed in certain directions in order make an external representation of the navigation plan.

In people's everyday work, dealing with contradictions develops new ways of working (Kuutti 1996). Contradictions can emerge within the relationship between people, tools and objects, or they can be imposed from the environmental conditions. On the fast patrol boats, the navigation team had to deal with contradictions both from internal and external issues. Contradictions affected the motive of the activity in the sense that the motive that the navigation team worked towards was not constant.

The framework of activity theory described several dimensions of the work of the navigation team. Activity theory described how the work is dynamic and takes place in a dynamic context. In a design process, activity theory suggests that artifacts have qualities beyond the function they are primarily designed for.

8 Design Workshop

The previous chapters have investigated how artifacts shape cognition and collaboration within the navigation team on Norwegian fast patrol boats. This investigation included use of the frameworks of distributed cognition (chapter 6) and activity theory (chapter 7) along with task analysis (chapter 4) and a usability study (chapter 5). These chapters described aspects of the work of the navigation team and their relationships and interaction with the navigation equipment on the bridge of the ships. The findings from the previous chapters will form the basis of a design process, and the results of this design process will be presented in the following. In total four different prototypes of navigation equipment will be presented.

The prototypes developed in this chapter are not artifacts ready to be produced and released on the market. The prototypes should rather be considered as a contribution to knowledge of navigation and design of navigation equipment. The prototypes represent solutions to how cognition and collaboration within navigation teams can be supported by design of new artifacts. The prototypes are initial suggestions that explore and express ideas and beliefs about the future directions of navigation equipment design. They need to be further evaluated and developed.

8.1 Background

Proceeding from findings to design work means a change of work domain. Design is prescriptive in the sense that it is about introducing changes to artifacts or work practices. Scientists are expected to accurately describe features of the real world, while designers are expected to act and produce solutions to problems (Lawson 2006).

In this thesis there is a separation between the regular scientific work on the one hand, and the design work on the other hand. The scientific findings in previous chapters can be subject to discussions about scientific criteria, about for instance reliability and validity. Such criteria are usually not be applied for the following design work. In literature, doing design has been described as an act of faith (Jones 1966), implying that there are steps where one acts and have little or no control of the mechanisms that lead to results. Creative processes are examples of such steps (e.g. Poincaré 1924). Rather than imposing a scientific framework on the design work, this thesis will reflect on the design process.

Although the design work itself is not regarded as scientific, the understanding of the founding problem is based on scientific work. Here, the notion *problem* means some description of the domain's structures, mechanisms and constraints. The previous findings describe a *problem space*. This problem space is knowledge that is brought to the design process with the scope to explore and express ideas, beliefs and questions about the future direction of navigation design. A recapitulation of the findings will be provided in the following. Further, an introduction to design theory will describe how the findings will be included in a design process, followed by the description of the design products. Eventually a discussion upon the design work will be provided.

8.2 How navigation teams work

This section highlights the most important findings from the previous chapters, and describes findings from the studies of the work practice of navigation teams on fast patrol boats. The findings are grouped into three areas; cooperation and collaboration between crewmembers and their available equipment in their work, factors related to the constraints of the work, and the mental representations held by the navigation team.

8.2.1 Cooperation and collaboration

Findings were that the navigation teams commonly use two different strategies in navigation. The first strategy used by the navigation teams was about planning and execution. The navigator conducted a planning task, mainly using a paper chart, rulers, and pencils. During the planning phase, paper charts were enriched in the sense that information was drawn onto the chart. During sailing the plan was executed by the navigation team. In this phase the charts represented the plan, and directed the teams' work. The second strategy used, was related to using available artifacts for problem solving. Artifacts were manipulated in order to explore solutions. As an example; when meeting another ship, the navigator explored alternative actions that could be carried out by the use the optical bearing device and the radar. The navigator consulted the charts, ordered a new course, controlled the outcome of the new course, and if necessary ordered corrections to the ship's course.

Both strategies for navigation involved communication between the team members. The artifacts used by the teams provided frames of reference for communication. Factors that framed the communication within the team were those relating to the execution of the navigation plan such as the directions and distances to be sailed, which were represented in the chart. Artifacts also framed communication in the sense that the physical attributes of artifacts contributed to a forming a language. As an example; to "pull down" meant to reduce speed and corresponded to the physical movements of the maneuver throttles.

A tenet of cognition within the navigation team was how artifacts were used to augmented memory or to hold information over periods of time. As an example, the optical bearing device was pointed in a certain direction in order to represent the next course to steer. The operation of artifacts provided information to the team, often this information was subtle. Heavy sounds from the wheel could indicate that the helmsman had problems with keeping the course. *Perceptually richness* (Hoff 2002) is a term that is used to describe the extent of perceptual channels used by a person to perceive information. The body movement of the operators itself provided information about the work within the navigation team. This information was usually not the persons primarily source, however the information provides the opportunity to confirm first hand sources.

The artifacts used by the navigation team had the purpose of mediating the persons' actions towards their goals. The artifacts were means for accomplishing the task and the focus should not be on the interface as such, but on the tasks that are to be accomplished.

8.2.2 Constraints

The navigation team related to the constraints of the domain. Constraints define limits for what can be done and what cannot be done by the team. Chapters seven identified two types of constraints in navigation related to the type of waters and to the meteorological visibility. In a wider meaning users of equipment were constrained in the sense that certain task required specific sequences of tasks to be carried out. For each extra step in a sequence there is one more thing to perceive, interpret or do: This means there is one more source for failure, omitting or misunderstanding.

Findings were that navigation teams were largely time-constrained in their work. The distance covered per time unit by the vessel when proceeding at high speed put extra demands on the crewmembers in their work, not only must task be carried out within a certain tolerance but also with a certain time frame. A central part of the navigation teams' work is then to balance the need for accuracy versus effectiveness.

8.2.3 Mental mapping

The navigation team operated complex technical systems but often used simpler heuristics for understanding the system and to communicate about the system. Position fixing was carried out by use of rough mathematical approximations, rather than based on accurate methods. The navigators' sense of the navigation plan built on the elements extracted during planning, rather than a comprehensive knowledge of the environment. The team members used their personal senses in their collaboration and cooperation.

Systems that could be operated in different modes were found to challenge the users' personal sense of the system status. Knowledge of the mode in use was important for system reliability, as well as understanding what modes that were available and how one changes mode.

The crews' artifacts were meaningful in the sense that the users have a scheme of the artifacts' use. In this way artifacts had qualities beyond their technical qualities, because the user scheme can be wider than the initial purpose of the artifact. An example was how artifacts were used to off-load cognitive effort in addition to their formal function.

8.3 Design approach

The previous section's description of how navigation teams work presented was extracts of the study of fast patrol boat navigators. The findings in previous chapters describe a domain where a large amount of possible variations come into play. The space of possible problems to solve for a navigation team is of such a range that design problems can hardly be clearly and unequivocally stated. This suggests that there is no one-to-one mapping between scientific findings and design solutions, and that one problem description can lead to several different design solutions. Lawson

(2006) expresses that commonly the solution space in design work is infinite and it is not possible to describe all variations of design problems and design solutions.

This study's approach to design is to regard the scientific findings as a problem space where a design solution contributes to one or more aspects of the problem space. Understanding the problem will lead to a design solution, and further working the design solution will refine or develop new understanding of the problem. In this process the problem and solution is seen as developing together, rather than following logically upon the other (ibid.).

Four concepts were chosen as a basis for design solutions. The concepts were electronic chart systems, automatic steering systems, auditive presentation of information, and alarm panels. For these concepts, the aim of the design work was to develop prototypes that reflected the problem space of fast patrol boat navigation. A prototype was here defined as an approximation of the product along one or more dimensions (Nielsen 1993; Ulrich and Eppinger 2003), and prototyping is the process of developing such an approximation of the product.

Since this thesis does not address testing and evaluation, can it be claimed that the design solutions will improve work conditions for users? Literature within usability engineering claim that design based on knowledge of user, task and context have economical benefits and improve work performance (Nielsen 1993, Norman 1988, Vicente 1999, ISO 13407, Faulkner 2000). Several authors have described factors that are associated with the reliability and performance of complex socio-technical systems. E.g. Hollnagel (1998) identified factors that influence reliability of a system process. Amongst these where factors related to teamwork such as; adequacy of man-machine interaction, availability of procedures, and crew collaboration quality. In the maritime domain Gould et al (2006) investigated factors associated with navigation accidents in the Royal Norwegian Navy, and suggested that the operational characteristics of the navigation system could be associated with navigation accidents.

To improve the working conditions for the navigation team this thesis takes the position that navigation equipment should reflect thinking and cooperation within the navigation team. The term *working conditions* are used to describe factors relating to the human part of the system, the technical parts of the system, and the interaction between humans and technology. The field study of navigation teams has suggested several characteristic aspects of collaboration and cognition in high-speed maritime navigation.

In the following the design work is described as four cases. First, a general description of the function of the concept is given. Then, hypotheses about system improvements and performance are described. The design solution is presented, followed by a short discussion of how the problem hypotheses are met in this particular design.

8.4 The vibrating chart system

An electronic chart system is a chart system that runs on a computer (Figure 8-1). Use of electronic chart navigation in the maritime domain has been increasingly common since the turn of the century. Usually the navigator operates the electronic chart system. The technology, functions, potential and limitations with electronic chart navigation is thoroughly treated in e.g Hect, Berking, Büttenbach, Jonas and Alexander (2002) or Kjerstad (2002a). The electronic chart system is like the paper chart a means for planning and executing navigation. When planning a route on the chart system the navigator operates a mouse for positioning different waypoints. Waypoints are then combined into a sailing route. In a paper chart the navigator draws the lines in the chart, in the electronic chart the system draws lines between the waypoints that the navigator has chosen. When route planning is finished, the electronic chart can evaluate the route and verify if real sailing on the route is feasible. The system checks basic constraints such as if there is deep enough water at each point on the route, and that the turns between the courses are not too tight for the ship to maneuver.

8.4.1 Problem description

In the design development some issues about planning functions on electronic chart systems were identified. When the system provides the navigator with information upon the route's feasibility, this is done after the whole route planning is finished. There is a time gap between the navigator input and the system feedback. This can be problematic because it is not mandatory to do a system evaluation of the route before navigation starts. There is a risk for navigating un-warned on a potentially dangerous route. It is regarded as potentially advantageous if the system could provide in time feedback about basic constraints. A second issue was about the form of the feedback provided. Normally, feedback about the route's feasibility are provided as text in windows. However, making feedback perceptually richer were seen as a potential improvement. Two hypotheses about how to improve an electronic chart system were expressed. The first hypotheses is that working conditions will improve if navigators' planning and system evaluation are taking place closer in time. Second, working conditions will improve if system information is represented perceptually richer.

8.4.2 Design solution

A design solution was developed based on commercially available hardware and software. A laptop was connected to a force feedback (haptic) mouse (Figure 8-1). Use of haptic interfaces in fast patrol boat navigation is described further in Bjelland et al. (2005).

In order to support the navigator during planning, regular electronic charts provide textual alarms connected to specific criteria, for instance if a route passes waters too shallow for the ship to sail. On this prototype, the idea was that the mouse would vibrate when the navigator planned a course that would meet the electronic chart systems alarm criteria. However, a regular electronic chart system provides such alarms only after the whole route is planned. This prototyped emphasized the need for more in-time information. In order to provide feedback to the navigator immediately when a route were in conflict with alarm criteria, simplified criteria for feedback were used. On the prototype a safe corridor was defined in the chart, and when the navigators course were outside this corridor, the mouse vibrated.

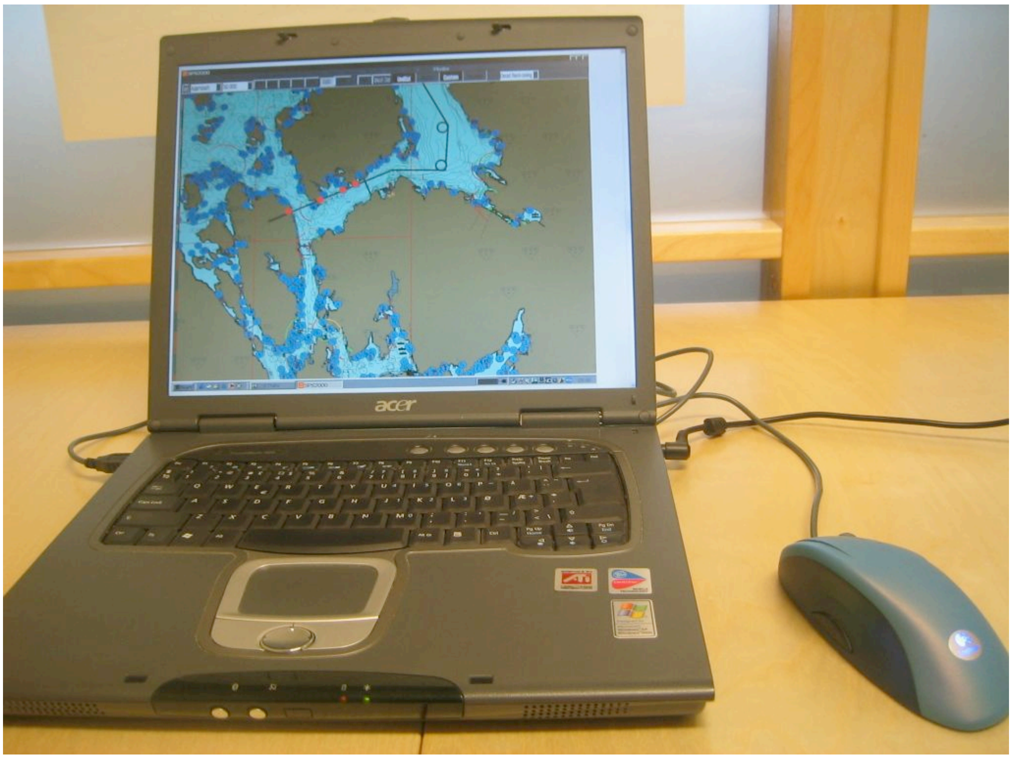


Figure 8-1: Electronic chart system with haptic feedback.

8.4.3 Discussion

The very purpose of any chart is to represent the constraints. In the marine domain constraints are land and shallow waters. An electronic chart system offers the possibility to automatically map the plan with representations of constraints. As observed on fast patrol boats, artifacts may benefit from perceptual richness. By using haptics, the prototype offers a richer feedback than traditional electronic chart systems.

The basic idea of the prototype was to use haptic feedback in order to inform the navigator. However, the prototype also suggests that information about constraints may be given real-time, that is during planning rather than after the planning is completed. On the prototype, the time lag between planning and feedback are reduced compared to other commercial systems.

8.5 The Slider – an automatic steering system

The second design case was prototyping an interface of an automated steering system. This kind of steering system is frequently used on modern high-speed craft, and will be taken into use on the next generation Norwegian fast patrol boats. An automated steering system basically replaces the helmsman. Instead of giving orders to the helmsman, the navigator himself operates the steering system. In addition, the automated steering system has one function that the helmsman do not have. The system can make the ship follow a route that is planned on an electronic chart system. The technical function of an automatic steering system implies that it is operated in 3 modes.

When the steering system only controls the course of the ship, similar to a helmsman, the system is working in *course mode*. In addition to controlling the course, the steering system can use inputs from satellite navigation to make the ship follow a planned track. This is denoted *track mode*. In track mode the steering systems not only follows a course. If the ship drifts off the track, the system steers the ship back on planned track. The system also changes course automatically in order to follow the plan. In contrast, when using the course mode the navigator must tell the autopilot when to turn, and what new course to steer. In track mode the steering system can sail the ship from harbor to harbor automatically.

In addition to the course mode and the track mode, there is a *manual mode* where the navigator controls the ship manually. This is achieved by directly controlling heading and speed. Table 8-1 presents the three modes of an automated steering system, what steering functions that are automated by using the different modes, and what are the required navigator inputs.

Table 8-1: The three modes of the steering system.

Mode	Automated functions	Navigator inputs
Track mode	Course Speed Change of course Compensate drift	None
Course mode	Course	Speed Compensate drift Change of course
Manual mode	None	Course Speed Change of course Compensate drift

8.5.1 Problem description

The major problem identified in automatic steering systems is related to the possible modes of operation, and how knowledge of the mode in use is necessary for human control of system performance. Design of a prototype of an automated steering system was based on four hypotheses about how such a system could improve the performance of the navigation team. First, performance would benefit from a clear representation of the mode of the system. The mode in which the system operates defines the possibilities and needs for navigator inputs and actions. In case the navigator is in doubt about which mode that is active, the system should provide clear information of the active mode. Second, performance would benefit from a mapping between the interface of the steering system and the conceptual models of the users. This aspect will make it easier for the navigator to hold an internal representation of the system functions. Third, performance would benefit from supporting intra-personnel mediation, that is to support how the team cooperates. Communication and awareness of what others do are believed to increase the team's ability to correct errors. Intra-personal mediation is about making arrangements so that other persons can contribute with knowledge and support within the team. Fourth, performance would benefit from a distinct operation sequence that can be observed by others on the team. This aspect is also about the team's ability to detect and correct own errors.

8.5.2 Design solution

A foam model prototype was developed and is illustrated on Figure 8-2. The interface is divided into three parts as indicated on the figure. Each part has spatially located the controls referring to the three different modes of operation. On the figure there is a white curtain covering the track mode controls. Because of the curtain, the prototype was named the "Slider". The navigator operates this curtain in order to change mode. On the figure the system operates in course mode. The course mode and the manual mode controls are available for the navigator. If the curtain is raised, the system will go into track mode and the track mode controls will be revealed. If the curtain is lowered, the system will go into manual mode, presenting only the manual mode controls to the navigator.

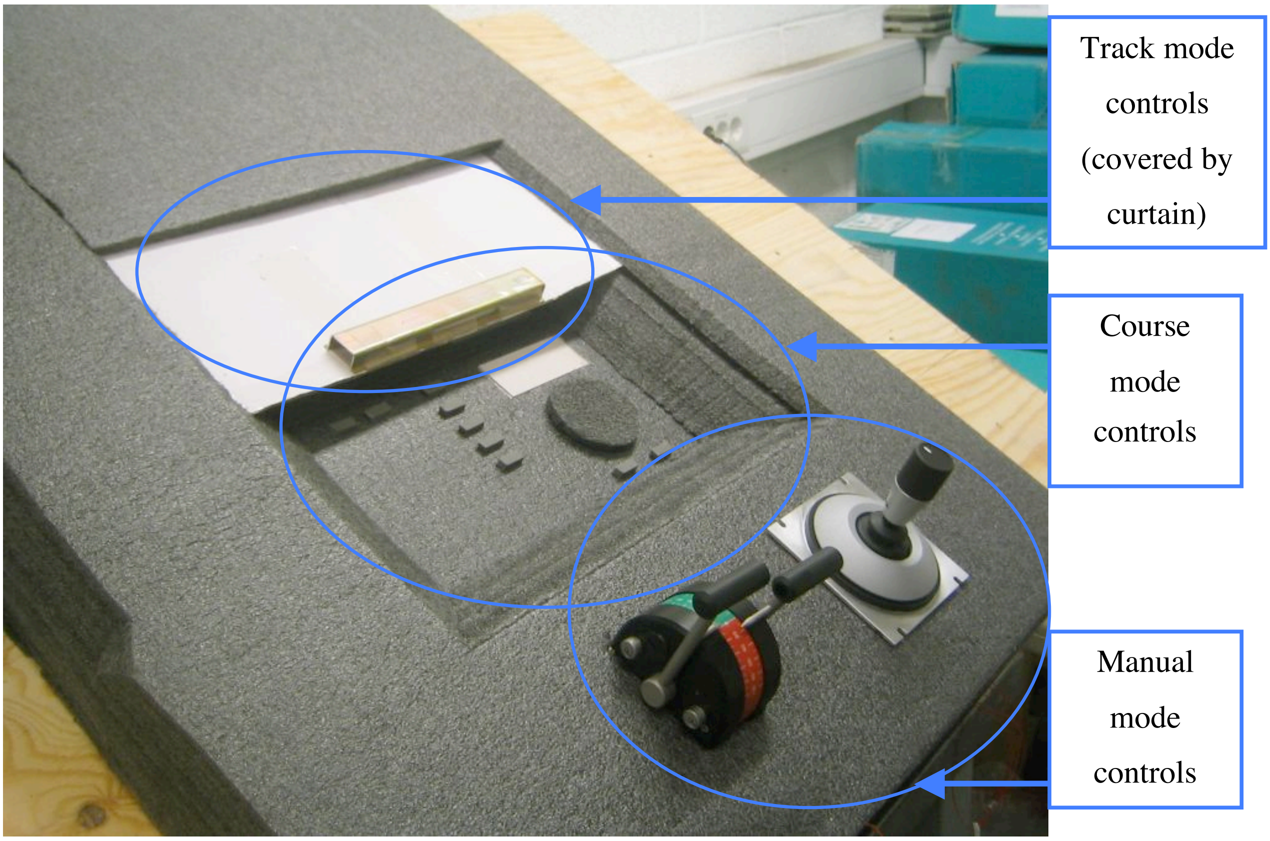


Figure 8-2: The "Slider" - a prototype interface of an automatic steering system.

The operation of the curtain implies that the interface presents the chosen operation mode as well as the mode that are less automated. If the navigator wants to enter higher degrees of automation, the corresponding controls must actively be revealed by raising the curtain. The controls are specific regarding the mode they refer to. This means that each control has a specific function regardless of the mode of the system. In manual mode, the navigator controls the ship's course by using a joystick. The engines' rotational speed are controlled by using the throttle. In course mode, the navigator inputs course directions by the circular wheel. In track mode (covered by the curtain) the system is connected to the electronic chart and the satellite navigation system.

8.5.3 Discussion

The first hypothesis expressed a need for a clear representation of the modes of the system. The prototype encompasses this by how the physical position of the curtain represents the operational mode. An alternative could be to operate the steering system from menus, e.g the steering system could be operated from a sub-menu in the electronic chart. On the prototype the mode of operation can be directly perceived from the artifact rather than inferred from represented information. The prototype interface also represents the space of possibilities, that is the modes that are possible for the navigator to choose.

The second hypothesis was about the mapping between the interface of the steering system and the conceptual models of the users. For this purpose, the structure in which information is embedded is simplified in the sense that each mode of the steering system has its own physical interface. The layout of the interface builds on the metaphor high and low degree of automation (Lakoff and Johnson 1980). High degree of automation reflects the amount of functions that are automated as described in Table 8-1. On the interface, the mode controls related to high degree of automation is spatially located high up, and the lower the degree of automation, the further down the controls are located on the interface. A physical representation makes it easy to compare the personal sense with the representation of the mode, for instance in order to verify the system state and the personal sense of the system state.

The third hypothesis described aspects of intra-personnel mediation, that is to support how the team cooperates. Here, communication and how the artifact affords communication is central. The metaphor high/low degree of automation has the believed implication that it provides a language for describing qualities of the artifact. Physical artifacts with physical manipulation seem to open for descriptions of functional operations. On fast patrol boats it was observed how the optical bearing device opened for descriptions such as “shoot up bearings”, also the ship’s movements were described with reference to the chart in terms as “up”, “below” or “just outside the chart”. The curtain opens for describing concepts of automation in terms of “open up”, “close”, “raise the curtain”, “lower the curtain” and so forth.

The fourth and last hypothesis was about the benefit of a distinct operation sequence that can be observed by others on the team. This aspect reflects the observations made on fast patrol boats that the persons on the navigation team monitored each others’ performance and corrected if necessary. A physical artifact operated by distinct body movements signal what operations that are carried out. Change of mode will be represented by corresponding movements of the navigator. These movements will be observable to other team members.

The autopilot prototype has demonstrated how hypotheses about cognition and collaboration are embedded in the design of an artifact. The design of the Slider automated steering system described the specific development of an artifact. In the following a more generic concept will be explored, the concept of using sound representation. This concept is not tied to a particular artifact but can be used for further improvement of e.g. an automatic steering system.

8.6 The Soundscape concept

Sound is an important information source on the bridge. In 1995 the ferry M/S Silja Europa grounded in the Swedish archipelago. It was claimed that new and more silent equipment contributed to hide malfunctioning equipment (AIBF 1995). Audio alarms are commonly used on ships' bridges. In addition to sounds that have an explicit function, other sounds such as the engine sound, yelling from the crew, and humming from parts of the ship provide information about what is going on. However, in bridge interaction design the use of sound has commonly been limited to alarm sounds. Sounds on the ship's bridge can be described as *noise* or *ambient sounds*. The difference is that noise does not represent any explicit information, while ambience is a representation of information. The idea of this case is to use a soundscape to represent information to the navigator

A soundscape can be described as three dimensional; frequency, volume, and complexity stretches out a space where sounds can be placed. If alarms are located in proximity to each other in this space, they will override each other instead of making use of the full potential. Sounds also have a wide range of other qualities, based on overtones. E.g. an instrument has full, rich overtones and is comfortable to listen to. A sinus beep has no overtones and easily becomes annoying.

8.6.1 Problem description

The soundscape concept in design of navigation equipment is based on the hypotheses that increased perceptual richness improves working conditions within the navigation system and increases the artifact's ability to inform the user. Sound can have different functions such as memory regarding automation mode, and provide reminders to the users about what mode the system operates in. A second hypotheses is that sound will improve inter personal mediation, that is enabling communication about the sound and provide a conceptual language, such as “you are clicking not clacking”.

8.6.2 Design solution

The soundscape concept was used to demonstrate how to represent the steering mode and change of steering mode. The result was a family of sounds that represented technical status of the ship's system. The starting point for the design was to re-create some of the properties of a mechanical gyro compass.

Figure 8-3: Sound technician at work.

A mechanical gyro compass repeater presents the ship's heading. When the ship is turning, the compass changes its presentation. Changing presentation produces a click that easily can be perceived. Usually the compass makes a click for each 0.5 degree course change. Newer digital compasses do not produce such a sound. In our design we made the compass present one click pr 0.5 degree change of course. In addition, the click sound had some important properties: In manual mode the sound is organic in order to signal that that the mode is done manually by a human. In auto mode the sound is more technical in order to discretely make the operator aware of the mode change. In track mode the tic is an unmistakably electronic sound.

On mode changes the bridge gives a short fast melody played on a Rhodes piano. The three tones are put in rising order when entering a higher mode of automation. When going to a lower degree of automation, the tones are played in decreasing order.

8.6.3 Discussion

The soundscape concept was developed in parallel with the interface of the automated steering system. The interface of the steering system demonstrated how each of the three steering modes was physically represented. The soundscape concept suggested even further development of perceptual richness. The relationships between physical representation of the Slider's interface and the sound representations are indicated in Table 8-2.

Table 8-2: Relationship between the Slider's interface, steering mode, and sound representation. Changes between modes is also represented by tones played in increasing or decreasing order.

The Slider's position	Steering mode	Represented Sound
Fully down	Manual	“tic-tic-tic”
Middel position	Auto pilot	“tac-tac-tac”
Fully up	Track pilot	“toc-toc-toc”

By augmenting the concept with several loudspeakers one could add spatial representation to the concept. This can be achieved by placing loudspeakers at different spatial locations on the bridge, and assign certain types of alarms to each loudspeaker. The spatial location of the sound sources would then have different meanings. A sound that origin from the starboard side of the bridge would have another meaning than a sound from a different location.

8.7 The Pop-up Alarm Panels

A notable feature of modern ships' bridges is that systems provide alarms and indicators to notify the user about conditions that require particular attention. The term *alarm* is used about warnings that represent serious conditions such as dangers. Alarms provide information about such things as deviations from planned route, area with special conditions, or system malfunction (IMO 1995). Alarms are normally presented acoustically, visually or by combinations of these two. Commonly, the same source sounds all acoustic alarms, independent of which system that has triggered the alarm. This means that the sound is identical for all types of alarms, and the sound is generated at the spatial location for all acoustic alarms. For visual alarms, the common way to represent is within the system interface. This can be found on e.g. electronic chart systems and radars, where alarms are presented as pop-up windows on the computer screen, as change of color or icons on the computer screen, or as indicator lights at the operator interface.

8.7.1 Problem description

Both alarms and the absence of alarms represent information. Alarms inform users that the system operates out of pre-defined limits, on the other side; absence of alarms should inform the user that the system is operating within the limits. Alarms should not only appear distinct when they are triggered, for the user it should be an easy task to perceive that no alarms are active.

In design of alarm panels one should include the perspectives that both presence and absence of alarms are meaningful states. This knowledge is important to all persons on the navigation team, and to support this shared knowledge, the design of alarm panels should open for communication and collaboration within the navigation team on the bridge of the ship. Information provided by alarms should be available to the team rather than the one person that acknowledges the alarm.

Previous chapters (chapters 6 and 7) have described how physical artifacts open for communication within the team. Physical artifacts also open for collaboration in the sense that physical artifacts are available for persons to perceive, touch and that they are physical demonstrations rather than abstract explanations.

Based on the issues described so far in this section, four hypotheses about how alarm presentations can improve the navigation team's working conditions were expressed: First, the structure in which the alarm information is embedded should be easy to perceive. Second, perceptually rich alarm presentation is believed to improve working conditions. Third, the presence or absence of alarm should be perceivable to the people that work with the system. Fourth, the alarm presentation should have physical attributes in order to open for communication.

8.7.2 Design solution

Figure 8-4 presents the "Pop-up Alarm Panel" (PAP). The PAP interface is separated from the functional interface of the system, that is where the operator normally provides input and perceives output. Each panel provides only information connected to one specific technical system, e.g. the satellite navigation system. Only in case of alarm the PAP presents itself by "popping up". If the system operates within limits, the panels are not presented. The PAP have three positions that have different meaning; full down and not visible the alarm represents that the system operates within limits. Partly raised the PAP can represent a pre-warning, and fully raised the PAP represents an alarm connected to the specific system.

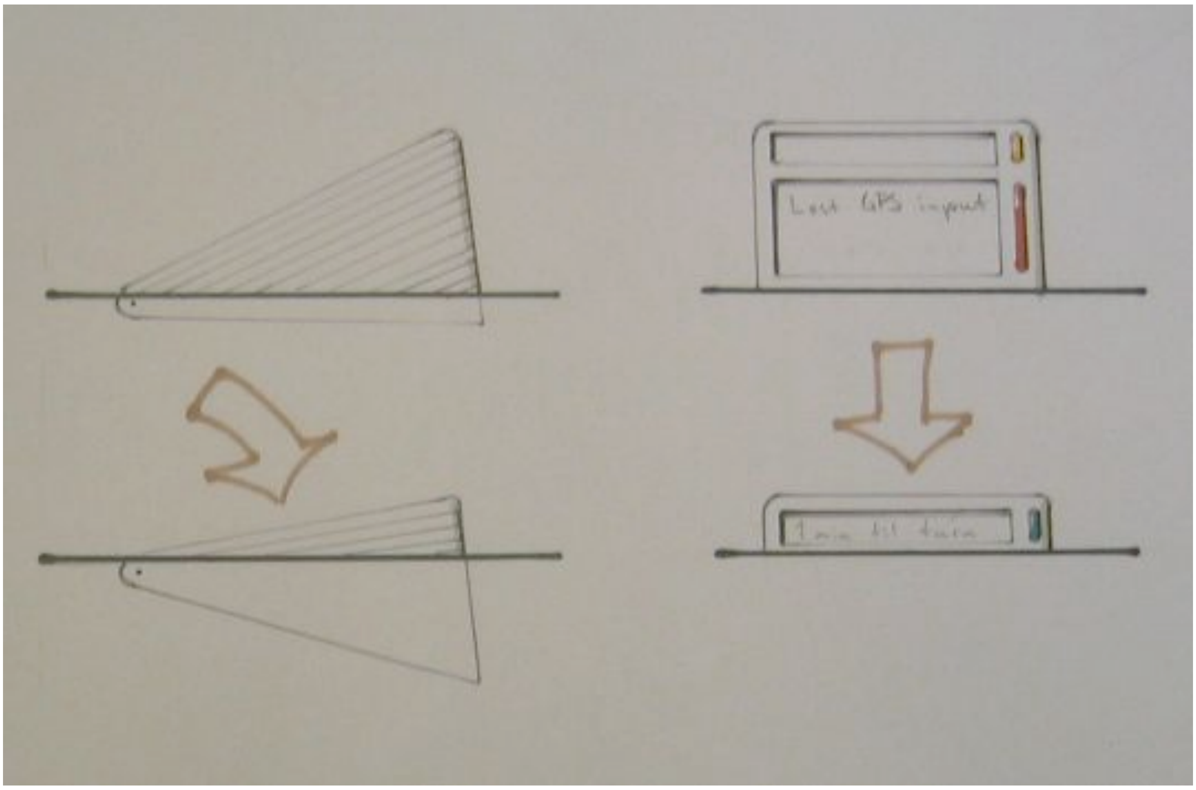


Figure 8-4: The "Pop-up Alarm Panel".

8.7.3 Discussion

The PAP provides a simple structure in which only the alarm information is embedded. Although the structure is simple, the information provided by the PAP has several dimensions. In contrast to the functional interface, the alarm interface only reveals itself in case of alarms. When the interface reveals itself, it represents an easily perceivable change of instrument lay out that express the presence of an alarm. As the PAP is associated to one type of equipment only, the spatial location of the

PAP will give an indication of what type of equipment that operates out of limits. The detailed information of the alarm is found on the display on the panel.

The popping up of panels is a way of increasing the perceptual richness of alarm presentation. Augmenting the system with sound can further increase perceptual richness. Use of sound has earlier been described in the Soundscape concept, here a few issues connected to spatial representation of alarms are elaborated on. Each PAP with its spatial location represents a certain type of equipment. When augmenting with sound, one could assign one type of tone to each PAP in order to increase perceptual richness. Further the source for acoustic alarms can be made different for different types of equipment, and the source can be given a distinct spatial location. In this way an alarm will be represented by the popping of PAP, a certain tone, a corresponding tone direction, and the alarm text.

One benefit from sound augmentation is that the presence of an alarm becomes available to more persons than the ones that are directly looking at it. Presenting an alarm by change of physical lay out also makes the alarm available to several persons. The alarm will be easy to perceive since a change of layout is believed more perceivable than a text line in a computer window. The physical alarm presentation also opens for different ways of communication about alarms; when all systems are within limits this can be described as “no pop-ups”. Another possible phrase can be; “pop-up on port side” which means that an alarm is triggered on the system that has its assigned PAP on the port side. The design here opens for describing the physical attributes of the PAP rather than communicate functional descriptions of equipment.

Finally, it should be noted that use of too many PAP on the bridge of a ship may be problematic and lead to panels popping up all over the bridge in an emergency situation. However, PAP interface is one possible design solution that can be used to represent particular information in a distinct way.

8.8 Discussion

This chapter has suggested design solutions of navigation equipment. The design work was based on studies of fast patrol boat navigation teams, and of cognition and collaboration within these teams. Based on findings from these studies, the design work suggested prototypes that were believed to improve working conditions for navigators. This section concerns issues related to the design work: Aspects about the design process are discussed, along with suggestions of how to proceed in order to further develop the prototypes. The design work suggested ways to improve navigators' working conditions. However, the work also accumulated knowledge about navigators' work. This aspect is elaborated in this section. Eventually, a discussion is made if the results from this thesis' design process apply to other types of ships or even other domains.

8.8.1 The design process

During the design workshop, four prototypes were made. The design solutions attempted to answer how to support the working conditions for the navigation teams. One way to improve working conditions was to inform the team about what each person does in their teamwork. In order to make one persons work visible to the other team members, equipment was designed to require visible body movements. A second way was to facilitate communication about the team's work. Equipment was designed with physical qualities corresponding to the conceptual function of the system. A third way was to use sound, distinct shape and form, and haptic interfaces to inform the team of system performance.

Usually, there is not a one-to-one relationship between knowledge available to the designer and good design. Good observations do not necessarily lead to good design, and good design does not always build on a solid knowledge base. Design processes are not always logically founded, in the sense that development of design is not based on steps that follow logically after each other. Lawson (2006) describes how designers often rather freely decide on some governing characteristics on which designs are based upon.

In the design process, the four prototypes can be considered as *primary generators* (Darke 1978). Primary generators are ideas that involve issues central to the problem, and these ideas limit the range of possibilities by focusing on a selection of constraints in order to quickly move towards some ideas of solutions. An obvious criticism towards such a process is that one focuses on a few issues, rather than forming a holistic understanding of the joint human-machine system. Focusing on the primary generators can lead the design in potentially dangerous directions because the designer has little control of factors outside the initial ideas.

Other authors advocate the need for a comprehensive study of the domain in question where the design should be the output of the study. The ideal is that problem description and solutions should follow logically upon each other. Vicente (1999) describes how the design should be the result of a step by step removing of degrees of freedom. Other authors like Sanders and McCormick (1992), Wilson (2000) and Vink (2006) advocate the need for a controlled step by step proceeding where steps include use of validated methods, establishing knowledge of best work practice, checking for effects of possible solutions, and use of control groups. Compared to the controlled and stepwise design process advocated by these authors, the design process in this thesis could be thought of as a rather uncontrolled jump from the scientific findings and to design solutions.

An argument for a less controlled design approach can be that complex socio-technical systems have a large space of possible outcomes, and it is an unrealistic assumption that a complete problem space can be identified and described before design work is started. On the other hand, one can see design as a process where the problem and solutions jointly emerge (Lawson 2006). This thesis takes the position that a reliable and valid investigation of the domain should be carried out. However, in addition a design process will lead to new knowledge of the domain. Because design contributes to new knowledge, problems and solutions can be seen as being interwoven.

Carrol et al. (1991) has described the task-artifact cycle. This cycle describes how tasks and artifacts influence each other. A new artifact taken into use will influence a person's tasks. The change of tasks implies that new artifacts can be made in order to better support and enhance work performance. So the cycle goes, tasks demand new artifacts, new artifacts demand change of tasks. Authors like Vicente (1999) has developed frameworks for design that can overcome the task-artifact cycle by focusing on the domain's constraints that are independent of tasks or artifacts. The design process of this chapter is no attempt to overcome the task-artifact cycle. On the contrary, since problem and solution is regarded as emerging jointly. This study emphasize the need for a cyclic development changing between design work and problem description. Lawson (2006) claims that when new artifacts are taken into use, people will learn and bring their knowledge into future designs. According to Lawson, design is "an endless story".

8.8.2 Implications of the prototypes

The prototypes were suggestions of how to improve working conditions for navigators. However, the prototypes may also have negative effects and create opportunities for new system failures. New technology may increase cognitive workload during situations which cognitive workload is already high - a condition Wiener (1989) called *clumsy automation*. Problems with taking new technology into use have been reported in several domains, for instance in medicine (Cook and

Woods 1996), air transport (Sarter and Woods 1997), and ship navigation (Lützhöft 2004).

One issue with the prototype that may cause problems for the users are related to the way the prototypes suggest changes to the use of language within the team. The prototypes were designed in order to facilitate talking about the major functional concepts of the artifacts. Table 8-3 gives an overview of changes in language that are suggested by the prototypes.

Table 8-3: Language suggested by prototypes.

Prototype	Possible implications for language	Examples
The vibrating chart	• Communicate that the mouse vibrates.	"No vibrations " "vibrations"
The Slider	• High and low position of cover may be used to communicate degree of automation. • Movement of cover may be used to communicate change in automation.	"open up" "close" "raise the curtain" "lower the curtain"
The soundscape concept	• The three possible automation mode represented by three different types of sound.	"system is tic-ing" "system is tac-ing" "system is toc-ing"
The pop-up panels	• Revealing of panel may be used to communicate alarm. • Normal state may be communicated by lack of panel.	"GPS is popping up" "No pop-ups"

One risk is that the users do not relate the language afforded by the prototypes to the conceptual function of the artifact. Although the artifacts open for a language to describe functions, the artifacts may also bring more complexity to the navigators' tasks.

8.8.3 Further development of the prototypes

The prototypes developed in this chapter are not ready to be produced and released on the market. The prototypes should rather be considered as a contribution to knowledge of navigation and design of navigation equipment. The prototypes represent solutions to how cognition and collaboration within navigation teams can be supported by design of new artifacts. The prototypes are initial suggestions that explore and express ideas and beliefs about the future directions of navigation equipment design. There are arguments suggesting that there is a need for further development of the design solutions. For instance, as the previous section very briefly discussed that there may be negative effects connected to the solutions.

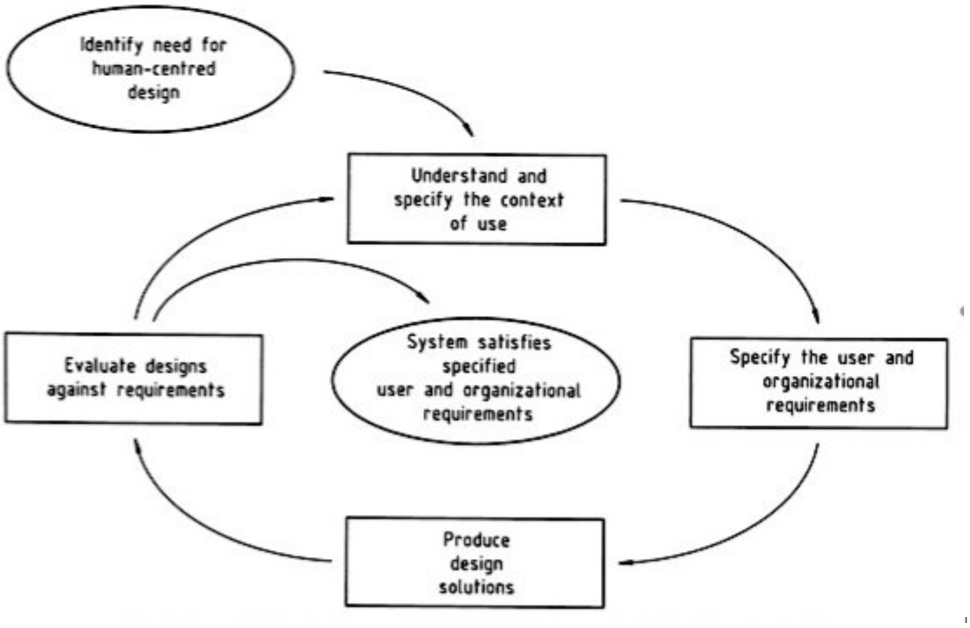


Figure 8-5: ISO 13407 – a human centered design process.

To relate this thesis' design process to a possible further development, the design process outlined in ISO 13407 (ISO 13407) will be described. ISO 13407 is a generic framework that incorporates phases also found in other approaches. A more detailed discussion on the topic of design processes can be found elsewhere, in for instance Ulrich and Eppinger (2003) or Lawson (2006). Figure 8-5 shows the cyclic nature of a design process where work iterates between understanding the user and tasks, specifying requirements, produce design solutions, and evaluation. The contribution from the application of theoretical frameworks, observations and studies is to develop the initial to understanding the context of use, and specification of requirements. Further, these inputs will be incorporated into concrete design solutions.

The cyclic nature of design implies that all phases should be revisited in order to incorporate new knowledge obtained during the design process. The work described in this chapter can be described as half a turn in the ISO 13407 process. Further work should include evaluation and further development.

The methods used in this study do not lead to one particular design solution for each prototype. As earlier expressed, there is not a one-to-one between scientific findings and design solutions. Probably human factors methods in general also opens for several design solutions to a given problem. This brings up the question about what is the best design solution for a given context. One answer can be that the solution preferred by the users is the best one. This suggests that a possible way of evaluation can be to use the methods described in the usability study (Chapter 5) as well as other types of usability evaluations.

8.8.4 The results of the design process

The human-centered design process of Figure 8-5 iterates until stop criteria are met, where the system satisfies the specified requirements. The aim of the human-centered design process is to develop a usable end product. However, the end product is not the only result of a design process. The iteration between developing understanding of requirements and production of design solutions will lead to accumulated knowledge. The development of prototypes described in this chapter also led to knowledge of cognition and collaboration in teamwork.

Woods (2002) claims that artifacts are not used in a cognitive vacuum. All new artifacts carry with them an implication for the involved persons' cognition and collaboration. Designers create, represent, or shape experiences for people. Those people learn something, form models and explanations, see patterns and balance tradeoffs. The result can be better or worse conditions under which a job will be carried out.

Woods and Hollnagel (2006) describes a *practice-centered* approach to design. This approach outlines how design for complex socio-technical systems should be based on authentic studies of the system in question, and that general patterns of work can be extracted from such studies. The abstracted patterns are not necessarily specific to the observed domain. However, domain expertise may be required to discover and understand their presence. The patterns can be related to how cognition and collaboration occurs within the complex socio-technical system. Based on the patterns, hypotheses about useful changes are forwarded, and prototypes are developed. The approach of Woods and Hollnagel (ibid.) is presented in Figure 8-6.

A tenet of this process is the formation of *design seeds*. Design seeds are along with prototypes an outcome of the design process. However, design seeds are not the prototypes, but related generic concepts that can be reused in other projects across different technology and settings (Woods and Hollnagel 2006).

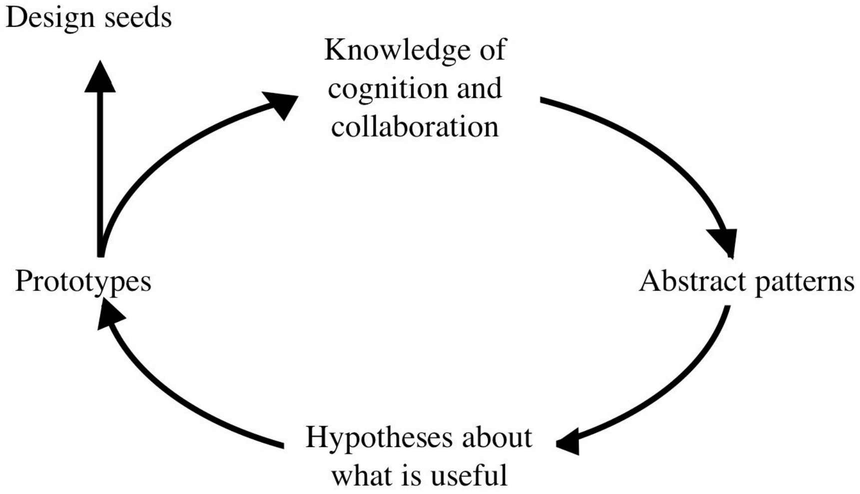


Figure 8-6: A practice-centered approach to design. Adopted from Woods and Hollnagel (2006).

The approach of Figure 8-6 can be demonstrated by an example from one of the prototypes developed. The observations of cognition and collaboration described how the crew used the optical bearing device to augment memory. The bearing device was directed in the direction of the upcoming course to steer. The abstracted pattern of this observation was that artifacts augment navigators' memory. It was believed that this pattern could be used in design of other types of equipment, like an automated steering system. In design of such a system, a hypothesis was that a physically operated interface could inform the user about the system's status. A prototype was developed where the physical location of a sliding cover represented the system's mode of operation. The outcome of the design process was an suggestion for how to improve an artifact, as well as knowledge in the terms of a design seed. The design seed, the moveable interface, represents knowledge of how to use a particular design solutions in order to augment memory.

When reflecting upon the design process, several questions are related to the elements of the process outlined in Figure 8-6. Such examples are: How to extract patterns? How to develop hypothesis? How to design prototypes? How to innovate design seeds? And, can one trust that the patterns, hypotheses, prototypes or design seeds are true? These questions have no clear answers. A design process largely represents the current understanding of a complex system and the current understanding on how to impose favorable changes to the domain (Woods and Hollnagel 2006). All aspects of the design process can be subject to re-interpretation and changes. As more knowledge is obtained in the domain; one should revisit and modify patterns, design hypothesis, current design solutions, and design seeds. Design as a process under continuous development is also emphasized by Lawson (2006). He also argues that design problems and their solutions remain a subjective matter. Both Woods and Hollnagel (2006) and Lawson (2006) claim that major contributions from a design processes are how the outcome contributes to the pool of ideas available to future designers and researchers.

8.8.5 Design application in other fields of work

A relevant question is whether the suggested design solutions can be applied in future design. Are the design solutions applicable to other users than fast patrol boat navigators? Are the design solutions usable for other types of military vessels or civilian vessels such as oil tankers or off-shore vessel? To answer these questions, the practice-centered approach to design should be taken into consideration.

The design solutions are based on hypotheses about cognition and collaboration. These hypotheses are founded on abstract patterns extracted from observations.

Although the hypotheses about cognition and collaboration are derived from particular observations of fast patrol boat navigation, the hypotheses are not specific to that field (Woods and Hollnagel 2006). The question about whether design solutions are applicable to other fields of use, is a question of what mechanisms that govern cognition and collaboration in that field. The design solutions of this study can contribute to a pool of knowledge, and the concepts can probably be re-used in any domain where the design seeds of this study can improve cognition and collaboration.

The design seed that probably has the largest potential for future use in a maritime application is use of sound to represent information. Use of sound to represent information is commonly limited to sound alarms. Given the potential sound has to represent a plethora of information, the method is clearly under-developed. Use of sound has potential to be used more widely than industry practice at present time. In this work, sound was described by three dimensions; frequency, volume, and complexity. Locating sound at different positions in the three dimensions can represent different status, like modes of automated system. Sounds can be used to provide ambient information as well as indicate system changes. Sound can be generated from different sources, the spatial location of the sound source itself can provide information. Sound can be distinct sounds like alarms or ambient information like background noises. Sound sources already exist on ships' bridges, developing the potential for sound representations are a matter of re-arranging.

The use of haptics and change of physical form are more technically complex ways of representing information. This study suggested vibromechanics used in a computer mouse to represent information. Change of physical form were used in design of the pop-up alarm panels, panels that revealed itself only when alarms were triggered. Both use of haptics and change of physical form includes introducing moveable parts and probably more expensive components than use of sound representation. While sound is a matter of re-arrangement, haptcis and change of physical form demands more changes to construction. However, use of haptics and change of physical form can be used for special purposes, e.g. to represent vital information such as to signal possible groundings or serious system degrading.

8.9 Conclusions

The design work in this study was founded on knowledge about the navigators, their tasks, and the context in which the tasks were performed. Based on this knowledge, hypotheses about how to improve working conditions were developed. Designs of several prototypes were based on these hypotheses. The aim of the work was to establish a relationship between theoretical findings and the prototypes. However, it was not the aim to have strictly logical defined steps in the design process.

The design process can be described by two approaches. The human-centered design approach (ISO 13407) emphasized the need for multidisciplinary and iterative work in order to gradually develop knowledge and improve the product. The outcome of the human-centered design process was a usable end product. The practice-centered design approach (Woods and Hollnagel 2006) also emphasized the iterative work in order to improve knowledge. However, the latter approach focused the knowledge of cognition and collaboration that was developed in the process. The outcome of the practice-centered design process was design seeds, that is ideas and solutions that can inform design and be implemented in work domains in order to improve cognition and collaboration.

The methods of this study did not lead the designer to one particular solution. The design solution space is possibly infinite and this brings up the question about what is the best design solution for an artifact. One answer can be that the solution preferred by the users is the best one. This suggests that a possible way of evaluating different designs can be to use different types of usability evaluations where the end user is included.

9 On the development of maritime technology

This chapter comments upon aspects of future development in navigation technology. As a starting point the development of navigation over the last 25 years is described. In this period ships' bridges have developed from manual systems to highly complex socio-technical systems. The development of Norwegian fast patrol boats is used to illustrate some of the aspects of the development. Later in the chapter, future directions for further development are outlined. In order to improve the usability of future technology in ship navigation, a structured human-centered design approach is advocated.

9.1 Trends in the development of modern navigation equipment

Over the last years navigation technology has developed considerably. 25 years ago, navigating a ship demanded experienced crews, and highly developed skills were required to operate instruments such as sextants, radars and radio communication. Instruments were operated manually; radars were adjusted and tuned manually, sextants were used to measure the height of stars in order to find the ship's position. Radio communication was used to obtain information regarding the course and speed of other ships. To a great extent, the navigator's task was about gathering enough information to sail the ship safely. The necessity to gather information is still reflected in the International Navigation Rules. The rules require navigators to use all available means to gather information upon which they make decisions. 25 years ago, lack of information available to the navigator was commonly regarded as something that led to ship accidents. Information overload was not a concern on ships' bridges at that time.

The 1980s and 1990s introduced new technology that changed tasks and organization on board ships. In 1996 the GPS became available to civilian users. The satellite navigation system provided accurate position data world wide, throughout the year, and in all weather conditions. GPS combined with the development within information technology gave navigators instruments such as electronic charts where ships' positions were automatically displayed. The development also led to automatic exchange of course and speed information between ships. Equipment increased autonomy; radars got automatic functions and automatic tuning. Autopilots became common, and so did even track pilots, that were able to steer the ship along a route. Although the navigator was provided with more technical support and with more accurate information, groundings and collisions still occurred. Ships' bridges increased their technical complexity and information overload for the navigators became an issue in the maritime domain (e.g. Edmonds 1999).

The development of the Norwegian fast patrol boats can serve as a particular illustration of the technical development in the field of maritime navigation. These ships were built in the early 1980s. Originally the ships were equipped with instruments that largely demanded manual work. Using paper charts required a plotter. Steering the ship needed a helmsman. In total, a five-person team worked together to navigate the ship. In the 1990s the Hauk-class was updated. It was believed that the development of new technology could improve ship performance. New radars with several automatic functions were mounted on board, along with an electronic chart system. Automation became available for the navigator to control the speed of the ship. The development of the Hauk-class can be described as evolutionary: Although new technology was taken on board, this technology supported the crew and provided them with new tools. The navigation team organization and division of tasks remained the same.

The Hauk-class will from 2008 be decommissioned and replaced by a new type of fast patrol boats, the Skjold-class. The new ships have a top speed of 60 knots, nearly twice that of the Hauk-class. Manning is reduced from five persons to two persons. The Skjold-class is largely automated and is equipped with modern navigation equipment such as autopilot steering and only electronic charts for navigation. The development of the Skjold-class can be described as revolutionary. The new concept poses new possibilities and challenges that cannot all be predicted until some experience or testing has been carried out. In this new type of ship, technology has taken over tasks previously performed by crewmembers.

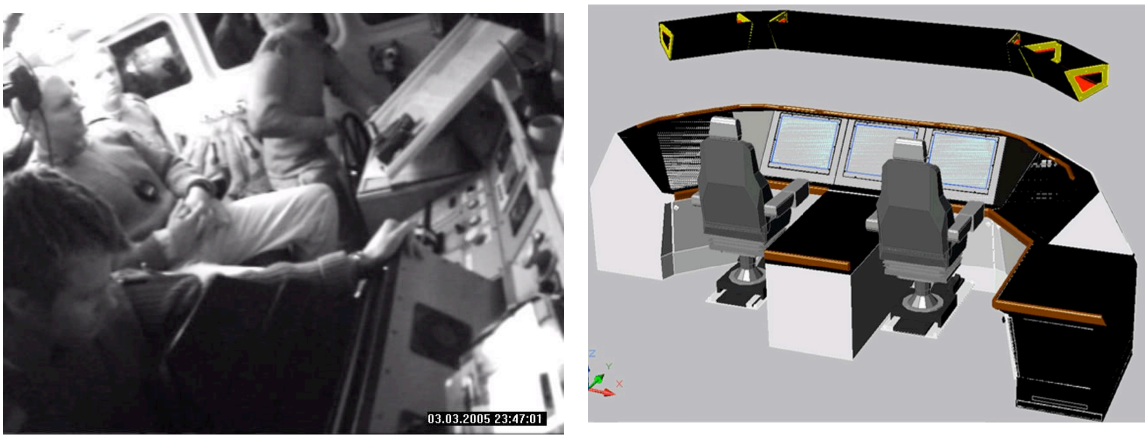


Figure 9-1: Overview of the bridge of the Hauk-class (left) and CAD drawing of Skjold bridge (right).

In a study of Hauk versus Skjold navigation equipment (Røed et al. 2005), it was found that Skjold navigators are required to operate more generic systems. The study used the specific-generic term in order to classify artifacts. The dimension refers to the relationship between controls and the functions that are operated. To give an example: An iPod controls a large number of functions from only four touch buttons and a touch wheel. This is an example of a generic interface. On the opposite, on a specific interface one control is connected to one function. An example is old TV sets, where on/off, each channels and light, contrast on so on had dedicated buttons.

On the Hauk-class 37 artifacts were used by the navigation team, whereas on the Skjold-class, the team used 39 artifacts. The relationship between specific and generic artifacts are presented in Table 9-1.

Table 9-1: Relationship between specific and generic artifacts.

	Specific	**Generic**
Hauk-class (37 artifacts)	24 (65%)	13 (35%)
Skjold-class (39 artifacts)	9 (23%)	30 (77%)

The study suggested that navigation equipment on Norwegian fast patrol boats had developed from specific interfaces to generic interfaces. In generic interfaces the user must relate to the structure in which information is embedded. This development is likely to change navigators' cognition, from requiring rather simple cognitive functions to more demanding.

9.2 Future development

Major manufacturers of navigation equipment have over the years updated and provided new versions of navigation equipment in terms of adding functionality and providing the navigators with more and more possibilities for actions. Many ships' bridges have evaluated into very complex systems. More on this topic can be found on the web pages of Maritime Ergonomics Special Interest Group[6], or at Lloyds Ship registers special initiative for human factors in the maritime domain[7].

---

[6] www.maresig.org

[7] www.he-alert.com

A trend in the maritime industry is to integrate even more systems on the ship. About ten years ago the integrated bridge was developed. Here, all navigation equipment was gathered within reach from the navigator's workplace. Further, the navigator could choose to integrate information by displaying e.g. radar and chart as overlays on a common screen. Today, several manufacturers proceed further and develop integrated navigation, communication, and ship automation (Koehler 2006).

Integrating more technical systems means that manufacturers will provide one common base for technology on board ships. Commonly today, there are several subsystems from different manufacturers. There is a need for boxes that translate data in order to make all systems function. Using one common piece of technology means more effective communication between sub-systems, and less cost for manufacturers in development, installation and maintenance. The interfaces on such systems will probably be computer monitors and mouse or tracker ball operation. Integration means that all types of information can be displayed on any screen on board. Future development may create even more complex systems for the navigator in his or her work (ibid.).

The development of maritime technology is much driven by the manufacturers of navigation systems. For all areas of commercial shipping, there is an international body of rules provided by the International Maritime Organization (IMO), where a important document is the overarching Safety of Life at Sea convention (SOLAS) (IMO 1974). The last revision of the SOLAS included human factors issues. The convention expresses a need for standardization of bridge equipment, provides guidance on system alarms, and emphasizes the need for training of seafarers. However, the convention is not comprehensive enough to provide much guidance for the design of bridge equipment.

Another aspect of the international rules is that IMO's rules apply to new vessels under construction. With a life cycle of 30 years for commercial ships, this means that effective implementation of human factors legislation is at least 30 years away in the maritime domain. The nature of the international rules suggests that development of new technology that takes the joint human-system performance into account is in reality in the hands of the commercial industry.

9.3 Usability in the maritime domain

One way to incorporate human factors knowledge in product development is by emphasizing a human-centered approach to design. In this context a human-centered design process and usability refers to the standards ISO 9241 and ISO 13407. Usability has three dimensions (ISO 9241)*; effectiveness* that denotes the accuracy and completeness with which users can achieve specified goals, *efficiency* that denotes the resources spent in relation to accuracy and completeness, and *job satisfaction* which includes freedom from discomfort, and positive attitudes towards the use of the product. In order to make a product usable, the ISO 13407 emphasizes the need to understand the user of the product, the task in which the product will be used, and the context in which the user will perform the tasks. A human-centered design process is a structured way of obtaining knowledge about user, task, and context in order to produce a usable end product.

There are especially three factors that argue that manufacturers should concentrate on human-centered design and usability:

Economy. A trend is to use more common and integrated computer technology, for instance to integrate navigation, automation, and communication. On the one hand the use of common technology platforms have the potential to reduce costs related to system development, installation, and maintenance. On the other hand, integrated systems open for development of enormous complex systems that pose very high demands on the operator. In order to fulfill the economic potential, the human operator must be able to effectively use the system.

Time. Today, the user is provided with technology without much time to learn the system before it is taken into use. In order to increase company income ships spend as little time as possible in port for system installation. In some cases ships have been retrofitted with a new bridge in less than four hours. However, with increasing complexity, there will probably be increased time pressure on users to learn new equipment. In order to minimize the resources in terms of time spent on learning the system, a usability focus is advocated.

Experience. Ships will in the future be manned with younger and less experienced crews that today (WIER 2005). Less experienced navigators combined with increased technology complexity suggests that users will possibly have to invest more resources in order to learn to use the navigation systems. A usability design approach may reduce the need for learning resources.

9.4 Towards a systematic design process

Traditionally engineers have had the defining power in the design of technological maritime navigation systems. Here, engineers are used in a broad sense, describing people working with technological requirements and specifications. Several manufacturers of maritime technology claim that their main asset is their strong technological knowledge in the domain.

The engineers' position in the maritime navigation domain leads this author to suggest that a human-centered focus should involve engineers and work through the engineers' domain. The engineers need to understand who the users of their products are, the tasks that are fulfilled, and the context in which work takes place. A way to proceed towards human-centered design is through interaction between human factors experts and system engineers.

Manufacturers of navigation technology have vast amounts of technological knowledge. However, knowledge of human factors is rarely represented in the end product. In order to introduce human factors knowledge into a design process, a structured approach is suggested, e.g. the human-centered design process of ISO 13407. In this process this study suggests three aspects of importance when combining different work domains:

Multidisciplinary. A human-centered design process is likely to include domain experts from the engineering and human factors domain. People will probably have high qualifications within their own domain, but will have less knowledge in other domains. Engineers will have high technical qualifications, on the other hand they have little knowledge of human factors. This gap of knowledge between disciplines calls for suitable working methods. Explaining aspects of any domain should be done in small steps and by reassuring that issues are understood. Methods and working techniques that afford team work should be preferred, e.g. sketching, low-fidelity prototypes, cardboard mock-ups. Illustrative techniques such as showing photos and videos will provide insight into the field of knowledge for domain novices. Exchange of knowledge should be done in small steps in order to ensure that people understand what the knowledge is about.

Iterative. The iterative nature of a design process comes from acknowledging that one will not get the product right the first time. The knowledge gap between people involved in the process also emphasizes that an iterative process has the benefit of gradually transferring knowledge between the domains. When proceeding in the iterations, more human factors knowledge can be addressed and find its way into design work.

Usability evaluation. Knowledge of the users, their tasks and the context of use will commonly suggest several possible designs solutions to a given design problem. In order to choose the most usable solutions that are, the user should be included in design evaluation. Human factors methods are believed to be important in order to ensure safety and performance of the joint human-machine system. When making the final decision about what system the navigator should be provided, the navigators themselves should be involved.

10 Summing up the study

This chapter presents the main points treated in this study. The most essential elements are presented in a condensed manner in order to provide an overview of the work and the outcome of the study.

- A fast patrol boat is a complex socio-technical system that includes crewmembers and their tools. A team of five persons navigate the ship, where the navigator is the person leading the team. The goal of the navigation team is to navigate the ship safely to a destination within a given time frame.

- Navigation of fast patrol boats is usually founded on a detailed plan. The navigator draws lines and symbols in nautical paper charts in order to represent the plan. The navigation plan is a resource for the team's actions and the charts are a frame of reference for the teamwork on the bridge.

- Teamwork is necessary in order to navigate the ship. The tasks of the navigation team are carried out under different environmental conditions. The space available for maneuvers and conditions for optical observations influenced the team's behavior. The behavior of the navigation team is not constant. The crewmembers adapted their behavior according to the working context. Often the change of behavior is subtle.

- Although many of the team's tasks are carried out according to procedures or established best practices, there are often several ways to complete a given task and reach the same result. Navigators frequently explore new ways of working in order to improve task performance.

- The work organization of the navigation team is not static but change according to context. The organization of the navigation team is to a large extent flexible in order to handle tensions and changes. The team members monitor each other and corrected mistakes when necessary. The crew's work organization makes them able to detect and correct mistakes.

- Work practices are modified in the sense that accuracy is traded in for efficiency. Heuristics are used in order to carry out tasks within a minimum of time. Fixing the ship's position is done by efficient rather than accurate methods. Although efficiency is given priority, the navigation team's control system variation in order to keep the ship within safe waters.

- The navigation equipment used by the crew is often modified in order to be more efficient. For instance, tables were cut in order to achieve a clear view of an instrument located behind it. Artifacts are used for purposes beyond their initial scope of design. The crew use charts and bearing devices in order to augment memory.

- A usability study on the fast patrol boat suggested that navigation equipment to little extent is user-centered. The modern navigation equipment on the ships is "black-box type" which means that processes within the system are not observable to the user. Compared to the manual work processes of the navigation team, the "black-box type" artifacts do not provide the crew the possibility to evaluate the on-going processes.

- A challenge for designers of navigation equipment is to make artifacts that can function in a variety of conditions. This study explores a user-centered approach to design of navigation equipment. A user-centered approach implies that design is based on knowledge of the user of the equipment, the task that will be carried out, and the context in which the task will take place.

- This study suggests that interfaces that use physical representations and perceptually rich interfaces may improve working conditions for the navigation team. Prototypes of navigation equipment were developed in order to explore user-centered design of navigation equipment. Prototypes of an automated steering system, electronic chart system, alarm panel, and audio alarm concept were developed. However, the scope of this project did not include user evaluation.

- Applying human factors principles in design suggest several design solutions that could possibly improve navigators' working conditions. However, there is a risk that new design will create opportunities for new types of failures. For this reason user evaluation are suggested as a necessary part of design development.

- This study suggests there are two outcomes of a design process. One outcome is the improvement of the design in question. The second outcome is the *design seeds*, that is concepts and techniques that can be reused in other development settings.

- Development of navigation technology is at present a domain with strong engineering influences and traditions. This study suggests that a user-centered approach should involve engineers and work through the engineers' domain. A design process for development of navigation equipment would benefit from being multidisciplinary, iterative and utilize user evaluation.

References

AIBF. (1995). *The grounding of M/S Silja Europa at Furusund in the Stockholm archipelago on 13 January 1995*. Accident Investigation Board Finland. Helsinki: Oy Edita Ab.

Bea, R. C., & Moore, W. H. (1993). Operational reliability and marine systems. In K. H. Roberts (Ed.), *New challenges to understanding organizations*. New York: Maxwell Macmillan International.

Beguin, P., & Rabardel, P. (2000). Designing for instrument mediated activity. *Scandinavian Journal of Information Systems. Special issue on information technology in human activity, 12*, 173-190.

Beyer, H., & Holzblatt, K. (1998). *Contextual design*: Morgan Kaufmann Publishers.

Bjelland, H. V., Røed, B. K., & Hoff, T. (2005, 18-20 March). *Studies on throttle sticks in high speed craft - haptics in mechanical, electronic and haptic feedback interfaces*. Paper presented at the First joint eurohaptics conference and symposium on haptic interfaces for virtual environment and teleoperator systems (WHC'05), Pisa, Italy.

Bjørkli, C. A., Øvergård, K. I., Røed, B. K., & Hoff, T. (2006). Control situations in high-speed craft operation. *Cognition, Technology and Work, Accepted.*

Blanding, H. C. (1987). *Automation of ships and the human factor*. Paper presented at the Ship technology and research symposium of the society of naval architects and marine engineers, Philadelphia, PA.

Bridger, R. S. (2003). *Introduction to ergonomics* (2 ed.). London: Taylor & Francis.

Bødker, S. (1989). A Human Activity Approach to User Interface. *Human-Computer Interaction, 4*(3), 171-195.

Bødker, S. (1996). Applying Activity Theory to Video Analysis: How to Make Sense or Video Data in Human-Computer Interaction. In B. A. Nardi (Ed.), *Context and Consciousness: Activity Theory and Human-Computer Interaction* (pp. 147-174). Cambridge: MIT Press.

Carrol, J. M., Kellogg, W. A., & Rosson, M. B. (1991). The task-artifact cycle. In J. M. Carroll (Ed.), *Designing Interaction: Psychology at the human-computer interface*. (Vol. 74-102). Cambridge, England: Cambridge University Press.

Clark, A. (1997). *Being there*. Cambrigde, MA: MIT press.

Cockroft, A. N. (1984, June). Collisions at sea. *Safety at sea*, 17-19.

Cook, R., & Woods, D. D. (1996). Adapting to new technology in the operating room. *Human Factors, 38*(4), 553-569.

Darke, J. (1978). The primary generator and the design process. In *New Directions in Environmental Design Research: Proceedings of EDRA 9* (pp. 325-337). Washington: EDRA.

Dekker, S. W. A. (2002). *The field guide to human error investigations*: Ashgate.

Donderi, D. C., & McFadden, S. (2003). A single marine overlay display is more efficient than separate chart and radar displays. *Displays, 24*(4-5), 147-155.

Donderi, D. C., Mercer, R., Hong, M. B., & Skinner, D. (2004). Simulated navigation performance with marine electronic chart and information display systems (ECDIS). *Journal of Navigation, 57*(2), 189-202.

Edmonds, D. (1999). Feedback from users of electronic chart technology. *Journal of Navigation, 52*(1), 141-148.

Endsley, M. R., Bolté, B., & Jones, D. G. (2003). *Designing for situation awareness*. New York: Taylor & Francis.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen & R.-L. Punamäki (Eds.), *Perspectives on Activity Theory* (pp. 19-38). Cambridge: Cambridge University Press.

Faulkner, X. (2000). *Usability Engineering*. New York: Palgrave.

Gauthereau, V., & Hollnagel, E. (2005). Planning, control, and adaption: A case study. *European Management Journal, 23*(1), 118-131.

Gibson, J. J. (1986). *The Ecological Approach to Visual Perception*: Lawrence Erlbaum Associates.

Gould, K. S., Røed, B. K., Koefoed, V. F., Bridger, R. S., & Moen, B. E. (2006). Performance-shaping factors associated with navigation accidents in the Royal Norwegian Navy. *Military Psychology, 18 (Suppl.), S111-S129*

Halverson, C. A. (2002). Activity Theory and Distributed Cognition: Or What Does CSCW Need to Do with Theories? *Computer Supported Cooperative Work, 11*, 243-267.

Hecht, H., Berking, B., Büttenbach, G., Jonas, M., & Alexander, L. (2002). *The Electronic Chart* (2 ed.). Lemmer, Netherlands: GITC.

Hederstrom, H., & Gylden, S. (1992). Safer Navigation in the 90s - Integrated Bridge Systems. *Journal of Navigation, 45*(3), 369-383.

Hockey, G. R. J., Healey, A., Crawshaw, M., Wastell, D. G., & Sauer, J. (2003). Cognitive demands of collision avoidance in simulated ship control. *Human Factors, 45*(2), 252-265.

Hoff, T. (2002). *Mind Design. Steps to an Ecology of Human-Machine Systems.* Dr.polit Thesis. Department of Psychology and Department of Product Design Engineering. Norwegian University of Science and Technology, Trondheim, Norway.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed Cognition: Toward a New Foundation for Human-Computer Interaction Research *ACM Transactions on Human-Computer Interaction, 42*(1), 174-196.

Hollnagel, E. (1998). *Cognitive Reliability and Error Analysis Method CREAM*: Elsevier.

Hollnagel, E. (2002). Time and time again. *Theoretical Issues in Ergonomics Science, 3*(2), 143-158.

Hollnagel, E. (2004). *Barriers and Accident Prevention*: Ashgate.

Hutchins, E. (1987). *Learning to navigate in a context.* Paper presented at the workshop on context, cognition and activity, Stenungsund, Sweden.

Hutchins, E. (1995a). *Cognition in the Wild*: MIT Press, Cambridge.

Hutchins, E. (1995b). How a cockpit remembers its speed. *Cognitive Science, 19.*

Hutchins, E. (2004). *Contributions of cognitive etnography.* Lectures at Linköping University, 14-15 December 2004.

IMO. (1974). International convention for the safety of life at sea: International Maritme Organization, London, UK.

IMO. (1995). ECDIS Performance standard: International Maritime Organization, London, UK.

ISO 9241:1998. Ergonomic requirements for office work with visual display terminals (VTDs) (1998). European Committee for Standardization.

ISO 13407:1999. Human-centered design processes for interactive system. (1999). European Committee for Standardization.

Jane's. (2005). *Jane's fighting ships 2005-2006.* Alexandria, US: Jane's Information Group.

Jones, J. C. (1966). Design methods reviewed. In *The Design Method.* London: Butterworths.

Kaptelinin, V. (1996). Computer-Mediated Activity: Functional Organs in Social and Developmental Contexts. In B. A. Nardi (Ed.), *Context and Consciousness. Activity Theory and Human-Computer Interaction.* (pp. 103-116). Cambridge: MIT Press.

Kirwan, B., & Ainsworth, L. K. (1992). *A Guide to Task Analysis*: Taylor & Francis.

Kjerstad, N. (2002a). *Elektroniske og akustiske navigasjonssystemer*: Høgskolen i Ålesund.

Kjerstad, N. (2002b). *Simulator for training and R&D in high-speed navigation.* Paper presented at the International MARTECH-2002, Singapore.

Kjerstad, N. (2003). *On the safety and training of High Speed Craft navigators along the coast of Norway.* Paper presented at the International Maritime Technology Conference, San Francisco.

Klein, G. (1993). *Naturalistic Decision Making: Implications for Design*: Crew System Ergonomics Information Analysis Center, Wright-Patterson Air Force Base, Ohio, USA.

Koehler, V. (2006). *Marine navigation, the human challenge of modern navigation.* Paper presented at the 7th Nordic Radio Navigation Conference, Stockholm-Helsingfors.

Kuutti, K. (1996). Activity Theory as a Potential Framework for Human-Computer Interaction Research. In B. A. Nardi (Ed.), *Context and Consciousness. Activity Theory and Human-Computer Interaction*. Cambridge: MIT Press.

Lakoff, G., & Johnson, M . (1999). *Philosophy in the flesh:* Basic Books

Lawson, B. (2006). *How designers think* (4 ed.). Oxford, UK: Architectural Press.

Lee, J. D. (1996). *Design of advanced ship systems: Emerging problems and human factors solutions*. Paper presented at the Centro Tecnico Navale (CETENA) Seminar on Human Factors Impact on Ship Design, Genoa, Italy.

Lee, J. D., & Sanquist, T. F. (2000). Augmenting the operator function model with cognitive operations: Assessing the cognitive demands of technological innovation in ship navigation. *IEEE transactions on systems, man, and cybernetics. Part A, Systems and humans, 30*(3), 273-285.

Leontev, A. N. (1974). The problem of activity in psychology. *Soviet Psychology, 13*(2), 4-33.

Lutzhoft, M. H., & Dekker, S. W. A. (2002). On your watch: Automation on the bridge. *Journal of Navigation, 55*(1), 83-96.

Lutzhoft, M. H., & Nyce, J. M. (2006). Piloting by heart and by chart. *Journal of Navigation, 59*, 221-237.

Lützhöft, M. (2004). *The technology is great when it works. PhD thesis*. University of Linköping, Sweden, Linköping.

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits in our capacity for processing information. *Psychological Review, 63*, 81-97.

Miller, T. E., & Woods, D. D. (1996). Key issues for naturalistic decision making researchers in systems design. In C. Zambok & G. Klein (Eds.), *Naturalistic decision making*. Mahwah, NJ: Lawrence Erlbaum Associates.

Mills, S. (2000). Safer positioning of electronic fishing aids. *Journal of Navigation, 53*(2), 355-370.

Mills, S. (2005). Designing usable marine interfaces: Some issues and constraints. *Journal of Navigation, 58*(1), 67-75.

Nardi, B. A. (1996a). *Context and Consciousness. Activity Theory and Human-Computer Interaction*. Cambridge: MIT Press.

Nardi, B. A. (1996b). Studying Context: A Comparison of Activity Theroy, Situated Action Models, and Distributed Cognition In B. A. Nardi (Ed.), *Context and Consciousness: Activity Theory and Human-Computer Interaction*. Cambridge, Ma: MIT Press.

Nielsen, J. (1993). *Usability Engineering*. San Diego: Academic Press.

Norman, D. A. (1988). *The design of everyday things*: Basic Books.

Norros, L. L. (2004). *Acting under uncertainty*. Espoo, Finland: VTT Technical Research Centre.

Norros, L. L., & Savioja, P. J. (2006). Towards a theory and method for usability evaluation of complex human-technology systems. In *Proceedings of the International Ergonomics Association 16th World Congress on Ergonomics*. Maastricht, Netherlands.

Olsson, E., & Jansson, A. (2006). Work on the bridge - studies of officers on high-speed ferries. *Behaviour & Information Technology, 25*(1), 37-64.

Perrow, C. (1984). *Normal Accidents*. Princeton, NJ: Princeton University Press.

Petersen, J. (2004). Control situations in supervisory control. *Cognition, Technology and Work, 6*, 266-274.

Poincaré, H. (1924). Mathematical creation. In *Creativity*. London: Penguin.

Rabardel, P., & Beguin, P. (2005). Instrument mediated activity: from subject development to anthropocentric design. *Theoretical Issues in Ergonomics Science, 6*(5), 429-461.

Rasmussen, J., & Rouse, W. B. (1981). *Human detection and diagnosis of systems failures*: Plenum.

Reason, J. (1990). *Human error*: Cambridge University Press.

Reber, A. S., & Reber, E. (2001). The Penguin Dictionary of Psychology, third edition. In. London: Penguin Books.

Rothblum, A. M. (n.d.). Human error and marine safety. from www.uscg.mil/hq/gm/risk/old%5Fsite/e%2Dguidelines/html/volume4/gen%5Frec/humanerr.htm

Røed, B. K. (2001). *Nautical safety for high speed craft. Integrity when using a satellite navigation system.* . MSc thesis, Department of marine technology, Norwegian University of Science and Technology, Trondheim, Norway.

Røed, B. K., Gould, K. S., Bjørkli , C. A., & Hoff, T. (2005). *Aspects of the technical development of Norwegian military fast patrol boats.* Paper presented at the Nordic ergonomics society 37th annual conference 10-12 October, Oslo.

Salas, E., Dickinson, T. L., Converse, S., & Tannenbaum, S. I. (1992). Towards an understanding of team performance and training. In R. W. Swezey & M. Endsley (Eds.), *Teams: their training and performance* (pp. 3-29). Norwood, NJ: Ablex.

Sanders, M. S., & McCormick, E. J. (1992). *Human factors in engineering and design* (7 ed.): McGraw-Hill.

Sanquist, T. F. (1992). *Human factors in maritime applications: a new opportunity for multi-modal transportation research.* Paper presented at the Human Factors 36th annual meeting.

Sarter, N. B., & Woods, D. D. (1997). Team play with a powerful and independent agent. *Human Factors, 39*(4), 553-569.

Sauer, J., Wastell, D. G., Hockey, G. R. J., Crawshaw, C. M., & Downing, J. (2003). Designing micro-worlds of transportation systems: the computer-aided bridge operation task. *Computers in Human Behavior, 19*(2), 169-183.

Sheridan, T. B. (1998). Rumination on automation. In *Proceedings of the 7th IFAC Symposium on the Analysis, Design, and Evaluation of man-Machine Systems.* Kyoto, Japan: IFAC.

Shneiderman, B. (1998). *Designing the user interface* (3 ed.). Reading, MA: Addison Wesley.

Snyder. (1991). *A Guide to Software Usability*: IBM Internal Publication.

Suchman, L. A. (1987). *Plans and situated actions. The problem of human machine communication*: Cambridge University Press.

Tzannatos, E. (2002). GMDSS operability: The operator equipment interface. *Journal of Navigation, 55*(1), 75-82.

Tzannatos, E. S. (2004). GMDSS false alerts: A persistent problem for the safety of navigation at sea. *Journal of Navigation, 57*(1), 153-159.

Ulrich, K. T., & Eppinger, S. D. (2003). *Product design and development*: McGraw-Hill.

Valsiner, J. (1997). *Culture and the development of children's action: a theory of human development*: John Wiley & Sons.

Vicente, K., & Burns, C. (1986). Evidence for direct perception from cognition in the wild. *Ecological Psychology, 8*(3), 269-280.

Vicente, K. J. (1999). *Cognitive Work Analysis. Toward Safe, Productive, and Healthy Computer-Based Work.* Mahwah, NJ: Lawrence Erlbaum Associates.

Vink, P. (2006). Positive outcomes of participatory ergonomics in terms of higher comfort and productivity. In *Proceedings of the International Ergonomics Association 16th World Congress on Ergonomics*. Maastricht, Netherlands.

Vygotsky, L. (1960). *Development of higher psychological functions*. Moscow.

Warren, R. (1976). The perception of ego motion. *Journal of Experimental Psychology, Human Perception and Performance, 2*, 448-456.

Wiener, E. L. (1989). *Human factors of advanced technology ("glass cockpit") transport aircraft* (NASA Contractor Report No. 177528). Moffet Field, CA: NASA-Ames Research Center.

WIER. (2005). *BIMCO/ISF Manpower 2005 update: The worldwide demand for and supply of seafarers*: Warwick Institute for Employment Research, UK.

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics, 31*(6), 557-567.

Winograd, T. (1987). *Three responses to situation theory.* : Technical report CSLI-87-106. Centre for the study of language and information, Stanford University.

Woods, D. D. (1998). Design are hypotheses about how artifacts shape cognition and collaboration. *Ergonomics, 41*(2), 168-173.

Woods, D. D. (1999). Human Factors 1999 Presidential Address. from http://csel.eng.ohio-state.edu/productions/hf99/

Woods, D. D. (2002). Steering the reverberations of technology change on fields of practice: Laws that govern cognitive work. In *Proceedings of the 24th Annual Meeting of the Cognitive Science Society, Atlanta, GA.*

Woods, D. D., & Hollnagel, E. (2006). *Joint Cognitive Systems - patterns in cognitive systems engineering*. New York: Taylor & Francis.

Zhang , J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science, 18*, 87-122.

Øi, Ø. (1985). *Håndbok i kyst og innenskjærs navigering*. Bergen, Norge: Sjøkrigsskolen.