Doctoral theses at NTNU, 2016:112

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Handheld devices for use within integrated operations in the petroleum industry

Doctoral thesis

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ISBN 978-82-326-1562-9 (printed ver.)
ISBN 978-82-362-1563-6 (electronic ver.)
ISSN 1503-8181

Doctoral theses at NTNU, 2016:112

NTNU
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Science and Technology
Thesis for the Degree of
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Trondheim, May 2016

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IMT-report 2016:112

Doctoral theses at NTNU, 2016:112

Printed by NTNU Grafisk senter

Abstract

Handheld devices have been used for several years in integrated operations in the petroleum industry. There is little knowledge of the effects of their design on efficient and safe plant operation, however. Moreover, little is known about how operators evaluate design and usability of mobile devices to support their work. The objective of this research work is to investigate how the design of handheld devices affects working routines to facilitate efficient and safe operations at gas processing plants and to what extent their use improve current procedures and satisfies users' needs.

For the purpose of creating design criteria for future product development, the research includes the collection and analysis of data on existing collaborative work practices in safety critical environments and evaluation studies of handheld devices that are currently used by operators on Norwegian land facilities. The criteria are based on theory and interviews, observation material, and video data from three ethnographic fieldwork studies conducted at the Ormen Lange and Hammerfest LNG onshore processing plants. The data were analysed using techniques from ethnographic analysis, video analysis, and design.

The thesis seeks to show relationships by taking a holistic view of human-computer interaction (HCI). It brings interaction with the real world — including sensory experience — into the focus of attention when designing future products. Creative decisions, in particular for mobile communication technologies, should be based upon theoretical considerations of the life world, embodiment, and Gestalt theory as well as on frameworks such as Distributed cognition and Activity theory because they are important for correct and effective use of technical devices. Handheld devices used in industrial contexts should be designed to support task performance rather than device performance. To succeed, the focus should, on the one hand, be on physical space in which work is done and on established procedures. On the other hand, user experiences and behavioural patterns as well as users' mobility should be taken into account. A logical outcome of this is simplification of technology complexity.

The aim of this research work is not to provide innovative technology but rather to emphasise the impacts of mobile technologies on people and business goals as well as on the physical and social environment in which technologies are used. The thesis is written from a design perspective and suggests aims for the design of handheld devices for use in the oil and gas industry. It presents a complex theoretical and empirical research and shows the dimensions that must be considered when designing seemingly small devices in order to meet their requirements. To answer the problem statement of the thesis, material from the fields of philosophy, cognitive science, and design theory was used and related to the empirical data collected from fieldwork studies. Based on a comprehensive design and context analysis, knowledge about handheld devices used in a hazardous work setting and information about user experiences is presented and data on the activity system of field operators provided.

Finally, design criteria for handheld devices are suggested and three concepts of mobile devices evaluated to identify their opportunities and challenges.

The research results show why it is necessary to design mobile technology from a user's perspective. There is, however, a need for more empirical research in time-constrained, data-driven environments where people are required to perceive data rapidly in fast-paced situations. In order to provide people with well-designed equipment, human aspects will have to play a greater role in technology development and in design and engineering sciences.

Preface

The thesis is submitted for the degree philosophiae doctor (PhD) at the Norwegian University of Science and Technology (NTNU). The research has been conducted at the Faculty of Engineering at Østfold University College (HiØ), at the Department of Product Design, Faculty of Engineering Science and Technology, NTNU, and partly at the Institute for Energy Technology (IFE). Trond Are Øritsland, associate professor at NTNU, has been main supervisor. Petter Øyan, professor at HiOA, and Achim Trebeß, professor at Hochschule Wismar – University of Applied Sciences, Technology, Business and Design have been co-supervisors. The research has been financed by the Østfold University College and by IFE.

Corrections

The thesis was submitted in August 2015. Some minor corrections are done for the final printed version of the thesis. Besides new page numbering and few type errors, the, respectively, last and first paragraph on pp. 56 and 57, and the last paragraph on p. 95 are slightly rephrased. In addition, the case story on pp. 145-146 is slightly rephrased.

Daniela Blauhut, May 2016

Acknowledgements

First, I am grateful to my supervisor Trond Are Øritsland for guiding me through the research work, for sharing his knowledge, and challenging me to think in the right perspectives. I like to thank Achim Trebeß for being an excellent co-supervisor. His sincere interests in this work, as well as his insights and philosophical perspectives have encouraged me to complete the thesis. To my second co-supervisor, Petter Øyan, thank you for the opportunity to carry out a PhD project in Norway, and also for your insights and discussions through the work. My special thanks go to Knut Lehre Seip, who has given me valuable and very professional feedback on my thesis.

Further, I would like to thank my colleagues from the Faculty of Engineering at HiØ, particularly my colleagues from the program of study Industrial Design and the Head of Department for supporting me and providing space. Thanks also to the Department for Product Design at NTNU for administrative support, and special thanks to Martina Keitsch and Casper Boks for valuable comments on my work.

The fieldwork at Nyhamna and Melkøya has been fundamental for this thesis. I am most grateful to the operators and engineers I met for participating in my studies, for sharing their time and valuable experiences and not least for their trust. I am particularly grateful to Hans Jørgen Wimpelmann for his kind support and the opportunity to conduct fieldwork at the Ormen Lange facility. I also thank Oddbjørn Fisketjøn, A/S Norske Shell, and Vegar Næss, Statoil ASA, for their help. Furthermore, I thank Jørgen Karlsen, Sarpsborg Avfallsenergi AS, and his colleagues for sharing their experiences with tablet PCs.

Thanks to my former students Karine Mile, Gitte Russøy Kalsvik, Trine Botten Karlsson, Oddgeir Lund Johannessen, Odd Georg Eriksen, and Håkon Torgrimsen, who participated in the semester project on radio communication at Borregaard. Special thanks go to Ole Gunnar Jakobsen and Kari Strande, Borregaard, for the opportunity to run this project and to use the results.

I am grateful to the Institute for Energy Technology (IFE) in Halden for supporting and funding my work. In particular I want to thank Jon Kvalem for his support, as well as Andreas Bye, Mario Hoffmann, and Brit-Kari Bjørlo for helping and providing me with an office in Halden. In addition, I thank Gisle Andresen and Øystein Veland for introducing me to IFEs research network and the Norwegian oil and gas sector. To Alf-Ove Braseth, thank you for your valuable feedback and our useful discussions and not least for your contributions to the Interaction design course at HiØ. Thanks also to Lars Hurlen and his colleagues for their support and contributions to my third-year students.

Finally, I thank my patient family for all their support in recent years.

Daniela Blauhut
Fredrikstad, August 2015

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List of abbreviations

AT	Arbeidstillatelse, Norwegian for work permits
CCR	Central control room
CSCW	Computer supported cooperative work
DOE	Department of Energy in the United States
ERP	Enterprise resource planning
GPS	Global positioning system
GUI	Graphical user interface
HAMMLAB	Halden man machine laboratory
HCI	Human-computer interaction
HSE	Healthy, safety and the environment
ICT	Information and communication technology
IEEE	Institute of Electrical and Electronics Engineers
IFE	Institute for Energy Technology
INL	Idaho National Laboratory
IO	Integrated Operations
IT	Information technology
LNG	Liquefied natural gas
LWRS	Light water reactor sustainability
MEG	Mono ethylene glycol
NPP	Nuclear Power Plant
OTTER	Operational and Technical Tasks for Efficient Rounds
PDA	Personal digital assistant
PI	Process information
PTT	Push-to-talk
RFID	Radio frequency identification
SSAT	System-structural theory of activity
TETRA	Terrestrial Trunked Radio
TUI	Tangible user interface
UCD	User-centred design
WLAN	Wireless local area network
WSN	Wireless sensor network

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1 INTRODUCTION

This research project is supported by IFE and thematically connected to the Centre for Integrated Operations in the Petroleum Industry (IO Centre) that was established by IFE, SINTEF, and NTNU in cooperation with major international oil companies and several scientific institutions. Integrated Operations include the integration of people, work processes, and information technology (IT) to enable personnel to make smarter decisions and better performance. The aim is to enable new ways of working to achieve efficient and safe operations through the implementation of innovative technology solutions. The following section introduces the general problem that is addressed in this project and outlines the research objectives, the research design, and the contributions of the thesis. It then provides an overview of the structure of the thesis.

1.1 General problem

Mobile technologies are used while people are acting and moving, be it the everyday use of mobile phones while shopping, walking, and working or the use of radio units while inspecting technical facilities. In the past two decades, the popularity of mobile handheld devices for use in professional settings has grown significantly. Mobile devices such as tablet computers and personal digital assistants *(*PDAs) have been implemented in education, medical practice, and industrial plants. They make it easier to manage work tasks and to organise information. To succeed, mobile devices must be well suited and thoroughly designed and tested to meet the requirements of all stakeholders of an organisation and thus, to simplify work routines and increase productivity. If a device does not fit into its intended context or if it is difficult to operate, then it has failed and the moments in which it failed have to be reconsidered.

Change of context from public to industrial use of technology

Products and systems affect human behaviour in work situations and in a communicative social context. For example, Apple's designers have influenced the way young and elderly people interact with technology and communicate with each other. Mobile devices such as the iPhone and the iPad became popular because of their design and high usability. Apple products are based upon a simple and user-oriented service system behind the products whereas many other devices by other developers are based upon technology-oriented systems to increase functions. Many devices are bloated with unnecessary features, and technology integration can become difficult. This is particularly critical in view of hazardous working conditions like those seen in the petroleum industry. In contrast to the everyday use of Apple's iPhone, mobile device use at processing plants is changing the way people perform their work. User tasks play an essential role in the application of technology in practice. The proper use of handheld technology by operators depends on external factors such as the physical workspace, visibility, weather conditions, operating plant process noise, and health and safety measures required for oil and gas operations. Other factors are the workload on operators, the need for rapid perception of information, and the dependencies between field operators and the control room. In terms of physical activity, field operators are required to cover long distances (often walking), to climb ladders and scaffolds, and to carry equipment (e.g. tools, measurement devices). These factors will have major impacts on how people interact with handheld devices, and hence on how efficient and safe plant operation is achieved.

Challenges of the hazardous workplace

On the science and technology side, knowledge has been published on the potential of modern technologies, in particular on touchscreen technologies. Moreover, contributions have been made to the research on collaboration in plant operation, and studies have been conducted on mobile wireless solutions to support plant personnel. On the industrial side, several companies (e.g. Motorola, Bartec) have developed explosion-proofed, rugged high-tech devices for use in hazardous areas in recent years. Today, field operators at Norwegian oil and gas facilities collect process data using handheld PDAs or manage work permits using computer tablets. However, there is a gap between high-tech technology and user experience that needs to be bridged. The operators' perspective and their experiences of life and work have not been sufficiently considered so far. Additionally, the impact of human motion on interactions with screen-based computer devices used in industrial settings has not been sufficiently explored yet. The lack of user acceptance of current handheld devices used in the industry sector may be due to the lack of product usability and the overall product design that may not attract the target group.

In terms of product usability, it seems that much attention has been paid to improving screen quality in recent years. For example, besides visual feedback, haptic response on touchscreens can provide users with tactile information while interacting with the graphical interface. On the other hand, less attention seems to be given to physical product qualities such as hardware buttons or material properties. However, tangible interaction became noticeable as a research subject in the late 1990s, and since then it has grown rapidly into a research area (Hornecker 2014). Tangible interaction emphasises materiality of interfaces, the physical representation of data, whole-body interaction, and the embedding of interface and human interaction in real spaces and contexts (ibid.), which means, into existing structures. This is a crucial development as tangible interfaces attempt to close the gap between the interactions with objects in our (physical) life world and the digital world. This might contribute to better control of computational information and is thus important for operators working in demanding work settings. Given the handheld devices for use in industrial settings, tangible user interfaces (TUIs) are still little considered. However, environmental and safety factors such as lighting conditions, climate, and working clothes as well as spatial conditions in terms of plant design may influence the use of handheld devices and can make multi-touch screen recognition difficult.

The general problem addressed in this thesis is the understanding of design in the context of a technologized life world in which human aspects have retreated into the background. Using the example of handheld devices that are used by operators in the petroleum industry, this research project seeks therefore to examine the role of design for technological products and their users exactly. Precisely because the project is about modern technology, the human aspect will be emphasised.

1.2 Research aim

Given the research subject, the research aim of this thesis is to investigate how the product design of handheld devices affects working routines to facilitate efficient and safe operation at two Norwegian onshore facilities, Hammerfest LNG and Ormen Lange, and the extent to which their use improves current procedures and satisfies users' needs. The thesis aims in particular to raise awareness on the complexity of the design task of human-machine interaction. It includes the following:

1) usability studies of handheld devices used at Norwegian gas processing plants with a focus
   on product qualities including graphical and physical user interfaces
2) exploration of the operators' experiences of current handheld devices and procedures
3) empirical investigation of operator-device interaction on site and identification of the factors affecting the interaction
4) elaboration of criteria and criteria values for designing handheld devices to bridge the gap between technology and user experience

Limitation of scope

One of the purposes of this work is to emphasise the importance of individual theoretical concepts for design in general and for HCI in particular. Individual positions are compared and evaluated in relation to design. However, this research work does not claim to be a comprehensive account of human cognitive abilities taking into account all relevant theories. The focus of the present work is the design of interactive portable products for use in hazardous workplaces. It will show, however, that a basic understanding of cognitive processes is needed for it.

The scope of the thesis is limited to handheld equipment used in work environments where zero-defect operation can be affected by environmental factors. Design issues such as graphical user interfaces (GUIs) of large-screen solutions in control rooms and technical issues of security of information, networks, and systems are outside the scope of the thesis, whereas scientific aspects of user-centred design (UCD), cognitive processes, and human factors are included in it.

Given the framing above, the main subject of the present thesis is *handheld devices for use within integrated operations in the petroleum industry.*

Research questions

Given the problem and the research aim above, the research questions of this thesis are as follows:

1. How does the product design of mobile devices affect efficiency and safety in Norwegian plants in the petroleum industry?
2. How do field and control room operators evaluate design and usability of mobile devices in support of field operations?
3. How should mobile devices be designed to meet efficiency and safety requirements?

1.3 Research design

Activity theory and an ethnographic approach have been used to answer the research questions that guided this research study. The main ethnographic field methods of the thesis are:

1) Qualitative interview
2) Participant observation in fieldwork
3) Video in qualitative research

It is important to note that a comprehensive ethnographic fieldwork, as in traditional ethnography, is not intended in this research because it is unrealistic for an outsider to stay at a gas processing plant for a long period. In this case, the research design is inspired by ethnography. It allows the investigation of the context and the descriptive and interpretative analysis of everyday work experiences and practices from the perspective of operators. In particular, in light of technological developments used in integrated operations in the petroleum industry, ethnographic methods are a promising way to gain empirical data on users in their natural environment. Nevertheless, these methods have their limits when applied in hazardous work environments. This is especially true for participant observation and video-based studies.

In this research, three brief fieldwork studies were conducted at two Norwegian gas processing plants. The traditional methods of ethnographic fieldwork helped understand processes, activities, and interactions and were appropriate for studying people and their experiences and for evaluating handheld devices in the real context of use.

The strategies for the data analysis ranged from categorizing information according to evaluation aspects found in interviews to making video material clear and effective. Nonverbal and verbal techniques (e.g. video artefacts and case stories) as well as tools and methods used in the field of graphic design were applied to support data analysis. On the theoretical side, the thesis draws on Activity theory as an appropriate framework to support the analysis of qualitative data. Activity theory helps identify different levels of human activity that are specific to operator-device interaction in process plant operation. It takes human activity as the unit of analysis and has been applied to a variety of research studies in HCI.

1.4 Contributions

The main contributions of the thesis are:

- knowledge about mobile equipment used in an industrial work setting that is not yet sufficiently documented in the HCI literature and description of the effects that the design of mobile devices has on efficient and safe plant operation
- empirical research material on the activity system of field operators working in the oil and gas sector and end-user assessments of quality and usability of mobile devices
- a theoretical frame on cognitive processes in HCI and sensory perception of objects for understanding the complexity of the design task for human-computer interaction
- design criteria and their value for designing mobile devices to help increase user acceptance and hence to help improve efficient and safe plant operation in hazardous environments
- evaluation of three different design approaches to identify opportunities and challenges of modern mobile devices

The contributions have implications on how we deal with challenges in designing interactive products for use within integrated operations in the petroleum industry. They are thus relevant for software developers and designers, researchers within the fields of human-computer interaction, information and communication technology (ICT), energy technology, and human factors and ergonomics. The research results also provide insight on how situations and physical space may affect human activity and may therefore have relevance for the oil companies.

1.5 Overview of the thesis

In the following, an overview of the structure of the thesis is given.

Chapter 2 emphasises the importance of the interplay of cognition and embodied action for the use of objects, which can be ascribed to the fact that humans feel. Sensations are closely connected with the sensual perception of objects and their aesthetic experience. The chapter suggests that understanding of an aesthetic is based on the gestalt of an object because gestalt includes the understanding of function and the real use of an object. This is important because the enjoyment of functionally oriented handheld devices occurs through real use; it does not develop by observation. The chapter shows that designers and engineers need to understand the complexity of interaction to get users to accept new technologies. Technology acceptance depends on the users' experiences — their stocks of knowledge — as well as actions that are directed to the environment in which they live and work and to objects used within the context of environment. Moreover, the chapter shows that future devices and systems are supposed to transfer HCI into the physical world, meaning they will relocate the interaction from screens to objects in the real world and that designers will have to explore the gestalt perception of complex objects by drawing on design principles *and* theoretical knowledge of cognitive processes.

Chapter 3 focusses on the sensory perception of objects, in particular on tactile and kinaesthetic sensory perception. It stresses that visual, tactile, and kinaesthetic impressions are of particular importance for experiencing mobile equipment with small screens, such as devices used in the oil and gas industry. That is probably because haptic object recognition can help to relieve operators from visual overload and stress in an environment where visual recognition of information and identification of buttons is critical. Additionally, haptic feedback can serve as orientation and confirmation for correct use of controls, given that users develop motoric habits based on experiences and spatial memory. The chapter argues that touchscreens may not supply sufficient tangible experiences and feedback, despite their benefits on dynamical information presentation and high-level interaction. Moreover, the impact of human motion on interactions with screen-based computer devices used in industrial settings has not been sufficiently explored yet. As currently used handheld devices are too large to be worn on the body, they do not properly support the way operators move, act, and communicate in the field. However, future handheld and wearable devices should aim to augment body and mind, rather than to replace physical and mental functions. This chapter, therefore, argues that computer performance must be developed in terms of meaningful computer assistance for actions and social interactions in the real world.

Chapter 4 makes evident that in the last decade, the use of wireless technology in the process industry has increased. However, paper-based methods for task performance seem to be common in the petroleum and nuclear industries, despite several research studies on handheld technologies that have been tested for gas and nuclear power plants. This chapter reveals that a participatory design approach should be the way to conduct research projects on handheld technology for industrial use, as participatory design focusses on the end-user rather than merely applying the newest technology. However, from a design perspective it is not enough to primarily consider the graphical user interface and the software technology of handheld devices. Future solutions also require designing product interface qualities. In terms of operator-device interaction, chapter 4 shows that the focus should be on the work task rather than on the device to ensure efficient and safe task execution.

Chapter 5 emphasises that traditional research methods such as qualitative interviews and video-based participant observation are meaningful instruments for qualitative design research on human activity in the domain of oil and gas. In particular, it highlights the combination of these methods as being more effective and valuable in terms of context understanding, insights into the (unknown) domain, and learning about tasks and the tools that are used to execute them. In addition, this chapter argues for the use of design as a research method and strategy for thematic data analysis and proposes the combination of nonverbal and verbal documentation of research results. Moreover, it highlights the value of Activity theory for research analysis because Activity theory considers human activity as the unit of analysis and differentiates between activity, action, and operation.

Chapter 6 presents the material collected during ethnographic fieldwork studies conducted at the Ormen Lange land facility at Nyhamna and Hammerfest LNG at Melkøya. As a result, it suggests that not only individual artefacts be considered in the design process, but rather that the entire complexity of plant operations be taken into consideration when designing future mobile technologies. This chapter explains why the improvement of work performance at oil and gas facilities to facilitate efficient and safe actions and operations cannot be achieved solely by developing new technologies to support certain operations in the plant. Instead, it shows that there is an urgent need to address many aspects of the natural gas production situation, including the parts of the activity system of operators and their dependencies that relate to the environment in which activities take place, rules and regulations that result from local conditions, and handheld devices used under the existing environmental conditions.

Chapter 7 suggests theoretically and empirically grounded criteria for designing handheld devices to support task performance at process plants in the petroleum industry and provides, based on these criteria, an evaluation of three different design approaches to identify opportunities and challenges of modern mobile devices. The approaches comprise one conceptual design study carried out by six third-year bachelor students at the Østfold University College who were supervised by the author and three cases from industry in which two computer tablets and one smartphone were tested for process control operations. The design study proposes a headset with a tactile user interface for radio communication.

Chapter 8 discusses the findings and limitations of the thesis. It further summarises the contributions and explains the extent to which they are relevant to practitioners, researchers, and oil companies.

Finally, *chapter 9* concludes the thesis and outlines issues for further research work.

To summarise, Figure 1-1 shows the overall structure of the thesis in a graphical way.

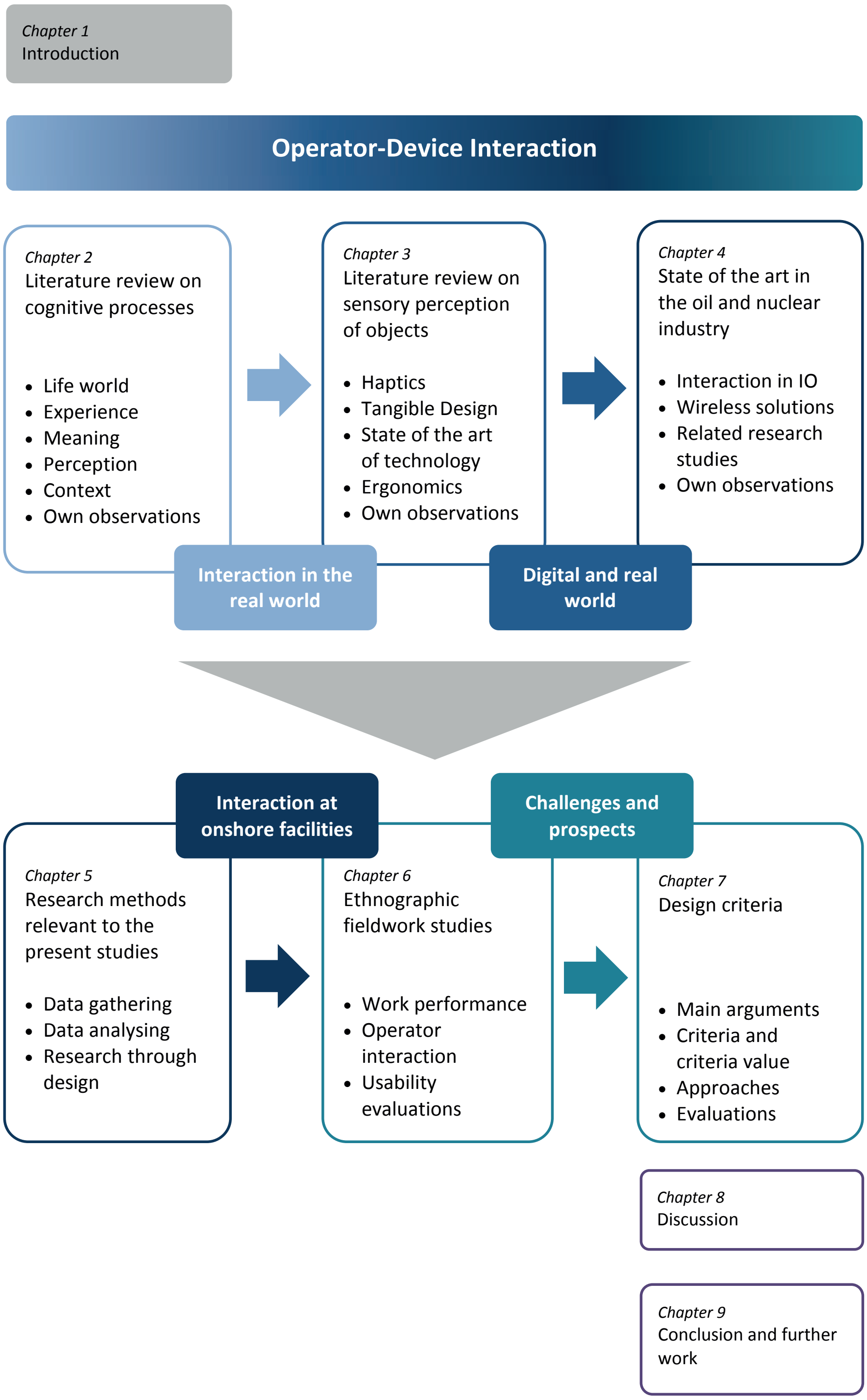


Figure 1-1: The structure of the thesis and the relationship between the chapters.

2 COGNITIVE PROCESSES IN HCI

The purpose of this chapter is to identify and present background knowledge necessary to understand the complex process of human activity. Based on theories of cognition, a number of cognitive frameworks have been developed to explain human behaviour and human experiences. The scientific material that is selected for this thesis provides knowledge of the relationship between action in the world and meaning as well as scientific analysis tools for human activities considering the overall context of interaction between people and the world. The chapter identifies the following theoretical concepts as being relevant for the research questions of the present thesis: I) the concept of the life world in phenomenology, II) the concept of embodiment, and III) Gestalt theory. It further identifies the following conceptual frameworks: IV) Distributed cognition and V) Activity theory. While concepts I), II), and III) argue for a cognitive science that considers cognition not only a pure neuronal phenomenon but also a type of cognition that happens outside the individual, frameworks IV) and V) deal with this "outside". From the perspective that the perception and action in everyday life play a special role, these cognitive approaches can provide scientific analysis tools for the design of new artefacts and systems that allow meaningful actions in the world. In particular, in light of the recent development of increasingly complex systems that must be operated by people in an increasingly complex environment, these approaches are therefore of great interest for design and HCI. Against this background, the chapter finally provides a first insight into the interaction between humans and mobile devices.

2.1 Phenomena of human experiences — the concepts of I) life world in phenomenology and II) embodiment

In order to understand the complex process of human activity, it is important to investigate phenomena of human experience and understanding in everyday life. Phenomenologists such as Husserl, Heidegger, Schutz, and Merleau-Ponty focused in their philosophical work on everyday acting in the world and took human action to be fundamental to our understanding of the world (Wetz 1995, Orthbandt n.d., Dourish 2001). Berger and Luckmann (1967), Gibson (1986), Lakoff and Johnson (1999), Dourish (2001), and Honer (2011) — although not standing in the phenomenological tradition — were inspired by phenomenology and developed perspectives on the construction of everyday reality and how we as individuals perceive the world and interact with our environment. All approaches followed the idea that action in the world and meaning are in a relationship and thus are relevant to embodiment and HCI.

In light of the research problem of this thesis, these approaches can be used to explore the challenges in operator interaction in demanding work environments. The following sections highlight basic ideas of the life world concept that are relevant to human understanding and experience of objects.

2.1.1 Phenomena of daily life

The concept of the life world was introduced by Edmund Husserl as part of his critique against science, which at the beginning of the 20th century was becoming increasingly independent and disconnected from human experience. For Husserl, the human being was not only a part of nature but also a personality, or a subject protruding from nature (Wetz 1995: 13). He particularly criticised science for being idealised and less concerned about concrete phenomena of daily life. In his view, the scientific conception of the world had distanced science from the everyday world and thus from the lived experience of people acting in the world (Dourish 2001). There is no objective truth independent of history, culture, and subjectivity. We live bodily, physically, and practically, and we live in communities. Husserl rejected the absolutizing of naturalism. According to Husserl, all science is founded in the life world (Hitzler 2011). The world is already structured and meaningful, and we as subjects are part of this world. We are bodily, socially, and culturally in the world (Thoresen, Wyller, and Heggen 2011). Husserl's thoughts on the life experience of people in the everyday world, in which they operate, are taken up by later concepts. For HCI, the relationship between action and meaning is central. To understand this relationship, we must first examine the involved processes of knowledge generation, understanding, and experiencing.

Life world — social and subjective stock of knowledge

The life world includes the current experience, what is remembered from former experiences, and expectations of future possible experiences. For guidance in our world, we rely on a subjective stock of knowledge, which in turn is in a relationship with the social stock of knowledge (Honer 2011: 111). According to Honer, the subjective stock of knowledge of a person is composed of basic elements of knowledge, routine knowledge, explicit knowledge, and potential knowledge. The basic elements of knowledge are related to the limitation of the situation, which means the temporal, spatial, and social structures in which an active individual exists, and to the conditions of subjective experiences. Routine knowledge that is linked to the basic elements of knowledge means casually applied knowledge. It is of permanent but rather minor importance. In contrast, explicit knowledge is determined by familiarity, certainty, and plausibility, and it is generally regarded as "the knowledge".[1] In addition, everyone has potential knowledge, which can be either recoverable knowledge or knowledge that must be acquired first (cf. Honer 2011: 111).

The social stock of knowledge is built up from the accumulation of subjective experiences. It can only be enriched if subjective processes in which knowledge is acquired are supplied and transmitted. On the other hand, the empirical social stocks of knowledge play a vital role in the development of individual knowledge. They are transmitted from generation to generation and are available to individuals in everyday life (Luckmann, 1999, Berger and Luckmann, 2000). Training institutions or media also contribute to the stock of knowledge of each individual. Thus, mutual understanding and interactions in everyday life are possible, despite all subjectivity. Even with Habermas — to whom I refer only briefly at this point — the life world has become the foundation of communicative action and understanding (Ulfig 1997). Habermas interprets the life world as common background knowledge of our understanding and action. In contrast to the awareness-theoretical approach of the phenomenological philosophers however, he relies on language as a subject of social scientific analysis (ibid.)

In the operator's life world, what matters is the phenomenon of physical action in everyday work performed individually or in teams with the aid of objects to enhance work. In their role as interacting subjects, operators always have to agree on something in everyday work, including their objects. Interesting for the course of this thesis is how to convey subjective experiences with concrete objects of everyday life to others in an understandable way. Moreover, what does this mean for the design of objects?

Understanding — assigning meanings to objects

Husserl's life world concept covers the given world as it is experienced by subjects in everyday life. Strictly speaking, every person lives in his own concretely experienced life world. Yet certain things can be essentially the same for other people. We cope with our everyday life with some of the same sense allocations and interpretations of things around us. Things as described by Husserl may refer to material and cultural objects or to living things such as human beings or animals, which may have different essences that we experience through our perceptions of nature, culture, and humanity (Woodruff Smith 2004). In contrast, Heidegger's phenomenological view of things is based not only on the experience of the world as an act of consciousness but on the way we exist in the world. Being-in-the world includes activities with objects that are part of the life world and that are inherently

[1] In addition, I may refer to Wolf Singer at this point, a famous German neuroscientist. Singer explains that our brains already have a lot of knowledge about the world - congenitally - because through trial and error, much knowledge of the world was accumulated in the course of evolution. This knowledge enters the genes, which is expressed by brain structures and finally into previous knowledge. It is knowledge of the "being like this" in the world in which we move. The know-how then comes in the course of development (Wolf Singer. 2004. Das Bild in uns. Vom Bild zur Wahrnehmung. Lecture from the public lecture series "Iconic Turn – Das neue Bild der Welt" at the Ludwig-Maximilians-Universität München. Published 2012. Hubert Burda Stiftung. Online on: http://www.youtube.com/watch?v=5YM0oTXtYFM&list=PL41C6B08A923E2C3B).

meaningful. These objects serve at the same time as sign carriers of meanings. While identifying and interpreting objects, we “understand” them. “Understanding” is a psychophysical activity that includes our assumption that those who also perceive the objects assign the same or similar meanings to them (Anz 2006: 406). In addition, we assume that those who have created the objects — for example, the artist a certain object type, or the designer a certain article of daily use — accord them the same or similar meaning (cf. Anz 2006). Honer (2011: 112) speaks of a social validity of sense allocations that result from this assumption that other people perceive things in a similar or the same way as we do. At the same time, we are aware that each person has his or her own personal standpoint and an individual view of things. For, although all humans can experience the same phenomena in a largely similar way, there are different perceptions and interpretations of the shared world (Honer 2011, Woldt and Toman 2005).

It can be assumed that historical and cultural backgrounds can build barriers of understanding. In particular, the understanding of linguistically guided communication — by written texts, for example — is highly tied to respective cultural and linguistic contexts. In philology, therefore, specific techniques and rules of understanding of texts have been developed. For design, the semiotics of objects plays an important role in the development process.

Understanding of signs and sign systems — semiotics of objects

The science of semiotics deals with sign processes and systems, whereas the science of hermeneutics deals with the question of interpretation and understanding. In processes of understanding, humans use signs, and the interpretation of their meanings is a hermeneutical task. Semiotics is the theory of the art of using signs effectively in different functional contexts (Franz 2006: 343). Semiotic studies focus on sign situations, links of signs, and conclusions from signs. The sign situation is of particular importance because it produces a “web of relationships between signs, author subject, interpreter subject, reference object, and referral potential” (ibid.). Signs are therefore not static units but part of a dynamic process. They must always be considered in the context of their specific use, the environment and the specific situation in which they are applied (Barth 2006-2011). Franz (2006) describes various models of sign situations, including sign situations in different social functional areas, sign situations in which different forms of signs (such as gestures, body movements, verbal language, images, or sounds) are used, sign situations in different storage media, and rhetorical or aesthetical sign situations. According to Franz, the aesthetical or art-aesthetical sign situation has the special feature that it combines two sign situations into one. “Due to its self-reflective character in the same sign situation, the aesthetic formed object occurs in the double position of object and sign. As an artefact with its own intrinsic value, we perceive and interpret it as an independent reference object; as an object with an exploitable reference field, it contains a complex reference potential and challenges for interpretation." (Franz 2006: 344, translation of the author)[2]

For product design that means that the product as a material object becomes a bearer of meaning and at the same time a communicator of its meaning and function. Under semiotic-semantic aspects, the product conveys a message through its nature or object properties such as materiality, surface texture, colour, and shape. This apparent separation of object and meaning is considered critical by Jonas (1992), who claims that objects *are* their meaning to the user. With reference to van den Boom, Jonas explains, "The messages of the media are indifferent; the medium is the message. Design theory understands design objects as media and unravels the messages they are". (Van den Boom 1984: n.pag, qtd. in Jonas 1992: 5, translation of the author) In other words, it is not the communication of meaning as a dynamic process that is important for product design; rather, product design should challenge meaning itself. What in product design creates sense? Moreover, how much sense, and in this context how much content can a product tolerate at all? Jonas argues that design cannot produce "real sense". It cannot provide "real life quality" or satisfy "real needs". "[…], social communication produces the conditions under which these ideas gain meaning. Design is a component in this circle. It is not at the beginning of the circle and thus, it is not the 'creator' of these qualities." (Jonas 1992: 13, translation of the author)

What Jonas and Boom omit in their semiotic discussion is that objects of utility serve the practical use and thus, objects have to inform on their opportunities of use. I draw again on Franz, who assumes that it is a fact that design also creates meaning and, thus, contributes very much to the self-understanding of our society. "Today, hardly anyone has to be convinced yet that artefacts also carry meanings — they are carrier of references to suitability, functional concept and construction; of characteristics of a self-expression of the designers, engineers and clients, of news about a society, era, level of civilization." (Franz 1980: 27, translation of the author) This brings us back to the sign function for design. Franz argues that any use of artefacts is mediated by a semiosis, which is any form of activity or process that involves sign use and –interpretation. The sign function in its essence can be understood as reference function that gives meaning to different signs. Semantic object — and semantic subject — relations always converge in the meaning of signs. This is because signs always refer to an object (which they represent in a certain way) and at the same time to the subject that uses the signs to express itself. (ibid.: 27-28)

[2] In addition to the art model, Franz has also developed one for the design. I will come back to it.

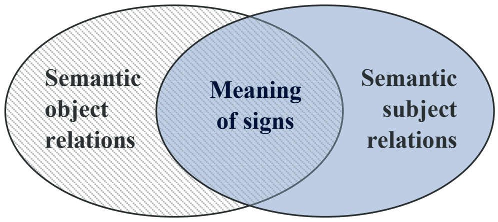


Figure 2-1: The meaning of signs is where semantic object relations and semantic subject relations converge.

Essential to product design is that the designed product is a material object developed for practical purposes. The design must mediate between:

- object and need
- construction and use
- function and meaning

The medium of this mediation is the *gestalt;* whereas the interplay between acts of indication (object) and understanding (subject) mediates the practical use of the object (ibid.: 29). The process in which the subject understands the symbolic properties of an artefact is closely linked to perception. It is determined by expectations and experiences, and is dependent on personality characteristics as well as social and cultural influences. Visible and invisible features that indicate its practical use determine the artefact, on the other hand. Thus, the graphic above can be extended with additional attributes that characterise an artefact or object in relation to its suggestive notes on functionality (semantic object relations) and with attributes that characterise the subject or user in terms of the act of understanding (semantic subject relations).

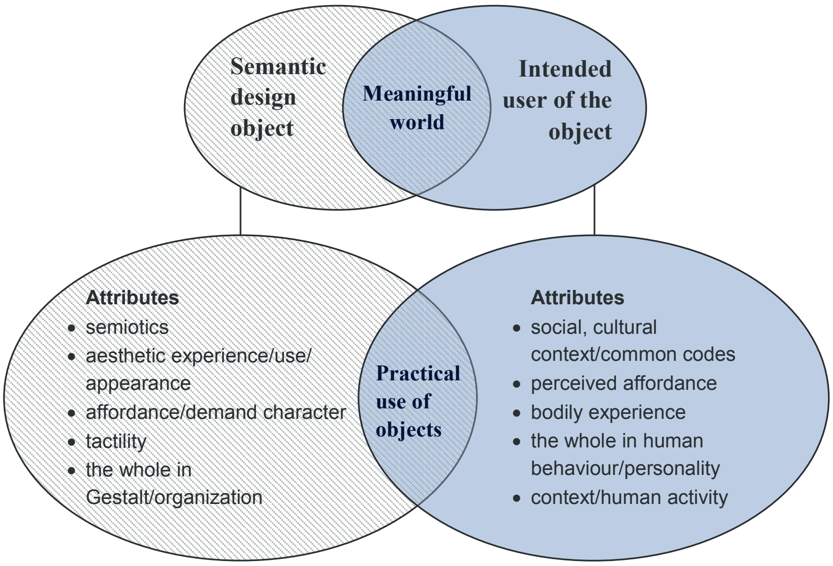


Figure 2-2: Objects and subjects (users) are part of a meaningful world in which action is afforded to individuals. The interplay between the act of indication of objects and the act of understanding of subjects presents the practical use of objects. Both objects and subjects can be described by attributes that characterise their nature.

These attributes will be discussed in more detail in the course of this chapter. First of all, the discussion of the semiotic significance of objects will be continued by comparing different theoretical positions.

Aesthetic experiences — the sensual appearance of objects

The German philosopher Franz von Kutschera (1998) considers the semiotic meaning of an object or product a theme of "aesthetic experience". In his work "Aesthetics", he deals with the sensual appearance of objects that we experience as viewers from outside. This form of external experience he calls "aesthetic experience". Kutschera argues that not only visual, audible, tactile, smell, and taste qualities but also expressive qualities contribute to the sensual appearance of an object (Kutschera 1998: 74). The properties of the product can thus not be limited to physically describable properties; they also include qualities such as expression, emotion, and content of a product. Regarding the visual appearance of an object, Kutschera distinguishes between three phenomena (Kutschera 1998): firstly, properties that characterise the appearance of an object — its shape, colour, size — thus properties that come from the object itself, completely independent of the observer. Secondly, certain observation conditions, such as lighting conditions, distance, or viewing media, can play a role. This phenomenon is described by properties that do not come from the object itself. These properties rather characterise the object's appearance in relation to the current external observation conditions. It is possible that observers get not a correct impression of the object with its actual properties, but an impression in objective observation conditions under which this impression generally arises. Third, it can be a purely subjective impression of the appearance of an object, which may be determined, for example, by impaired visual perception. Kutschera concludes that the appearance of an object is the way in which the object appears to the observer under certain external conditions. This intersubjective same appearance is only a rough criterion. Because for us, the same objects viewed under the same observation conditions do not always appear in the same way. Thus, the aesthetic experience tends toward subjectivity (Kutschera 1998: 75-76).

Hirdina argues for a different aesthetic understanding, and introduced the understanding of gestalt. While Kutschera limits the aesthetic experience of objects to the perception of surface and form, Hirdina argues for the concept of *gestalt,* which combines all perceptible qualities, including the content and function of an object (gestalt is the German word for 'shape, form'). An understanding in which the mere form is the aesthetic is referred to as *formalism*. In formalism, form is intended as an antonym to content and idea. Form, therefore refers not to the inner but to the outer appearance; it refers not to the invisible but to the visible (Goer 2006: 115). With form as goal, form and function are not reconciled but separated. However, function refers to the handling of objects, their use and consumption, and therefore it cannot be neglected in design. In terms of perception, content and function of an object are just as included as shape and surface. They are also perceivable, even if not always visible. Content and function open up through use. Hirdina says, "Aesthetic enjoyment of functionally oriented products usually not develops by observation alone. It happens via the detour of the real use, which we can describe as oriented on convenience, rationality, and effort-like time-saving handling". (Hirdina, H. 1978, published in Nehls, Staubach, Trebeß (ed.) 2008: 37-38, translation of the author) In this sense, industrial products have a double determination — they are used and perceived. Art does not have this dual function. It is intended for viewing, not for practical use. Hence, art is sensually perceived in a different way than design (ibid.: 22). Kutschera seems to disregard this aspect. Aesthetics seeks the relationship among structure, function, and gestalt, as well as subjective perception of them. It does not refer to unique characteristics but identifies relations. Among the most important is the sensory perception of designed objects and their meanings (Hirdina, K. 2006: 29).

For this work, the question arises to what extent aesthetic-sensual experiences are made in the context of work processes. Especially in a non-ordinary working environment, such as in the oil and gas industry, where extreme external conditions play a role, the sensual appearance of an artefact will be experienced in a completely different context, such as the sensuous appearance of an art object in a closed exhibition space or a technical product for home use. Moreover, a second question arises, namely the extent to which workplaces are designed. With Burckhardt (1980), the design of situations is treated as well, whereas for Jonas and Franz, it depends on the design of objects. In the design of workplaces, Burckhardt sees not only traditional design aspects but also aspects of the way workplaces produce and prevent cooperation.

Understanding and interpretation as part of a communication process

At the same time, sufficient attention must be paid to the practice of communication and understanding. Anz (2006: 406) describes understanding as "partial activity in a dialogic communication process of mutual understanding with others about something" (translation of the author). In the daily practice of communicating, understanding is a largely unconscious process. If understanding is conscious and reflecting, it involves interpretation (ibid.: 407). Interpretation is the process and the result of the sense-giving understanding of an object (Rüttinger 2006: 185) or, in the semantic sense, the decoding of signs, especially acoustical and visual signs. To ensure understanding between communicators — including humans, animals, and machines — the sender (author subject) and receptor (interpreter subject) of signs need common codes (Barth 2006-2011). These codes correspond to syntactic and semantic rules for dealing with signs. Syntactic rules concern the relationship of signs to one another; semantic rules concern the meanings of signs. These rules are based on social graces and customs, are stored in the social stock of knowledge, and are thus closely linked to culture.

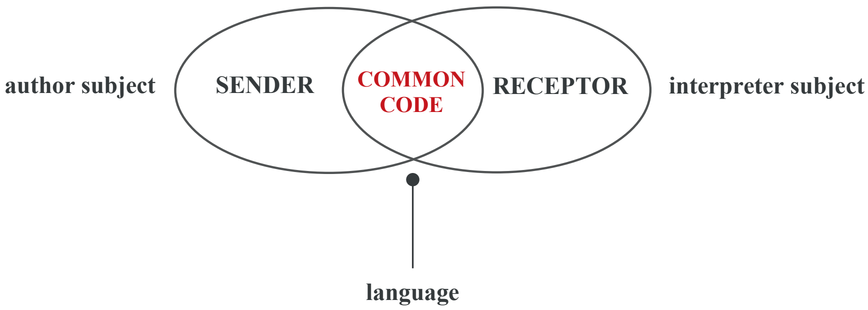


Figure 2-3: Common codes as a prerequisite for understanding. The figure draws on the sign theory by Barth (2006-2011).

Common codes produce a language. They are required to understand the interrelationships of the medial sign structure, such as display symbols. Visual signs can only be linked to new conclusions through common codes that enable participants to consciously understand or rather interpret their content.

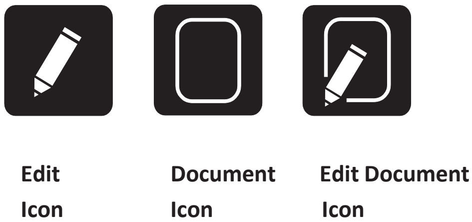


Figure 2-4: Linking of signs (syntactics). Example of a visual coding; display symbols can be linked to a new conclusion. Here the understanding refers to the identification of the meaning of an optical sign combination. Therefore, the signs must be decoded or interpreted. (Graphics: author)

Conditions for communication and understanding are that people who communicate with each other already have something in common — such as cultural, emotional, or social experiences and stocks of knowledge — or that the commonalities are missing, not yet produced, or uncertain. The interpretation or decoding of signs presupposes dialogical access to possible meanings of common objects of perception (Anz 2006). Given the current situation in the oil- and gas industry, different cultural and professional backgrounds of stakeholders affect communication and understanding processes. However, finding commonalities and common understanding of objects related to task performances is extremely important for efficient and safe plant operation, and that in turn challenges the meaning of objects — a challenge that must be met by designers.

The following sections go into themes of the bodily aspects in terms of human experience and understanding and explore the concept of object affordances.

2.1.2 Embodied practical action as the source of meaning

As mentioned before, social and subjective stocks of knowledge are in a relationship and form the basis for orientation and thus communication and understanding in our shared life world. I also mentioned, with respect to Honer (2011), that the basic elements of knowledge concern the conditions of subjective experiences. These conditions imply that we are bound to our body and its location in the world. We are restricted by the situation, which means the ability to perform bodily movements such as running, bending down, or lying is limited. As Berger and Luckmann stated, "The reality of everyday life is organised around the 'here' of my body and the 'now' of my present. This 'here and now' is the focus of my attention to the reality of everyday life". (Berger and Luckmann 1967: 22) This is of importance in human-computer interaction because meaningful interaction in the world occurs at the point of contact between an artefact and the human body, with its abilities and limitations. In the particular case of operator-device interaction, the ability to perform bodily movements is notably determined by local conditions, including the architectural structure and design of the work environment and weather conditions.

The relationship between practical action and meaning is what Dourish (2001) calls "embodiment". Inspired by the phenomenology of Husserl, Heidegger, Schutz, and Merleau-Ponty (Dourish 2001, Svanæs and Young 2011), Dourish explains the bodily aspects of the human experience, which are grounded in the assumption that meaning arises from physical interaction with the world and the objects and people around us. He argues that the world we live in is socially constructed. It is a kind of network of family, colleagues, and people we interact with daily. At the same time, it is a world of physical facts. We encounter daily physical phenomena such as gravity and inertia as well as physical objects on which we sit or lie, which we push or turn etc. Thus, our daily experiences are both social and physical. This is central in Dourish's work. He defines embodiment as "the common way in which we encounter physical and social reality in the everyday world". (Dourish 2001: 100) In this respect, his view is closer to Heidegger's concept of "In-der-Welt-Sein" or "being-in-the-world" than to Husserl's dualism of mind and body. While Husserl's phenomenology focused on mental phenomena, arguing that thinking and being are two different sets of phenomena, Heidegger's idea is that daily experiences happen in the world. His intellectual approach is that thinking is derived from being. His question is *how* we exist in the world; not *whether* we exist (Orthbandt n. d.). Schutz and Merleau-Ponty go one step further and expand Husserl's and Heidegger's phenomenology of the individual experience of the world to produce a common experience of the world. The social world inhabited by social actors is central to their work. While Schutz's philosophy centred on an intersubjective understanding of the world (cf. Berger and Luckmann 2000), Merleau-Ponty's focus is on the role of the body in perception and understanding (Dourish 2001).

Cognition is more than a neural phenomenon

Gibson later discussed another dualism; he criticised in traditional approaches that *seeing* was considered separately from *acting*. In his view, visual perception is connected with being and acting, and thus cognition must not be considered purely a neural phenomenon rather than a phenomenon in a complex structure of organism, action, and environment (Gibson 1986, Dourish 2001). Lakoff and Johnson (1999) argue that considering the neural level alone is not sufficient to understand all aspects of the mind. They describe three levels that are necessary for an explanation of the mind: cognitive operations at the neural level ("neural embodiment"); the conscious level, which consists of everything we can be aware of ("phenomenological level"); and the level that includes our unconscious knowledge and thought processes ("cognitive unconscious") (Lakoff and Johnson 1999: 102-103). They emphasise that all three levels are dependent of one another: "The details of the character of the cognitive unconscious and of conscious experience arise from the details of neural structure." (ibid.: 104)

It seems indisputable that there are complex processes that form the basis of our experience, thought, and action. Interesting in this context is the discussion about brain research in recent years. One of the strongest neuro-sceptics is the scientist and science journalist Felix Hasler (scientific assistant at the Berlin School of Mind and Brain of the Humboldt-University Berlin). He criticises in his book "Neuromythologie" (Hasler 2012) the exaggerated demand of neuroscience to explain the world and the brain, mainly based on magnetic resonance imaging and its basic principle that all human behaviour is determined by the activities of nerve cells and their organisation in the brain. Halser emphasises that brain research does not know all about biological processes that determine our experiences and our mental and physical actions. Meanwhile, a network of critical neuroscience has been established that seeks a holistic approach to human behavior that embeds the brain and cognition in the body, social environment, and political world (Hasler 2012: 229).

Similar to Hasler, the science journalist Hans-Arthur Marsiske (2013) expresses in his contribution "Verkörperte Intelligenz" ("Embodied Intelligence") that the activity of the brain cannot be understood without consideration of the body or without culture and sociality. In robotics, researchers speak of "morphological computing" when it comes to the implementation of knowledge about the relationship of consciousness, thinking, intelligent action and the body. Currently developed robots, for example, use the mechanics of their "artificial body-construct" when running.[3] Due to the fact that the body itself calculates much, the brain is relieved; a basic principle that humans also use, according to Marsiske. He argues that, ultimately, individual body cells have a certain degree of self-intelligence. They do not need the brain to do what they are supposed to do. As an example, he mentions the backswing-phase of the leg when running, which is done without control of the brain but only by the interplay of muscles, tendons, and gravitational force. Marsiske leads this back to biological evolution, which has used the principle of adaptation to the environment in order to produce increasingly complex and intelligent creatures (Marsiske 2013:84).

However, intelligence cannot be considered data processing alone and thus pure brain activity, because then the person would be completely replaced by machines. Even though since the invention of the digital computer machines exist that can perform intellectual functions to a certain extent (measuring instruments, calculators); we must differentiate between the intelligence of man and the intelligence of machines. The human directly experiences the world with his hands and his body. These experiences make information processing and thinking possible. The machines or instruments used by man are directly connected with his own intellectual, cognitive and feeling functions (Weizenbaum 1977). Weizenbaum describes the rejection of direct experience as the characteristic feature of modern science. The Western European culture imposed by the clock is the clearest example of creating a new reality in which feelings of hunger and physical cues to go to bed and get up

[3] I use the term "artificial body-construct" in order to make clear that human characteristics cannot be transferred to the non-human or in other words; robots cannot be anthropomorphized. That's why they cannot have a body.

have been disallowed, replaced by an abstract model of hands a and dial (ibid.: 45-46). Today, it is hard to counteract this estrangement of man from nature. It is therefore all the more important for today's design of human-machine interaction to put human experience back into the foreground — the physical as well as the cultural and social experience. In a world characterised by the use of so-called smart devices, design must decide in which way humans should be supported by these devices. The question of whether certain cognitive processes in the sense of data processing can be supported by technical aids or even replaced is followed by the approach of "Distributed cognition", which will be discussed later in the chapter.

2.1.3 The interplay of cognition and action

In his "ecological approach to visual perception", Gibson also contradicts the conception that the mind is in the brain. In his view, the process of perception includes ambient awareness because we constantly change our perspectives. As observer, we walk and move around an object of interest, with the head turning; not static. Thus, our vision is not fixed; perception can also be localised in the muscles. However, the sensorimotor regulation system is located in the brain. Through the senses, skin, muscles, and joints, we receive stimuli that are processed inside the brain and passed as impulses to the central nervous system. From there we get motor responses in the form of posture and movement reactions. Sensorimotor connections are provided mainly by the vestibular system, which regulates functions such as control of eye and neck muscles, positioning of the head and body in relation to space, walking upright, rotation and acceleration of the body, and posture and balance reactions. Thus, the system not only integrates sensory components; it coordinates motoric processes in the same way (Diederley and Gallinat 2001, Feldkamp 1989). This interplay of cognition and action is described by the term s*ensorimotor loop.* An organism receives signals from the environment through its sensor system, acts on it, and perceives in turn the changed world through its sensors (Marsiske, 2013).

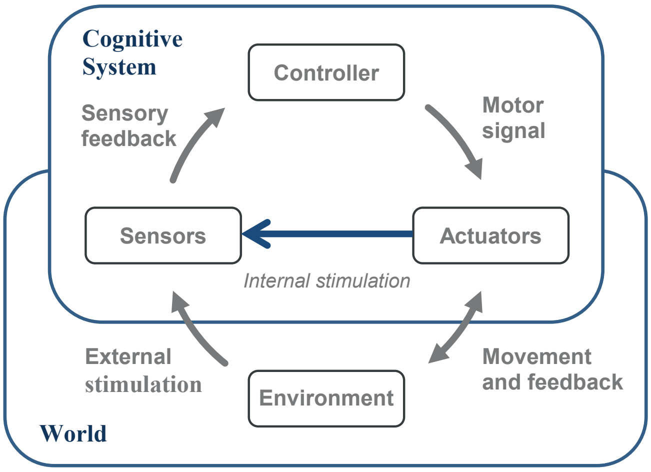


Figure 2-5: The interplay of cognition and action described by the sensorimotor loop. The illustration is based on graphics by Keyan Zahedi, Information Theory of Cognitive Systems, Max Planck Institute for Mathematics in the Sciences, http://www.mis.mpg.de/ay. Reproduced with permission of the author.

Singer (2004) emphasises how closely visual perception is linked to motor function. In his lecture at the Ludwig-Maximilians-University Munich (published on YouTube in 2012), he explained that a large part of the visual system is used for preparing the motor function for a specific gripping movement. If we are looking, says Singer, we are already preparing all motor responses (such as precision grips) that we need to implement what we have seen into action. Even when we are watching other people doing something, by visual inspection, our motor system prepares itself to the extent that it can mimic the same action or movement. This shows how closely visual perception is connected with the preparation of motor skills.

Gibson's critique of the standard approach to perception

It seems that even in neurology, it is not disputed that the process of identity, -thinking, -linguistic and social development arises from perception *and* motion, meaning from concrete activities. However, Gibson's main criticism was not that perception and motion have been considered two different functional systems. He criticised that the process of perception is supposed to be localised only in the head and that it begins after the sensory input reaches the central nervous system. According to Gibson, the standard approach of perception that is based on sensory inputs fails because it assumes that knowledge of the world already exists. "In order to perceive the world, one must already have ideas about it." (Gibson 1986: 304) In his ecological approach, Gibson argues using the example of a young child, who does not need to have ideas of the world in order to perceive it. If perception of the environment is based on the extraction of the invariant; not on glimpses, goes Gibson's argument, existing knowledge of the environment is no longer a precondition for perception (ibid.). However, if we stay with the example of the child, let's say an infant; it is mainly the sense of touch that plays an important role in perception of the world because infants experience the world by grasping and touching (and in addition they take things in their mouths). Petruschat (2008: 59) explains, "The primary access to the world of human infants is not visual, but tactile, not in seeing but in grasping and touching. For this reason, the suckling infant is well-named, because he seeks and finds the source of all of his happiness and all of his existence with the sensory cells, many of which have grown in his lips and his little fingers".

Gibson's concept of visual affordance vs. affordances perceived by several sensory channels

Also in Gibson's main work, vision is central. The concept of "affordance" has had a large impact on HCI. The theory states that the world is experienced not only in terms of object shapes and spatial relationships but also in terms of object possibilities for action. According to Gibson, the perception of our environment necessarily leads to activity. This implies that perception is an active process itself, which is particularly evident in the process of touch. That also means that indications for actions are perceived directly such as in buttons for pushing, handles for pulling, or knobs for turning (Gibson 1986). Many researchers have so far based their work on this approach. For example, Norman (1988) applied the concept to everyday artefacts and introduced the term *perceived affordance*, Gaver (1991) has worked on technology affordances, and Shneiderman (1998) mentioned the concept of affordance in his HCI work on interface design. However, Bærentsen and Trettvik (2002), who wrote a theoretical analysis of Gibson's concept of affordance, acknowledge some indistinctness in HCI concerning the idea. They regard the focus on the perceptual side of the approach as one reason for the misunderstanding of the idea in HCI. According to them, Gibson underrates activity of an organism as an implicit precondition for perception. They suggest extending the analysis of affordances and its foundation in organismic activity to the development of "human activity in societies that is organised on the basis of extensive and ubiquitous divisions of labor" and found the solution in the Activity theory (Bærentsen and Trettvik 2002: 53). This is also noted by Holzkamp (1973), who describes object meaning as meaning in the context of human life activity. The shape of an object does not have an independent value. "Human perception is representational and meaningful. It cannot be reduced to a merely stimuli-based basic concept." (Holzkamp 1973. Published in Pias et al. (eds.) 1999: 338) When we perceive objects that have a specific meaning, their usefulness appears to us. In perception we encounter the real nature of things. And thus, the recognition character of objects or their demand character is closely linked to perception.

Gaver (1991) also argues that Gibson focuses almost exclusively on visible affordances, leaving out that affordances may also be perceived using other senses. For example, we can feel what can be done with an object and even hear some affordances. The opportunity to press a mouse button is not exclusively provided by a visual object property; I can feel that the button is moveable and hear a click sound while pressing. There is an apt quote by

Petruschat (2008: 57): “We perceive more than we see”. Petruschat’s explanation is that it requires a multi-sensory data set in order for sight to become conscious. The data absorbed by the eyes and transmitted to the brain are not sufficient. Only the combination of current data from multiple sensory channels with data from experience (memories) leads to a conscious experience. That is, vision may not be limited to the eyes; it is a data set consisting of visual and non-visual sensory channels and domains of experience that forms our consciousness (Petruschat 2008). Petruschat further argues that “the integration of data from one sensory channel into data from other sensory channels is indispensable for orientation of the body, perception and action” (ibid.: 57). He explains that this integration of current incoming data into stored data contexts constitutes our understanding of things. Thus, the criticism of Gibson’s approach to visual perception does not seem to be groundless. And in terms of design, it is inherently important to look beyond visual sensory channels.

Gibson’s concept and Gestalt theory

Gibson’s work was strongly influenced by Gestalt theory, which was originally founded by Christian von Ehrenfels. Gibson refers to the idea of the Gestalt psychologists, who stated, “Each thing says what it is. […] a fruit says ʽEat me’, water says ʽDrink me’ […].” (Koffka 1935: 7, qtd. in Gibson 1986: 138) According to Gibson, the concept of affordance is derived from the idea that things or artefacts invite and demand action. However, he does not agree to the point that an object has a demand character only when an observer needs to use the object, and he draws on the example of the post box, which demands mailing a letter whether a person wants to mail a letter or not. Gibson claims that the affordance of something does not change; it is always there to be perceived, whether there is need for its perception or not (Gibson 1986: 138). He agrees with the point that object values seem to be perceived immediately and directly, but his explanation is different. While the Gestalt psychologists regard objects as phenomenological objects, Gibson speaks of physical objects that “*seem* to be perceived directly because they *are* perceived directly” (ibid.: 140). For Gibson, an object is perceived as part of the environment, regardless of whether observers are attracted to it due to the need for using it. Gibson’s affordance of an object is thus similar to Koffka’s “demand character” of an object in the sense that each thing indicates what it is supposed to be used for. In terms of cognitive processes in HCI that affect the development of products and systems significantly, both the principles of Gestalt psychology and Gibson’s concept are important.

In the following section, I want to elaborate on the meaning of Gestalt theory for product design, in particular for product design of handheld devices used in demanding environments, such as oil and gas processing plants.

2.2 Complex perception — the nature of the whole in III) Gestalt theory

The challenges of product design, including the human-computer interface, cannot be discussed without addressing the perception of *gestalten*, which is the main subject of Gestalt theory. Gestalt theory is a multidisciplinary theory that provides a framework for different psychological knowledge and its application. Thus, Gestalt theory is not only limited to the Gestalt factors of perception; it must be understood more comprehensively. Today, the concept is applied in a variety of fields, such as linguistics, education, psychotherapy, musicology, and mathematics (listed on the website of the Society for Gestalt theory and its Applications, GTA, www.gestalttheory.net, 4.10.2013). For design, and in particular for HCI, the ideas of the Gestalt school of psychology, represented by Wertheimer, Koffka, and Köhler are of particular interest because they can help direct researchers and practicing designers in problem-solving. Bryan Lawson exposed in his work "How Designers Think" that the way the representatives of the Gestalt school saw problem-solving sounds more like designing than other approaches (Lawson 2006). The psychologists of the Gestalt school started studying processes and organisation and concentrated on structural relationships between things and relationships in the interaction with people.

On gestalt-qualities

"Gestalt" is a German word that can be translated roughly as "form" or "shape". It describes in the broader sense any formation/shape that we perceive as a self-contained entirety and gives attention to the relationship between several parts and the whole of a composition. The term was coined in 1890 by Christian von Ehrenfels in developing a theory of complex perception. From the attempt to answer the question *what is melody*, Ehrenfels derived the theory that *the whole is greater than the sum of its parts* (Ehrenfels 1937, Kutschke 2006, Woldt and Toman 2005). He remembered that we even recognise a melody when it is presented in a transposed way, e.g. we recognise the same melody transposed from C major to C sharp major, and most of us do not even notice that the groups of notes have changed (Ehrenfels 1937, Wertheimer 1924). Thus, the idea that a melody is "the sum of individual notes which make up the melody" fails. "If the melody were nothing else than the sum of the notes, different melodies would have to be produced because different groups of notes are here involved." (Ehrenfels 1937: 521) Ehrenfels derived from this paradigm three basic criteria of gestalten (Kutschke 2006). 1) The whole is greater than the sum of its parts, in the sense that the whole is qualitatively more and qualitatively different than the sum of its individual elements. 2) Gestalt is independent of its elements, its materiality, and its locality, insofar as the latter can be exchanged against others; the gestalt (form/shape) is not changed. For instance, a melody can be transferred to a different key, can be played faster or slower, or can be presented by different instruments without losing its characteristic form. 3) The gestalt of a thing is a gestalt-quality. In 1890, Ehrenfels published the essay "On Gestalt-qualities", in which he explained the sense of his theorem. In the essay, he distinguishes gestalt-qualities as temporal and non-temporal gestalt-qualities. Temporal gestalt-qualities reflect the notion of processes, such as melody and motion, and the notion of non-temporal momentary states, such as harmony and spatial structure. But Ehrenfels limits melody and harmony not only to musical tones. There are, for example, melodies and harmonies of colour and melodies and harmonies of speech. Thus, the range of gestalten is large. For example, each word of a language is a gestalt-quality (Ehrenfels 1937: 522). Gestalt-qualities in terms of the "Berlin school of Gestalt psychology", which was founded by Wertheimer, Koffka, and Köhler at the beginning of the 20th century, means in contrast shape properties, such as symmetry, regularity, and simplicity (Kutschke 2006). These are the perceived qualities that are combined by the concept of *Gestalt* and are parts of the aesthetic experience.

On Gestalt-laws of organisation

In contrast to Ehrenfels, who bases gestalt-qualities on sensual and mental phenomena, the work of the "Berlin school" identified the perception of gestalten as a holistic process. In 1912, Wertheimer published research on perceptual grouping and the perception of movement, described in the Gestalt rules of perceptual organisation. The rules mainly describe laws of grouping that are effective in the perception of shape, such as the law of closure, the law of proximity, the figure-ground relationship, and the law of similarity (Kutschke 2006, Lidwell, Holden, and Butler 2010). These laws are summarised in the *law of prägnanz* (German for "conciseness") of Max Wertheimer, which says that good, concise forms are characterised by regularity, symmetry, and simplicity (Kutschke 2006). These findings from visual perception have an impact on the design of architecture, interior architecture, information architecture (as in software engineering), and design. By their proper use, complex information structures can be optimally communicated, and thus the presented information nearly optimally perceived is what one hears from media designer circles. But to what extent is the tendency toward closeness and uniformity good for product design? In a lexicon entry for the keyword *gestalt/gestaltung*, Michael Franz raises the question of whether stimulus constellations that are not exactly new or surprising and are at the same time inconsistent can provoke moments of orientation behaviour. He argues that there are historical-cultural situations in which instability and ambiguities are searched for and aesthetically enjoyed (Franz 2006: 144). However, in the context of design, Barth (2001-2010) argues that due to improved clarity, the absorption, reaction, and decision speed of the observer can increase by up to 30 per cent. In practice, this means to group and formally encode content and information (ibid.). Both tendencies are probably correct, and for a certain range, common rules cannot be derived from them. In terms of human-machine interaction in hazardous areas, such as the oil and gas industry, the tendency toward clarity seems to be more important.

Many applications of the Gestalt principles of perception in design are described in literature. However, the principles are mainly applied to HCI with a focus on GUI design, e.g. Nielsen (1993), Svanæs (1997), and Zwick et al. (2005), and graphic design with a focus on effects of two-dimensional images and text, e.g. Lidwell, Holden, and Butler (2010). Still, in 2008, Lisa

Graham argued that visual artists and designers have used Gestalt principles to improve their two-dimensional works in terms of composition and visual communication. While she found many adoptions in graphic and visual design, she saw significant gaps in applying Gestalt theory to interactive media designs, such as web design or multimedia design. Taking into account that interactive media designs may include multiple media in complex interactive environments, Graham considers the application of Gestalt-laws of organisation in interactive media design to be important (Graham 2008).

Today it seems that the laws are often cited in terms of web design, application design, or dashboard design. However, little has been published so far about applications of Gestalt principles to three-dimensional product design. This is surprising, since the visual perception of product details is of equal importance to layout details in graphic- or web design. Moreover, product details can be perceived tactilely; the grooved structure of a rotary knob that affords its function can be experienced both tactilely and visually. The haptic properties of knobs, buttons, and slide controls — to stay with the theme of operating elements — are achieved through its object qualities, such as structure, construction, and material quality. These object qualities are gestalt-qualities that incorporate gestalt rules such as symmetry, proximity, and simplicity. In the context of computer interfaces and multi-sensory displays, Chang, Nesbitt, and Wilkins (2007) conducted an experiment to find out whether people use the sense of touch to group display elements in the same way they group elements visually. By applying the Gestalt laws of similarity and proximity, the researchers designed displays in two modes (colour and texture/visual and haptic) using different elements of the same shape and size, which consisted of sandpaper and cardboard that differed in surface texture and colour. The experiment showed that in 90 per cent of the cases, participants used texture or colour to group the display elements when there was an equal spacing between them. When there was unequal spacing between the elements, the test persons grouped based on spatial position. The study results thus supported the researchers' hypothesis that the principles of similarity and proximity are applicable for both visual and haptic grouping.

This can also be supported by examples from three-dimensional instruments and controls. For example, instrument panels in cars are arranged visually and tactilely around the steering wheel. The logically structured arrangement of the controls supports the perception and proper use of the functions. We find other very complex examples in integrated ship bridge systems and airplane cokpits. These often seem to be subject to strict geometric frames, and many mechanical measuring instruments have been replaced by computer-based displays. Other geometric examples — even though much less complex — can be found within the entertainment industry. For instance, control consoles as shown in Figure 2-6 are being used industry-wide in television and radio broadcast, recording, and multimedia production. Common to these examples is their organisation of both visual and tactile information. For the purpose of an intuitively usable interface, however, the question arises whether the organisation of elements can be perceived both visually and tactilely. The answer must be yes, because there are differences in the haptic properties of controls due to their different structures and constructions. In addition, specific material on product details may enhance the feel of an element. In the case of the control surface illustrated below, Teflon is added to better feel the trackballs of the control surface because of its good sliding and non-stick properties, its high resistance to aging, and its anti-adhesive surface.

Figure 2-6: Organisation of information: Control surface Eclipse CX by JLCooper Electronics. The product is designed for precision control of colour correction and editing software. The device features abundant controls including three distinct trackballs made of Teflon (for controlling the hue in the highlights, midtones, and shadows), a numeric keypad for quick timecode entry, different types of buttons and keys, dials, and a jog wheel with a concentric shuttle ring (allowing the user to shuttle through audio and video media). The wheel around each trackball lets the user adjust the luminance. Information and illustration are available on: https://jlcooper.com/_php/product.php?prod=eclipsecxm (accessed 18 September 2014).

This colour control surface is interesting because of its special focus on controlling digital information in a tangible way. The user can feel the adjustments and thus move more quickly. Speed is the best advantage of the surface, according to the producer. Since users can make multiple adjustments at one time using both of their hands, time is saved. These multitasking abilities are achieved through differently designed haptic controls that are arranged in terms of similarity and proximity. But even setting just one adjustment is faster because the user does not need to find the control on the software with the mouse. The user can adjust the right norm by feel without taking his eyes from the screen. (At this point I want to refer to the third chapter, which will discuss the advantages of tangible interaction in detail.) On closer viewing of geometrically linear products such as control devices, we find parallels with graphical interfaces (see the dialog box of Photoshop in Figure 2-7). The preferences dialog box of Photoshop is one example of the use of Gestalt principles in interface design. The laws of proximity and similarity are used to group the items and provide the user clearly represented setting options. At the same time, the design language of the Photoshop window is strongly reduced, and it is not significantly different from other dialog boxes. In the context of operation and communication security in hazardous areas, designers and software engineers should discuss what kinds of effective graphical medium for screen devices could be applied.

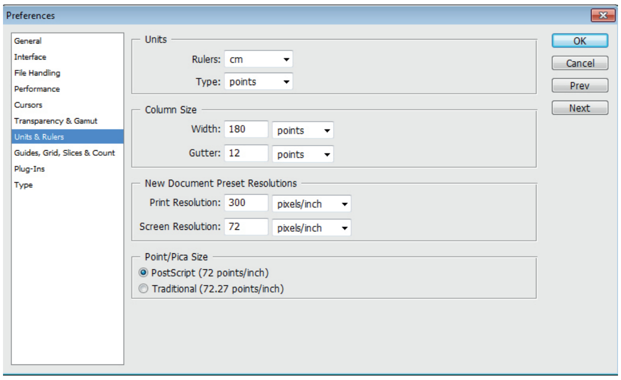


Figure 2-7: Simple organisational concepts: the preferences dialog box of Photoshop is based on a reduced design language that avoids any use of colour coding, patterns, or icons and instead focusses on linear grouping of items in terms of Gestalt principles in interface design. Although avoiding codes limits some options, a quite clear presentation of information is provided. However, users will probably be better guided through graphical interfaces that provide powerful visual experiences by different layout characteristics. (Screenshot)

Nevertheless, in terms of interface design — both graphical user interface design and product interface design — Gestalt laws generally help establish regularity and clarity within a system. Systems taken as a whole often appear ambiguous and complex. By applying laws such as the laws of proximity, similarity, continuity, and unity, the overall product or system can be designed to be more concise as its items underlie principles of organisation. In other words, the character of the whole determines what is available in detail. The Gestalt psychologists have analysed these so-called *Ganzbedingungen* (Wertheimer 1924, German for "whole-conditions") not only in the context of visual phenomena but also in the context of human behaviour.

The nature of the whole in human behaviour

In addition to perception, the nature of the whole in human behaviour has been analysed. While Wertheimer, Köhler and Koffka are mainly known for their research work in the fields of perception, thinking, and problem solving, Kurt Lewin became important through his field theory and social-psychological work that is based on Gestalt theory. Lewin's field theory is based on the experience and the behaviour of man in his environment and thus has a huge impact on psychotherapy, and particularly on group dynamics and its effects (Kästl and Stemberger 2005). For Lewin, the actions of the individual happen in a spatio-temporal field. All actions in this field are interdependent. They are in a relationship of interaction. Lewin transferred the term "field" to the social living environment (Blankertz and Doubrawa 2005). Wertheimer, on the other hand, speaks of perceptual fields. In his research, he described the man as part of a field and as a part of interaction with other people. For example, in a particular work in which different people work together, the man is one among others. In terms of the whole in human behaviour, the different people cooperate. In this process, the company goal is often the common goal, and thus each man works as a functioning part of the whole. "Only under very special circumstances does a 'I' stand out alone" or do "they constitute a mere-sum of independent Egos" (Wertheimer 1924: n.pag.). At the same time man — as a part in a field — has his whole-character and in this his reactions. Wertheimer argues that human reactions are connected with alterations in field conditions, including life and environment conditions, and manifest themselves in the form of a change in attitude, a striving and a feeling. Thus, all human actions are determined by whole-conditions arising from environment and living conditions (Wertheimer 1924).

The concept of Gestalt theory emphasises the need to understand human experience and understanding not only in relation to one's own psyche but also in relation to the totality of social relations. This brings us to the concepts of Distributed cognition and Activity theory. In both concepts, the idea that cognition also takes place outside of the individual is essential.

2.3 Cognition also occurs outside of individuals — contextualism in IV) Distributed cognition and V) Activity theory

As mentioned in Sections 2.1 and 2.2, researchers have previously argued for a more comprehensive view of human activity in order to understand human perception. The dualism of mind and body has been overcome, and the theory that cognition takes place only within individuals is scientifically disproved. The central idea that cognition is more than a neural phenomenon has been reflected in several theories, such as the life world concept of the phenomenologists, Dourish's concept of embodiment, Gibson's ecological approach to visual perception, and Gestalt theory.

The concepts of Distributed cognition and Activity theory in particular explain what is outside the individual, because this *outside* is considered part of the human cognitive process. Both approaches extend the cognitive system of the individual to several persons and objects in the environment and thus enable complex analyses of cognitive activities (Rummel 2008). Not just the individual alone but also the context is of interest. In view of the present state of development of increasingly complex technical products and systems that need to be operated by people in an increasingly complex environment, these two approaches are therefore of great interest for HCI.

2.3.1 IV) Distributed cognition

The concept of Distributed cognition was developed in the 1980s of the 20th century at the University of California in San Diego. It can be applied as a framework for considering cognitive processes. Its founders Edwin Hutchins and fellow researchers were concerned with the integration of environment in the understanding of cognitive processes. Activity theory, which considers action in the social context to be central, inspired them (Rummel 2008). Distributed cognition plays a special role in understanding the interaction between people and technology. It provides a framework for the analysis of human activities by viewing the context and the inclusion of the entire environment and the resources and materials that are present in this environment. The focus is on how we act in our environment and how we coordinate our activity in it. This theoretical foundation serves both, the understanding of HCI and the development and evaluation of digital systems and artefacts (Hollan, Hutchins, and Kirsh 2000).

Levels of consideration and principles
Distributed cognition presumes at least three levels of observation or rather three different methods of distribution of cognitive processes and thus storage, usage, and transfer of knowledge:

- Cognitive processes can be divided between different members of a social group.
- Cognitive processes can integrate the coordination between internal and external structures; that is, a distribution between the internal cognitive system of individual persons and the external material and environmental structures.
- Cognitive processes can be distributed over time, that is, products that have emerged from past events can transform the nature of future events (Hollan, Hutchins, and Kirsh 2000: 176, Rummel 2008).

The following examples from everyday life illustrate cognitive processes in the sense of Distributed cognition:

- If somebody wants to be reminded by a colleague of something, this is an example of the distribution of cognitive processes (storage of knowledge) between individuals within a group.
- The view in the Outlook calendar on the computer or mobile phone (external), which provides information on a self-written schedule (internal) and helps to coordinate dates with other people, is an example of the storage and use of knowledge through coordination of the internal cognitive system and external material structures.

▪ The manual input of measurement values in a standard system or database is an example of the transfer of knowledge. Data is transferred to another medium, wherein both operator and technology are involved in the information transfer process.

The process of knowledge transfer using external means plays an important role in Distributed cognition and requires an exact description in the analysis of cognitive activities. Here, the distinction between two cognitive processes is important — the process of tool operation by man and the operation performed by the tool itself. Together with other assumptions of the theory, this forms a theoretical basis for HCI research. In section 2.3.3, I will discuss the role of external means in more detail.

Firstly, I want to get back to the distribution of cognitive processes. As described above, storage, transfer and use of knowledge not only take place within individual persons but may be divided in several ways. Distributed cognition is thus expanding the realm of what is traditionally considered to be cognitive and leads up to what extends outside of the individual. This wider view of cognitive processes includes interpersonal interaction and interaction with resources and materials in the environment. In their work on Distributed cognition, Hollan, Hutchins, and Kirsh (2000) elaborated a Distributed cognition approach that illustrates three principles:

▪ *Socially Distributed cognition* includes, in addition to the social distribution of cognitive processes in groups, phenomena that emerge from social organisation. The idea is that social organisation itself is a form of cognitive architecture. Hollan and colleagues argue that social organisation and its structure, which is given by the context of activity, determines the way information flows through a group and thus may itself be regarded as a form of cognitive architecture (ibid.: 177).

▪ *Embodied cognition* means that cognition is embodied, in the sense that the human body and the material world play a central rather than a peripheral role. As described before, one idea of Distributed cognition is that cognitive processes include the coordination between internal and external structures. That means there is an interaction between internal (person-related) and external (environment-related) resources. With respect to the design of external environments — for example, work environments that include artefacts such as mechanical tools and digital devices — it is important to understand that these artefacts may become elements of the cognitive system itself (see Section 2.3.3, material environment: the role of external tools for supporting human cognitive processes). As Hollan, Hutchins, and Kirsh (ibid.: 178) described, “Just as a blind person’s cane or a cell biologist’s microscope is a central part of the way they perceive the world, so well-designed work materials become integrated into the way people think, see, and control activities, part of the distributed system of cognitive control”.

▪ *Culture and cognition,* the third principle of Distributed cognition, includes the role of culture. Since people live in cultural environments, the research on cognition cannot be considered separable from research on culture. Culture environments involve both culture that emerges out of the activity of people in their historical contexts, and culture in the form of a history of objects and social practices. This object- and practice-generated culture in turn shapes cognitive processes that are distributed over people, material objects, and environments (ibid.).

In Activity theory — and cultural-historical psychology as its immediate predecessor — culture and society also play a special role in understanding cognition and mind.

2.3.2 V) Activity theory

Lev Vygotsky and his colleagues developed cultural-historical psychology, which is considered the origin of Activity theory, in Russia in the 1920s and 1930s. Fifty years later, Aleksey Leontiev, a student of Vygotsky, founded Activity theory (Engeström 2005, Kaptelinin and Nardi 2006).[4] The main object of Activity theory is to use human action in a social context as a central framework for the development of the human mind (Rummel 2008).

Similar to the approach of Distributed cognition, the main idea of the Russian psychologists is that the human mind is intrinsically linked to the overall context of interaction between people and the world. The analysis of the human way of thinking hence always needs to include analysis of the interaction between humans and the world, in which the mind is embedded. Cultural-historical psychology and later Activity theory assume that reality itself is provided with meanings and values. We develop our own values and meanings not by the pure processing of sensory influences but by the appropriation of objectively present values; we appropriate in the world existing values and meanings (Kaptelinin and Nardi 2006). Kaptelinin and Nardi summarise the two main ideas of Activity theory as follows:

- Consciousness and activity form a unit.
- The human mind is of a social nature.

The first idea illustrates that human thinking and understanding can be considered only in the context of the subject-object relationship. The second idea claims that society and culture as generative forces are directly involved in the process of human thought and understanding (ibid.: 65-66).

Subject-object relationship
The subject-object relationship means the connection between a subject who performs an activity and an object (physical or ideal) towards which the activity is directed. There is a dependency in the sense that all human activities are geared towards specific objects, and in turn, objects will direct and restrict our actions.

[4] In recent years, these two approaches are sometimes referred to as CHAT, since many ideas of cultural-historical psychology directly flowed into Activity theory. CHAT stands for cultural-historical Activity theory (Kaptelinin and Nardi 2006: 36).

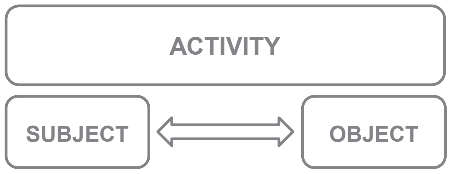


Figure 2-8: Subject – Object relationship

Kaptelinin and Nardi stress that objects cannot unilaterally determine activities, but activity in its entirety — the subject-object relationship — determines how both subject and object will develop (Kaptelinin und Nardi 2006: 66). With reference to Leontiev, they further explain that the principle of object orientation means that people are living in a reality that is objective in a broader sense. Things and artefacts that make this a reality, not only possess physical, chemical and biological properties according to scientific criteria; they have also socially and culturally determined properties, which are also objective properties (ibid.: 67). Thus, the consideration of the physical environment may not be limited to the description of representational object properties. Social and cultural contexts — in relation to people and artefacts — must be involved.

Action as object-oriented process in a collective activity system

The principle of object-oriented action became the key to the understanding of the human mind (Engeström 2005). While Vygotsky in his analysis model for activity still focused on the subject as an individual (see Figure 2-9a), Leontiev extended the analysis unit to a collective activity system. In this context, Engeström developed a graphical model in 1987 (see Figure 2.9b) and focused his research on the further development of Activity theory. The "third generation of an Activity theory", as declared by Engeström, aims at developing tools and models for the understanding of dialogue, multiple perspectives and networks of interacting activity systems (Engeström 2005). Figure 2-10 shows an extension of the basic model that includes two interacting activity systems (ibid.: 63).

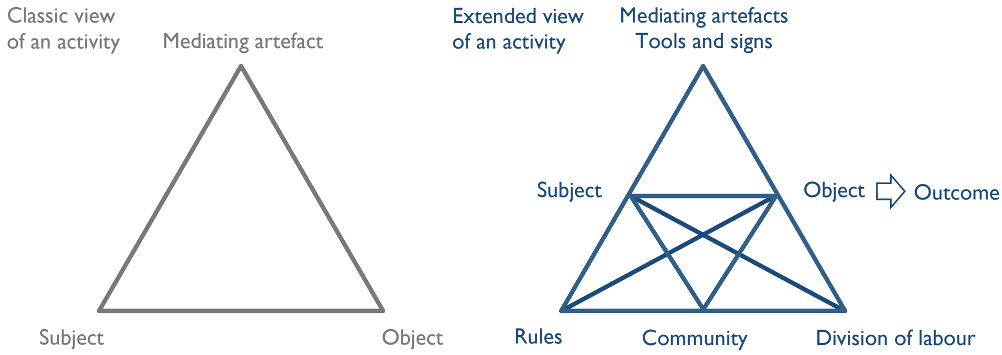


Figure 2-9a (left): Vygotsky's model of a mediated act. The idea of mediation of actions is expressed as the triad of subject, object, and mediating artefact. *Figure 2-9b (right):* The extended model of the structure of a human activity system. Adapted from Engeström 2005. Reproduced with permission of the author.

According to Engeström, the limitation in the classical representation of human activity is that action is described within an individual activity system. It does not illustrate the social and collaborative nature of actions and thus does not present action as a process in a collective activity system. Engeström argues for an extension of the classic view towards a visual representation of the motive behind actions. The object, as the central issue of Activity theory, is what connects individual actions to collective activity. It results in socially important meanings and new patterns of interaction; it forms what Engeström calls "the projected outcome". This projection from the object to the outcome represents the motive of an activity and makes individual actions meaningful (Engeström 1999: 30-31). In Figure 2-10, objects 2, which are meaningful in a collective sense, and which move to a potentially shared object 3, illustrate the outcomes of two interacting activity systems. The model shows the object of activity as a moving target (Engeström 2005: 63). This point of view offers an analysis tool for complex activity systems such as teamwork and extends the individual focus to a broader perspective on human activity and interaction. Whereas the Russian activity psychologists mainly studied activity systems in the context of play and learning in child development, recent research in HCI focusses on extending the domains of activity (Engeström 2005, Vygotsky 1978).

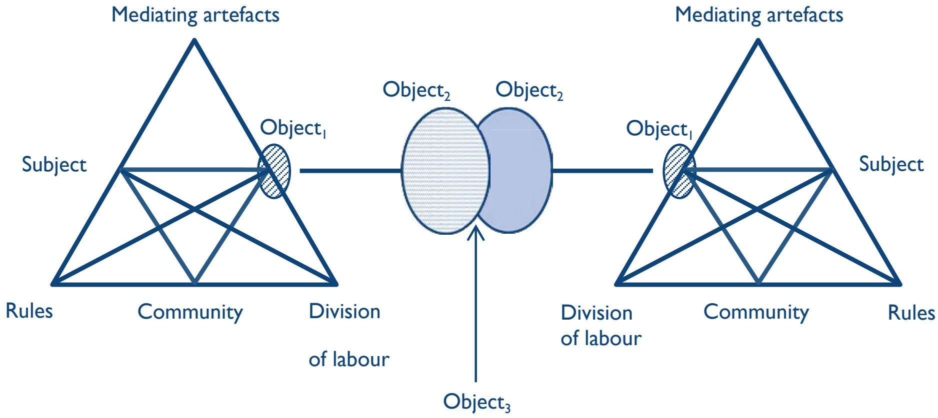


Figure 2-10: The expanded basic model includes two interactive activity systems. Adapted from Engeström 2005. Reproduced with permission of the author.

The significance of Activity theory and Distributed cognition for research in HCI and interaction design lies in their units of analysis. Both units, *cognitive systems* (used by Distributed cognition) and *activity in a context* (used by Activity theory), are useful in analysing cognitive activities. The approaches are to be regarded less as independent cognitive theories than as frameworks for the analysis of complex activity systems. In particular, the initial work of Vygotsky and later colleagues that takes the "object-oriented action mediated by cultural tools and signs" as its unit of analysis (Engeström and Miettinen 1999: 4) and the current work of Engeström and his colleagues that focusses on "complex interrelations between the individual subject and his or her community" (Engeström 2005: 61) are of special interest for this thesis. They provide a framework that involves the interaction between individuals/groups, mediating artefacts, and the material and social environment.

The unit of speech, action, and perception

Important in Vygotsky's work is the extension of the concept of mediation in human-environment interaction to the use of tools as well as signs. Vygotsky distinguished between a) externally oriented tools that lead to changes in objects by using them to exert human influence on the object of activity and b) internally oriented instruments of psychological activity. The sign acts as an instrument of internal psychological activity (e.g. remembering, choosing, comparing, and reporting), whereas the external tool in labour is meant to be used for physical interaction (e.g. writing, measuring, creating, and designing). While technical external tools act on the material environment of the tool-using subject, sign systems (or psychological tools) such as language and number systems do not directly change the environment. They rather structure human thinking. According to Vygotsky, the analogy between sign and tool rests on their mediating function in a mediated activity (Cole and

Scribner 1978, Vygotsky 1978). Signs, as mentioned in Section 2.1, are not static units but part of a dynamic process because they are standing in relationships with several subjects (author, interpreter), the reference object, and their potential to refer to something respectively to mediate something. Complex sign systems such as speech, Vygotsky found out, form a unity with perception and action. Based on experimental work and observations, especially of children, he concluded that "the most significant moment in the course of intellectual development, which gives birth to the purely human forms of practical and abstract intelligence, occurs when speech and practical activity, two previously completely independent lines of development, converge". (Vygotsky 1978: 24) The observations of children led to the further conclusion that "children solve practical tasks with the help of their speech, as well as their eyes and hands. This unity of perception, speech, and action, which ultimately produces internalisation of the visual field, constitutes the central subject matter for any analysis of the origin of uniquely human forms of behaviour". (ibid.: 26) This means that speech plays a specific role in carrying out practical activity; it is connected with perception, action, and thinking.

The focus of the present thesis is on working tools of process operators that are used in their daily work for physical interaction with a particular environment. The close relationship to psychological tools, such as sign systems becomes apparent in the analysis of certain activities. The concept of an *activity system* suggests *activity* as a set of levels. These various levels are described in Chapter 6. Based on empirical cases from two Norwegian onshore facilities, I will report on a particular activity system of plant operators and visualise its different but linked activity levels. The following sections will first discuss the importance of external working tools for cognitive processes, as well as the effects of activity and interaction on human consciousness and behaviour.

2.3.3 Material environment: the role of external tools for supporting human cognitive processes

Technical aids, such as software, measurement instruments, communication technology, or just pen and paper, are now involved in the processes of development, accumulation, and mediation of knowledge as well as problem-solving processes. They form the physical environment substantially and are part of our cognitive system. According to Norman (1993), they help us people with cognitive processes by supporting our existing skills; cognitive processes become therefore easier. Hutchins, one of the representatives of the Distributed cognition approach, on the other hand, assumes that cognitive processes can be completely taken over by external technical aids; there is thus a qualitative difference between the operation of the tool and the implementation of an operation by the tool (Rummel 2008, Hollan, Hutchins, and Kirsh 2000).

Examples from the oil- and gas industry

Figure 2-11 illustrates the different processes using the example of a PDA. With the aid of the barcode scanner MC9090Ex, the operator records equipment and measurement instruments that are used on the outdoor plant and enters an assessment or specific values in the system. The mobile scanner performs the task of data recording; the operator performs the transfer of the measured value into the data system. He draws on information (knowledge) that is provided by other systems, such as when he reads the measured value on a specific measurement instrument to then enter it into the mobile device. Thus, the technical aid assists the operator not only with remembering measurements of the plant by improving his memory; the tool takes over the storage of the measured data and becomes figuratively itself a memory.

Figure 2-11: Collecting of processing data, such as pressure and temperature, at Shell's processing facility for Ormen Lange. (Photograph: author)

Another example is shown in Figure 2-12. The entire facility is managed and monitored from the control room. A brochure about the processing plant Ormen Lange, published by Shell, says, "The control room at Nyhamna is the actual brain of the Ormen Lange project. Two operators are stationed here at all times, monitoring and controlling the facility to using advanced control system." (A / S Norske Shell n.d.: 20) Obviously, the cognitive processes that are required to operate the control system are not the same as the computations and analyses and the information presentations on the screens performed by operating the system. While the operator directly manipulates the system, the computer software takes on the analysis and presentation of the received data. In this sense, the system technology does not enhance human cognitive processes; it replaces them. The digital feedback happens, however, by the operation of the system, and human cognitive processes are involved.

Figure 2-12: Control room at Shell's processing facility for Ormen Lange. (Photograph: author)

However, external technical tools not only take over cognitive processes; they also influence our thinking. With the advent of computers, the way we structure and retrieve our knowledge has undoubtedly changed. One conclusion of this is that higher mental activity is not only explained biologically; it is also influenced by the social-cultural context (Rummel 2008, cp. Hasler 2012).

2.3.4 Social activity: the effects of activity and interactions on human consciousness and behaviour

Karl Marx's famous sentence "Das gesellschaftliche Sein bestimmt das Bewusstsein" ("Social being determines consciousness") may be understood as a leading idea in Activity theory. Indeed, Marx's theory of society played a fundamental role in Vygotsky's thinking. A central principle of this theory is that changes in society and the material environment mean changes in human consciousness and behaviour. According to Marx, the human produces his own being in free conscious activity. In communicating with others, he reveals his being at work and realises it in the product of labour (dtv-Lexikon 1997). Subject and object thus change in work. The human as a social subject executes and forms an object, and simultaneously he develops and realises himself. Due to the activity of the human being in which he uses different kinds of tools, not only nature and the material contained in it is changed, but also the active human being changes. The social system in turn influences the activity or working conditions of the people, according to Marx. Based on these principles, Vygotsky developed his theory starting from the fact that human consciousness and thinking highly depend on participation in interactions or activities, e.g. work, and the psychological and external tools involved in these processes (Rummel 2008). For Weizenbaum, a former computer scientist at MIT and developer of the speech-analysis software ELIZA, the machines of the human being have decisively determined his understanding of himself and the world. Drawing on the fact that people are able to plan, they can test the effectiveness of tools in their imagination (in the act of designing them). This means that the human being is aware of a world that is amenable to a certain extent (Weizenbaum 1977: 35).

However, in terms of HCI it is of particular interest that human social development is directly connected with the development of action (e.g. work) and technology. Important in this context is a responsible use of machines, responsible in terms of a) the use of technology (not all tasks should be solved by machines) and b) the design of technology, which should lead to a conscious and responsible interaction with people. The following section concentrates on human-object interaction as a component of activity. It gives an overview of particular interactive devices used by plant operators working in the oil and gas industry and takes a closer look at their affordances.

2.4 The interaction between humans and objects

In a work context, interactive objects are objects of utility, whether physical objects, such as handheld radios or virtual objects like computer screens. They serve practical use and are not intended for pure contemplation in an artistic sense. The execution of an action with an interactive object determines the aesthetic judgment of the user — in other words, it determines the success and acceptance of the object. "Handling and perception are, [...], the two basic points of the use of industrial products", Heinz Hirdina writes in an essay on industrial design (Hirdina, H. 1978, in Nehls, Staubach, and Trebeß (ed.) 2008: 24). I argue that industrial and product design also includes the design of interactive products and systems, and that the same evaluation criteria apply for these products as apply for industrial products. I go one step further to argue that a number of products, which we call "classic industrial", are interactive products. Household appliances such as vacuum cleaners, simple coffee machines, and juicers or mixers usually have no display, but they interact with their users by means of appropriate shape- and control elements that trigger, with proper use, a particular function. Handling and perception are critical to the aesthetic judgment of the user of any objects of utility. According to Hirdina, at this judgment, the experience of the hand is involved in particular, in addition to visual and acoustic experience. The hand has, through evolutionary conditioning, evolved into an independent work tool and has acquired a sensibility, which determines tactile contact with objects (ibid.). The object-relation to a specific activity that is carried out through the use of the object can be understood as a product function (ibid.: 32). In the interaction with the technical product, the user evaluates it under the aspect of how it will meet its function. The conditions of handling are vital. A high degree of technical complexity that also becomes apparent, disorientation due to lack of structure, and physical burden due to ergonomic deficiencies in the design can limit or compromise the use of technical products. Hirdina states, "The rigorous and ruthless focus on technical and constructional production conditions contains the risk of limited use: technical and constructional laws are poorer than the real use conditions of the biologically and socially determined human being". (ibid.: 34, translation of the author)

Types of physical interaction

The nature of the physical interaction between users and mobile devices plays a very special role because small devices pose more challenges in designing the user interface than 'big' devices do. This is because the context for mobile device use is much more flexible than for non-mobile devices. 'Big' devices, such as desktop computers, are normally operated by seated users, whereas portable devices, such as PDAs and mobile telephones, are supposed to be taken anywhere. Thus, the design options for the graphical user interface and the overall product interface depend far more on the method of user interaction and the context of use. There are two main types of physical interaction with portable devices: one-handed and two-handed interaction (Zwick, Schmitz, Kühl 2005). Devices such as mobile phones with telephone keypads often allow the user to interact one-handed and to carry out other activities at the same time; devices such as smartphones and computer tablets require two-handed operation.

2.4.1 Affordances of devices used in plant operation

I already mentioned earlier the term *affordance,* which was coined by James Gibson and further developed by Donald Norman. An affordance of an object or environment refers to its physical characteristics and at the same time to the actor in the environment. This means that particular shape elements afford their intended functions and thus indicate their use. In the context of design, Norman emphasises perceived affordances as a critical issue — the challenge is what people perceive the object to be able to do (Norman 1993: 106). Especially with respect to electronic devices, the contrast between complex features of technology and actual user tasks requires designers and engineers to apply affordance to technology. I want to illustrate this with two examples of devices used in plant operation.

In Figure 2-13, the digital handheld radio MTP850 Ex is shown. It provides high-quality communication for plant operators working in hazardous environments and is equipped with a powerful set of features. However, interviews with operators working at Borregaard (one of the world's largest bio refineries) and operators working at Shell's processing facility for Ormen Lange have shown that certain features are rarely or not at all used. For example, the portable radio includes a message function enabling users to send text messages that are pre-defined or from a template. However, many operators fail to use the feature — partly because they do not know how to use it and partly because they do not need it. All operators surveyed[5] indicated that they use the radio terminal mainly for voice communication. Thus, the keypad

[5] The survey refers to the interviews with operators working at Borregaard conducted by third year students of the Østfold University College, and to the interviews with operators working at Shell's process facility for Ormen Lange conducted by the author.

and the display of the device largely remain unused. The use of the keys is limited to the programmable side buttons (one option is to switch the channels) and the PTT-button placed between the programmable buttons.

Figure 2-13: MTP850 Ex TETRA radio by Motorola.

It is obvious that the device has a set of affordances, but only a few of them are relevant for the operators in their particular context, and only a small set of affordances is perceived by the users. Gaver (1991: 80) suggests separating affordances from perceptual information about them by giving four explanations of types of affordances:

- *perceptible affordance,* when perceptual information is available for an existing affordance
- *hidden affordance*, when there is no information available for an existing affordance
- *false affordance,* when information indicates an affordance that doesn’t exist
- *correct rejection,* when users feel they are not demanded to act because there is neither an affordance nor any information indicating an affordance

When applying Gaver’s classification of affordances for devices that are used in plant operation, the question arises to what extent hidden and false affordances can lead to improper device use with unforeseeable consequences for both efficient and safe plant operation. At the same time, the question arises whether user satisfaction and product acceptance will decrease. Norman (1993: 106) pointed out that people tend to use an object in the way inspired by the most salient perceived affordances, not in ways that are hard to find. If we assume that affordances can be designed, then engineers, software developers, and designers should aim to design objects and environments that afford their intended function. Or, as Gaver concludes, “Making affordances perceptible is one approach to designing easily-used systems.” (Gaver 1991: 81)

2.4.2 Physical objects vs. virtual objects

If designed appropriately, physical and mechanical object characteristics of handheld-radios can directly communicate their intended functions. The rotary knob with its structured surface on the top of the radio affords users to turn it. In addition, the large oblong button on the side affords them to push it. It is different with graphical interfaces. Icons and images on the display of a handheld-PDA indicate their functions much less directly. Nevertheless, well-designed visual interfaces can offer various types of information for interaction. One example is shown in Figure 2-14. Based on the design and functionality of real objects, digital images indicate how to adjust volume settings: the user is supposed to tap and move the slide bar to increase or respectively decrease volume.

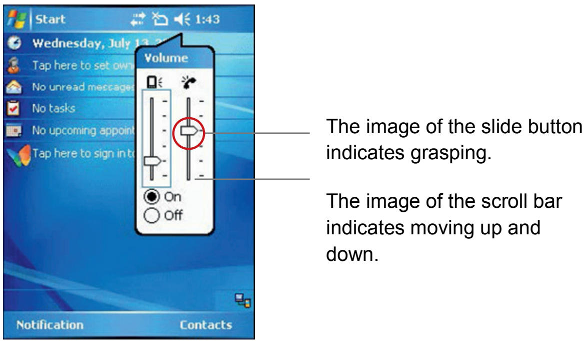


Figure 2-14: Volume dialog box on the mobile computer MC9090-G RFID (MC9090-G RFID user guide supplement, March 2008, p. 32).

In his research on technology affordances, Gaver (1991) introduced the idea of *sequential affordances*, which describes affordances for complex actions. Using the graphical interface of the dialog box in Figure 2-14, the affordance of grasping in the first step leads to the affordance of moving in the next step. Thus he applies the concept that one affordance leads to another to physical and visual information. However, the image of the slide button that indicates grasping cannot lead to the next action (moving the button indicated by the image of the scroll bar) without looking at the images. Images require people to look at them and to perceive them visually because they cannot provide tactile information for existing affordances. This can lead to less flexible and less efficient use of display-oriented devices, although images of common physical objects (e.g., buttons) can enhance a device's usability. As Lidwell, Holden, and Butler (2010: 22) explain, "[…] a drawing of a three-dimensional button on a computer screen leverages our knowledge of the physical characteristics of buttons and, therefore, appears to afford pressing. […] the images, themselves, do not afford anything". Affordances refer solely to the qualities of physical objects. Since people are familiar with the affordances of physical objects based on their experiences with them, they are able to perceive their non-physical counterparts and use them in the same way. Important in this context is the relationship between human experience and human action.

2.5 Conclusion

The theoretical concepts of I) life world in phenomenology, II) embodiment, and III) Gestalt theory provide the basis for understanding the complex process of human activity and the interaction between people and the world. They are thus important for the design of interactive products because people, who are embedded physically and socially in the life world, interact with objects in this world. The interplay of cognition and embodied action has a special role in the use of objects. The reason is that humans are not machines; humans feel. Feelings are closely connected with the aesthetic experience of objects, or in other words, with the sensual perception of objects. In the literature, aesthetic understanding is represented in two ways: based on formalism, and thus appearance-related, and based on the gestalt. The aesthetic understanding of Gestalt includes the function and the real use of an object and highlights the connection between objects that afford their intended functions and object perception involving visual and non-visual sensory channels and data from (stored) experience.

The context (and what constitutes the context), namely the inclusion of external influences in the consideration of human activity, is the central theme of the conceptual frameworks of IV) Distributed cognition and V) Activity theory. In going through the different theoretical approaches, it has been shown that the design of the interface between user and object must meet much broader criteria than being "user friendly". To ensure that users accept products, designers need to understand the full complexity of interaction. Product acceptance depends on the experiences and actions of the user. It is directed to the environment in which people act and learn, and to objects that are actively used within the context of the environment. This results in evaluations because, whether a functional product can be enjoyed aesthetically arises not from pure observation but from action; more precisely, from the use of the object and the associated object perception. These criteria need to be examined by designers to understand them. And these examinations in turn should be an important part of the overall design process. Large companies, it seems, unfortunately still lack this insight. (In the following chapters, it will become more apparent that user-centred design, which includes the involvement of the user in the design process, is an important aspect in the development of successful products.)

In view of a professional context of use of interactive technologies, the theoretical considerations of human experience as a complex process of human activity are of particular importance. Design decisions for communication technologies should therefore be based on philosophical approaches, and their findings should become central to design considerations. Many researchers have practically explored the theoretical frameworks on cognitive processes. For example, Hummels and colleagues (2008) have been inspired by Dourish and Gibson and have applied the ideas of a meaningful social and physical world, in which action is afforded to individuals, in their design teaching. In project work, students then worked on the developing of communication devices that address different meaningful aspects (cf. Hummels et al. 2008: 6-11). Svanæs and Young (2011) analysed a participatory design study in which participants improvised Nintendo Wii games. Inspired by Merleau-Ponty's concept of the lived body, they found that a cognitivist approach to HCI with sensor-based technologies that allow for full-body interaction would contribute to new insights related to the bodily aspects of user experiences. Antle (2009) described the consequences of embodied cognition for design using the example of interaction technologies for children. And in robotic science, the realisation that consciousness, thought, and intelligent action are possible only in connection with the body has resulted in research and construction of humanoid robots, robotic hands, and play machines (Marsiske 2013).

To summarise, future products and systems are supposed to transfer HCI into the physical world. For the design of future technologies, this means the relocation of human-machine interaction from screen to objects of the real world, leaving keyboard entries and pointing devices such as the mouse behind (Reichenbach 2011). Some examples already exist: input options via gestures are for example explored in data gloves, gesture-controlled gaming devices such as the Nintendo Wii controller are used for playing a variety of games, and multi-touch screens allow for mobile use (further examples from research and technology will be given in the next chapter). At the same time, design must concern itself with the gestalt perception of complex objects, and we must wonder how much increased product complexity affects our gestalt perception. On the other side, it is necessary to explore what the effect of reduction in the design of products may be. Can function be better identified by reduction? To answer this question, design must draw not only on design principles but also on theoretical knowledge of cognitive processes, as provided by approaches discussed in this chapter.

In the next chapter, I will present knowledge on the sensory perception of objects, with a focus on the tactile and kinaesthetic senses.

3 SENSORY PERCEPTION OF OBJECTS

The following chapter provides a review of sensory perception in light of the concept of embodiment and Gestalt theory and in light of the current research case of operator-device interaction. The focus is on sensory perceptions of objects, in particular on tactile and kinaesthetic senses. In recent years, extensive research on visual perception of user interfaces and information representations has been done. This chapter examines the role of tactile and kinaesthetic senses for the design of handheld devices. It will draw on the work of researchers such as Ishii and colleagues (1997, 2004), Poupyrev and Maruyama (2003), Moore (1974), and others who have been concerned with the value of haptics in human-computer interaction and conducted research on the subject of tangible interactions. However, the main emphasis of the present work is less on how digital information can be made tangible than on the value of tactile feedback for human-machine interaction. While the understanding of visual perception is essential to the design of graphical information or data information, e.g. in screen design or Information Rich Display Design (Braseth, Veland, and Welch 2004), the investigation of tactile and kinaesthetic sensory input is essential to the design of three-dimensional products. In particular, it is important for the design of handheld products that are supposed to enhance bodily movement and work performance in demanding work environments. On this background, the relationship between human-computer interaction and human motion is discussed, and ergonomic aspects of handheld devices are explained.

3.1 Tactile and kinaesthetic senses

Before going into the themes of tactile perception of mobile devices and haptic interfaces, brief background knowledge on tactile and kinaesthetic senses will be provided to understand why and how people perceive objects.

The tactile sense mediates a perception of shape, size, proportion, and surface of an object. Thus, we can get an idea of what we hold in our hands. This is because the skin has, in addition to tactile corpuscles, different types of receptors for touch sensation, including the sensations of temperature and pain. These receptors respond to different touches (for example, constant pressure, tapping, stretching, or vibration), and they have different adaptation speeds.

The overall impression of touch arises mostly through the interaction of all receptor types. Although all receptors are distributed in different densities on the entire body surface, it is the sense of touch of the hands which is of particular importance for human development. This is partly due to the high density of receptors in the area of the hands and fingers; on the other hand, it is related to the fine motor skills of the hand. The combination of tactile sense and motor precision allows for active scanning and manipulating of objects. Thus, the hand becomes a tactile tool that shapes the environment decisively (Wehr and Weinmann 2009).

Each perceptual process begins with the translation of a physical stimulus, which is recognised, recorded, and translated into the language of the nervous system by means of a receptor. While the senses of smell and taste perceive chemical stimuli, the cells of the retina react on electromagnetic waves when seeing, and while in the ear sound waves are translated into electrical discharges, the sense of touch perceives mechanical pressure. Perception is not only selected in the nervous system, however; it is already selected and interpreted in the hand itself. This is related to the location of the tactile stimulus, which is determined according to which areas of the skin are affected (these areas are called receptive fields) and how big they are. Only when the stimulus is within its receptive field can the corresponding receptor be activated (ibid.).

Extension of touch information through kinaesthetic impressions

The sense of touch, as already mentioned, conveys a feeling of a surface that is based on sensations of smooth, rough, cold, warm, rounded, or edged. However, the sense of touch alone cannot provide a feeling of a three-dimensional object, that is, the sensation of dimension and position in space cannot be provided by touch alone. Mere touch communicates only a part of the touch information. However, touch is always connected with a temporal sequence of perceiving impressions because the tactile perception of a shape is in stages. It is experienced little by little, detail-by-detail. Once the hand moves over the object, it is possible to gain a detailed and differentiated touch impression. In summary, to be able to perceive differentiated impressions, the kinaesthetic impressions must complement touch impressions. This requires the integration of the sense of touch and of proprioception, which is the ability to sense the position and movement of the body in space, or in other words, to sense proper motion. This sensation of proper motion is a prerequisite for target-oriented acts. It enables people to perceive a three-dimensional object spatially and to determine its mechanical properties. It is also referred to as kinaesthetic awareness. Kinaesthesia is thus the general sense of position and movement. It refers to the awareness of limb positions, muscle tensions, velocity, and forces. Kinaesthesia is conducted via sensory receptors in skeletal muscles which supply the brain with information about changes in muscle length and tension. Without kinaesthesia, humans could not execute activities not maintain upright body posture, walk alone, or even talk (Moore 1974, Tan and Pentland 1997, Wehr und Weinmann 2009).

Together, kinaesthetic and tactile sensations are therefore fundamental to manual action and locomotion. In their interplay, they provide a basis for perception of and action on our environment. This includes the close interplay of visual sensation and motor skills that has already been discussed in Chapter 2 (see the section titled "The interplay of cognition and action", page 23).

3.2 Tactile perception of mobile devices

Skin contact is the basic condition of tactile impression. Ulbricht (1988) argues that touch provides the most immediate sense impression, because it relates to the reality of one's own body. Since the touched object appears to us to be the real object, the sense of touch seems to have a greater significance for belief in reality of the environment than the other senses (Ulbricht 1988, published in form+zweck 18, 2001: 31). For the design of handheld devices, the way of touching is important. Ulbricht explicates that tactile perception is preferably performed by using one or more fingertips, the palm of the hand, or the ball of the thumb. The interaction of the fingers results in a new quality of the sense of touch because it is clearer and more differentiated than touching with only one finger (notice the way we are operating our mobile phones). Ulbricht notes that "this interaction of the fingers accomplishes a unique achievement" when touching to experience thickness, for example the thickness of paper, adding that "it is possible to differentiate between thicknesses of one fiftieth of a millimetre, in some cases even to a hundredth of a millimetre" — impossible for the human eye (ibid.).[6] With respect to the tactile perception of objects, the impressions that are mediated by the hand refer to their shapes, materiality, structures, surface texture, weight, and thermal properties. Accordingly, we perceive the qualities of being round, angular, sharp-edged, raw, smooth, soft, hard, heavy, light, cold, and warm.

Material recognition as a source of information

Studying surfaces by touch provides information about material structures resulting from the arrangement of the touched elements. In case of industrial controls, for example, the touch differentiation of push buttons can be improved by distinct surface structures such as distinct shapes, textures, or even thermal conduction: a material with a rough surface will be perceived as warmer than the same material with a smooth surface. In addition, material contains a type of acoustic structure that is also involved in material recognition (notice the noise that arises when writing with the keyboard). Noises produced by the hand itself when touching object surfaces may provide further information about material. This information again may inform opportunities for use (see also the explanations for the semiotic meaning of objects in Chapter 2.1, page 14).

[6] Interesting in this context is Ulbricht's reference to Ehrenfels' theory of complex perception in using the following description to the quality of the sense of touch: "The whole hand is more than the sum of its fingers. Despite the tips of the fingers being apart, the impression of an intact surface is made." (Ulbricht 1988, published in form+zweck 18, 2001: 31)

This leads to the idea of tactile coding by applying different materials on surfaces, such as surfaces of buttons. However, production costs and maintenance effort would be high. Instead, a system that combines different shapes, sizes, and textures can be produced easier and cheaper.

Function recognition through shapes

As in the example of buttons, attempts have been made to represent functions by tangible shapes or common stereotypes such as arrows for direction (see Figure 3-1a and 3-1b). However, state-of-the-art mobile technology shows that the creative scope for tactile buttons remains relatively unexploited. Today, the design research mainly focusses on two-dimensional shapes, either in terms of differing product-graphics on, by and large, similar physical buttons or in terms of digital button design. This is undoubtedly because today's method of device operation has changed; we rarely navigate through the menus of mobile communication devices by means of physical buttons. In the course of the development of modern touch-input technologies, navigation keys on mobile devices have been replaced by virtual keys on touchscreens.

Figure 3-1a (left): Industrial PDA i.rock 420 Ex with an embossed keyboard that gives tactile feedback. The navigation buttons have an arrow-shaped form and indicate the direction of movement. *Figure 3-1b (right):* Nintendo Wii remote controller with its typical cross-shaped directional pad.

However, as early as in 1974, T.G. Moore — at that time a researcher at the Department of Ergonomics and Cybernetics, Loughborough University of Technology — conducted a study on tactile and kinaesthetic aspects of push buttons focussing on the design and layout of control buttons for industrial equipment. Convinced that tactile and kinaesthetic senses are important for button design, Moore reported on an experiment whereby 25 push-button shapes were tested for tactile differentiation and allocated to control functions (see Figure 3-2). Although the focus was not on mobile equipment (and regardless of how technology has evolved), the study findings are of interest for the present work since they support the assumption of the general importance of tactile and kinaesthetic impressions for the sensual experience and practical use of objects. The experiment showed that those shapes with simple, large patterns such as shape 1 and 4 (see Figure 3-3) and respectively concave/convex and angular shapes such as shapes 21-24 were seldom messed by subjects. The researchers around Moore then continued the experiment to allocate the six button-shapes to given control functions.

In our case, it is less important what kinds of shapes were preferred for specific control functions, as the focus is on mobile equipment, and functions must thus be considered in another context. Of interest is the general fact that, by tactile geometric shapes alone, distinctions of buttons and the allocation of functions can be made.

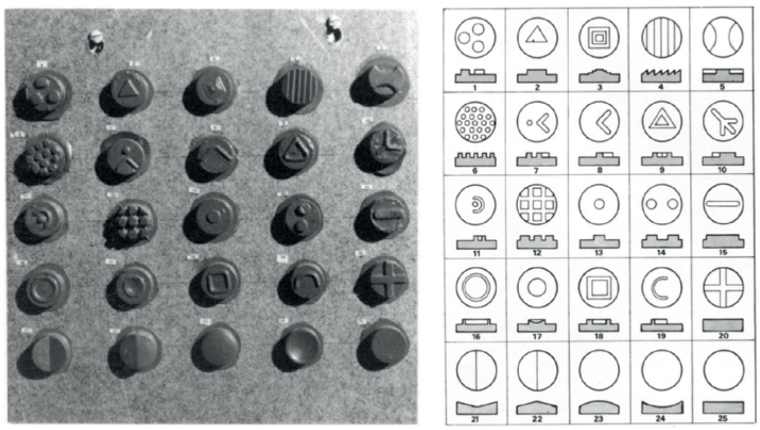


Figure 3-2: Twenty-five shapes designed at the Department of Ergonomics and Cybernetics at Loughborough University. The prototypes were produced by vacuum-forming plastic over wood and metal forms. The purpose of the study was to find out to what extent the shapes are mutually distinguishable by touch alone, even when rotated (Moore 1974: Tactile and kinaesthetic aspects of push buttons. In Applied Ergonomics 1974, 5.2, p. 67.).

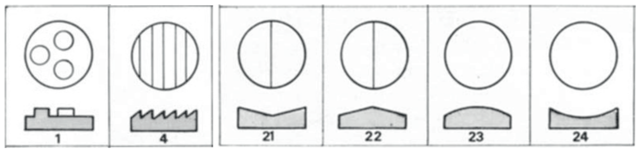


Figure 3-3: Based on tests, six shapes were chosen as being most distinguishable.

The experiment resulted in a set of recommendations for the design of push buttons that Moore divided into recommendations with respect to tactile coding and recommendations with respect to kinaesthetic coding. Even though the design challenges for small devices are different compared to mechanical equipment of heavy industry, some similar problems exist for all sizes of buttons. With this in mind, the recommendations are worthy to be taken into account. The following is an excerpt.

Tactile coding:

- *Shapes to be distinguished by touch should have as gross a shape as possible — without deductions — covering an area which can be touched by one finger.*
- *Geometric shapes, numerals, or letters should be formed from outlines rather than solids.*
- *Shapes should be made to vary along as many tactile dimensions as possible unless groups of similar functions need to be delineated, in which case the tactile dimensions can be used to denote these functions.*

Kinaesthetic coding:

- *Where possible, common function buttons should be placed in standard positions within each control panel and stereotyped expectations of operators should be sought to aid in the determination of layout.*
- *The position of the control panel on the machine should ensure that the buttons could always be operated with the hand in the same orientation (e.g., with fingers forward and palm downward).* (Moore 1974: 70)

3.3 Experiences and motoric habits

Among other things, Moore recommended the identification of stereotyped expectations of users of control panels to incorporate them into the button layout. An operator of control buttons uses spatial memory to find what he expects to be the correct button. This part of human memory is responsible for spatial orientation and is based on experiences. It only works by the use of the kinaesthetic sense. In the concrete case of mobile devices such as handheld radios, users probably have expectations with regard to buttons and knobs that denote functions such as on/off, volume, or channel switching. As an example, today, many operators in the process industry are equipped with radio devices that include an emergency button placed on the top of the device. Many users, however, probably expect the on/off button at this position. Because of formerly used devices that included the power-function on the top, operators spatially remembered this button. They did not expect an emergency button at this position.[7] With this in mind, designers of mobile devices must pay attention to potential standardisations of the positions of certain buttons or control elements. Especially in

[7] This information refers to interviews and conversations with operators working at Shell's process facility for Ormen Lange and at Borregaard's bio refinery.

relation to the user, this is of importance because users of devices use spatial memory for orientation and thus develop motoric habits. Those kinds of positional rules are closely related to haptic feedback that serves as orientation and confirmation for correct use.

3.4 Discussion: haptic interfaces and their limitations in current research

The term *haptic* refers to manipulation as well as to perception through the tactual senses (Tan and Pentland 1997). Haptic feedback in the context of HCI is in general related to vibrotactile and kinaesthetic feedback, also known as force feedback. It is been employed in telerobotics, training and medical simulation, computer gamepads, and increasingly in touchscreens. The advantage of a programmable touchscreen is obviously that a single-touch panel can replace several mechanical controls, such as buttons, knobs, sliders, and switches, and provides high-capacity communication with the user. However, the transition from physical to electronic controls poses a challenge to the human-machine interaction: tactile cues are not present. Whereas tactile feedback lets us find the radio volume knob in the car without looking, the integrated infotainment system demands that the user look at it. Over recent years, research in HCI has focussed on addressing this challenge by providing innovative approaches for haptic interfaces, e.g. tactile interfaces for visual displays or small touchscreens (Harrison and Hudson 2009, Poupyrev and Maruyama 2003, Fukumoto and Sugimura 2001). However, the study of literature reveals that the use of the term *interface* in the area of human-machine interfaces seems to be generally restricted to graphical user interfaces involving display-oriented systems (see also Chapter 2.2, on Gestalt-laws of organization, pp. 28-31 – the focus on GUI design in literature has also become apparent in connection with the application of Gestalt principles). One could get the same impression in terms of haptic interfaces: research seems to restrict augmenting GUI design with tactile feedback and thus visual information. But what about existing haptic (and acoustic) qualities of three-dimensional objects, such as language of form and material structure (including acoustic structure) of mobile devices? To what extent can existing qualities be improved and extended in order to enable effective and particularly error-free operation? The computer — or more broadly, the electronic machine — is used today in many different settings (e.g. cars, information and communication technology, and household appliances) and thus, it exhibits enormous complexity of interface design. This design complexity and the increasing amount of available information provided by technology should engage designers to look at existing product features and to integrate multiple sensory channels (see also the explanations on affordances perceived by several sensory channels in Section 2.1.3). I claim that the only focus on augmenting GUIs will lead to loss of interaction quality. Instead, inspirations from other fields of design should be incorporated into the development of haptic interfaces. This includes a broader view on interfaces in general. Figure 3-4 illustrates a possible way to describe interface design.

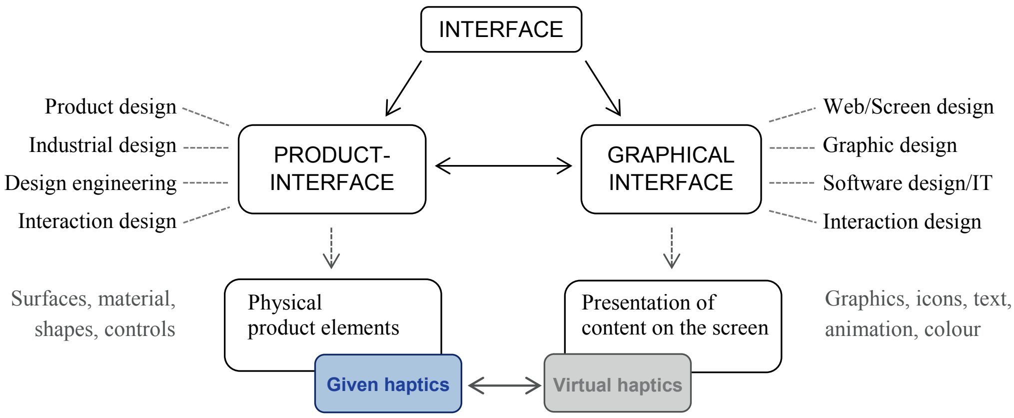


Figure 3-4: Interface design incorporates graphical and physical interfaces and should include various design- and research areas. Whereas the focus of the graphical interface design is on information presentation on screens, product interfaces include physical information communicated by product features. Physical- and virtual-based haptic information should complement each other.

The design of physical or haptic characteristics has always been an essential part of product design because consumer products (including electronic consumer products) are tangible from the beginning, as opposed to software products. Only if this aspect of the design succeeds can a product convince a user and be properly used.

The value of haptic feedback for mobile devices

In terms of touchscreens in mobile devices, tremendous interface flexibility is provided, but no tactile qualities are offered. Poupyrev and Maruyama determine, "Indeed, despite evidence that touch screen keyboards are faster and more accurate for text entry, handwriting techniques still prevail on mobile devices. This may be attributed to better kinaesthetic feedback in writing: it may simply *feel* more natural to the user to write than to poke on a soft keyboard." (Poupyrev and Maruyama 2003: 217) Although this quote refers to touchscreens, which were far less responsive than today's technologies, it is still relevant. For good reason, the Swype input method for touchscreens has been integrated in today's smartphones, allowing users to enter text by moving the finger or stylus across the virtual keyboard. The finger or stylus slides from letter to letter (lifting only between words) and, thus, it strongly reminds one of writing by hand. In addition, touchscreen graphical buttons cannot provide the same quality of kinaesthetic and haptic feedback as real buttons, where users can directly feel the action. With the work context of field operators in mind, users of mobile devices are often preoccupied with tasks such as walking, writing, and maintenance. Thus, a mobile context requires the need for non-visual tactile communication. Furthermore, the small display size of mobile devices, environmental noise, social restrictions, and interruptions are interferences that affect effective visual and audio feedback in mobile applications. Tactile feedback of product elements can provide immediate information to users during their task execution. This method of continuous control may allow them to more quickly adapt to challenges and to better respond to changed situations. Moreover, tactile feedback can be effective in reducing device operation time, as research studies have shown (e.g. Fukumoto and Sugimura 2001). Touch is thus a communication channel that enables human eyes to better attend to other control functions. In most cases, however, operators are required to wear gloves. This in turn limits the gathering of detailed information by touch. Still, haptic feedback significantly determines the quality of human-machine interaction. Several research models and systems have been developed to provide users with more intuitive and effective interactions. The following section shows some examples.

3.5 Examples of haptic communication devices

Since the early 1990s, research on tangible interaction has been conducted at MIT. For example, Hong Z. Tan and colleagues were inspired by the Tadoma method (a non-visual and non-auditory communication method for deaf-blind people), which moved them to develop tactile displays for information transmission. One example is the "TACTUATOR", a three-finger positional display that consists of three independent motor assemblies which stimulates the finger pads of the thumb, index finger, and middle finger. The goal of this work was to evoke and study sensations via the kinaesthetic and vibrotactile aspects of the sensory system of the hand (Tan et al. 1997). Also at MIT, Chang et al. designed the vibrotactile communication device "ComTouch", a sleeve that fits over the back of a mobile phone and augments remote voice communication with touch. The handheld device translates finger pressure into vibration whilst each finger is allowed to press independently. The goal of this work was to provide for private and personal communication by using touch as a medium for nonverbal communication, and at the same time to enhance audio conversation by providing additionally information (Chang et al. 2002).

Further research has been focussed on touch panels of handheld devices. In 2001, Fukumoto and Sugimura reported on an interface mechanism, called "Active Click", that adds tactile feedback to the touch panel of a PDA. The researchers attached a small actuator to the PDA's body or the backside of the touch panel. A short pulse signal is supplied to the actuator for making it vibrate, and the vibration is then transmitted to the grasping hand or tapping fingertip. The researchers concluded that the system is effective in improving usability and input speed in touch-panel operation, especially in noisy situations (Fukumoto and Sugimura 2001).

Actuator-based tactile feedback for touch-panels has also been investigated by Poupyrev and Maruyama (2003). The researchers investigated the advantage of tactile feedback of basic GUI elements on a Sony PDA touchscreen. A tactile actuator, called the "TouchEngine" actuator, was embedded in the device screen to simulate the feel of real mechanical controls.[8] This novel actuator communicates the tactile feeling by vibrating the entire device instead of the device body and enables independent control of both the amplitude and frequency of vibration (see Figure 3-5a, page 59). Thus, a variety of tactile feelings for different GUI elements can be provided, whereby the feedback is supplied to the user in response to different gestures: touching a GUI control with the finger/pen, dragging or holding the finger/pen, and lifting off the finger/pen. When touching a GUI element, such as a button, the user will feel a "click" under his/her finger (this feeling is also provided when the user lifts the finger off). Holding a menu or scroll bar element provides the user with a "springy" feeling. Only the finger that presses a GUI control feels tactile sensations due to the actuator's thin and small size (Poupyrev and Maruyama 2003: 217-220). The researchers received a positive response to their prototypes, which have been tested in several usability studies. The tactile feedback was exceptionally well-received by their users (ibid.: 220).

Discussion: the click feel is not enough

However, these examples illustrate constraints that arise from merely focussing on virtual aspects. In their article on "Active Click", Fukumoto and Sugimura state that "ordinary touch panel devices fail to achieve comfortable and accurate operation because they do not provide the *click feel* when tapping". (Fukumoto and Sugimura 2001: 121) However, is the *click feel* enough? Simulations of feelings of real objects only supply the user with an imaginary version of the real object. There is still a lack of real experience of surface structure, materiality, shape — shape can provide rich information, as we have seen before — and size that cannot be provided by small-size vibration actuators. Moreover, it can be assumed that the power-consumption for handheld devices with embedded actuators is higher because the entire device must be vibrated. Indeed, there are research works and examples of haptic communication devices that seek to bridge the gap between the flexibility of touchscreens and the benefits of tactile properties of physical product interfaces.

Tactile feedback

The Finnish company Senseg "turns touch screens into Feel Screens" (Senseg 2014) by producing haptic feedback without any mechanical component parts. Senseg's patented technology uses the principle of attraction between electrical charges and creates sensations of different textures, edges, vibrations, and more on touchscreens (see Figure 3-5b). By attraction or repulsion of the contact finger by means of electrostatic fields, users can feel a variety of effects on the smooth touch surface. Unlike effects generated by mechanical vibration through actuators or bending piezoelectric strips, this technology is silent. Moreover, the thin sensor layer, called Senseg's "Tixel™", can be applied to small touchpads, smartphones, tablets, and large touchscreens. The system consists furthermore of the

[8] Indeed, four "TouchEngine" actuators were embedded and placed in the corners of the touch screen between the TFT display and the touch-sensitive glass plate (Poupyrev and Maruyama 2003: 218).

electronic module for activation of the sensor surface and the software that manages the touch effects in the respective applications (Kuhlmann 2012, Senseg 2014).

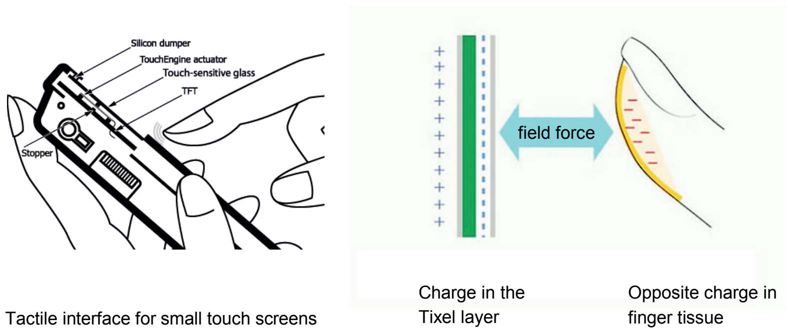


Figure 3-5a (left): Illustration of a haptic display with embedded "TouchEngine" actuator (Poupyrev and Maruyama 2003: 217). Reproduced with permission of the author. *Figure 3-5b (right):* Using the force between finger and touch surface in an electrostatic field, Senseg creates different textures (Senseg n.d. Available on: http://senseg.com/experience/senseg-technology).

Harrison and Hudson (2009), who created dynamic physical buttons by pneumatic actuation in a visual display, show another principle. The display contains deformable areas that allow for program-controlled dynamic modification of physical aspects, such as form and appearance. The construction is simple: inexpensive materials such as acrylic, glue, and latex are used for the design. The acrylic layer includes cut-out areas, such as rectangles, circles, arrows, or simple figures. On top of this is a thin latex layer attached with an adhesive that functions as a deformable projection surface. When the air chamber is pressurised with a small pump, the latex deforms. It can be pressurised positively and negatively so that both concave and convex shapes can arise. The shapes are determined by the cut-out areas of the acrylic layer and may become more complex by producing layers with complex cut-outs. The display is flat when no pressure is used. Harrison and Hudson state that these surfaces go beyond simple on/off actuation; they rather provide a range of different tactile expressions. However, this idea has limitations because of its technical application, especially for use in mobile devices. The integration of a pneumatic pump into a small device poses a challenge to the design. The researchers, therefore, have applications within the domains of automobile dashboards, large screens, kiosks, and cash machines in mind (Harrison and Hudson 2009: 299-305).

Also based on pressure — though not pressurised air — is the tactile touch surface provided by the company Tactus Technology (see Figure 3-6a). With its Tactile Layer, the company creates reversible digital keyboards on a smooth touchscreen. The layer consists of a multi-layer, transparent polymer with a transparent liquid, and it is on the display above the physical touchscreen. The underlying technology of small fluid channels that cross the polymer enables fluid to expand the top layer to create physical buttons. The buttons rise up from the touchscreen surface by applying pressure to the liquid and disappear when the pressure is removed from the liquid. A small controller controls the state, height, and hardness of the reversible buttons. The technology allows for seamless multi-touch with both fingers and stylus. It is thought to be used in displays and button layouts for input devices (Kuhlmann 2012: 148-149).

Microsoft Research conducted another interesting study in 2013. The software research organisation showed a 3D touchscreen, called "3D Haptic Touch", that provides haptic feedback as a person pushes three-dimensional cubic objects around a virtual space. The system is based on a force feedback monitor that is mounted on a robot arm which moves the monitor back and forth. The monitor consists of a 3D display and a multi-touch overlay on top of the display. Force sensors that detect how hard the touchscreen is pushed are placed between the overlay and the display. By touching the cubic objects, the force feedback monitor gives the user the sensation of different materials with different physical properties and friction. In addition, the weight of individual objects can be simulated with the monitor. In supposedly heavier objects, the robot arm provides significantly more resistance than in lighter objects. The researchers at Microsoft Research hope that this technology will find an application in medicine, education, or the 3D game industry (Jørgenrud 2013, Spier und Janssen 2013).

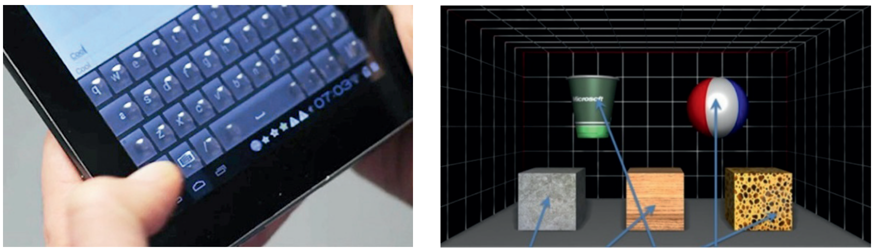


Figure 3-6a (left): The touchscreen tablet with reversible keyboard, developed by Tactus Technology, responds to pressure. *Figure 3-6b (right):* Actuated 3D display with haptic feedback. Different objects give the feel of different textures when touching the objects displayed on the touchscreen (Photo: Microsoft Research).

The described research includes examples of buttons that allow for touch stimuli by responding to exerted pressure. Still, the approaches do not include physical buttons. A closer look at the smartphone market, however, shows that some producers put on *real* haptics in the product development. The South Korean group LG, for example, launched its Android smartphone LG Optimus G2 in 2013. It is equipped with a rear key on the back of the phone (see Figure 3-7a). The key assembly includes the side key operations power button and volume control and is placed right underneath the camera. The switch is easy to reach because it is slightly raised, whether the device is used one-or two-handed, left-or right-handed, or in portrait or landscape format. Moreover, the integrated design of the power button and the volume rockers enables users to easily distinguish shapes through touch and kinaesthetic impressions. Given the practical application of the device, this is important.

In addition, BlackBerry introduced a smartphone that provides physical keys (see Figure 3-7b). The Canadian company, which is known for its safe products, has with its Passport smartphone brought a device on the market that combines a hardware keyboard and touchpad function. To integrate both the keyboard and the touchscreen, the device was given a wide format in the dimensions of a passport. The physical keyboard is limited to three rows. Missing components are context dependent and displayed on the screen. For example, punctuation or word suggestions appear at the bottom of the screen (Weber 2014).

In terms of mobile devices for hazardous areas (especially in the oil and gas industry), the new ruggedised smartphone Impact X, presented by the Norwegian company Bartec Pixavi in 2014, is of special interest. In cooperation with Eggs Design, Bartec Pixavi developed an explosion-proofed Android smartphone with a focus on design and user satisfaction (see Figure 3-7c). Apart from product qualities like video communication in HD-quality and connection to enterprise resource planning systems such as SAP, the device also has four physical control buttons on the front. The buttons cover the Android functions Home, Back, and Menu in addition to a camera function. Their physical design has a positive impact on the product’s usability and on the ability to operate it with gloves. Moreover, the smartphone replaces several devices by incorporating a camera, barcode reader, video, light, etc. It is slightly thicker than other phones because of its double battery capacity, extra-thick Gorilla glass, and chassis milled from a single piece of aluminium (Valmot 2014). The product is otherwise an ordinary smartphone and is in no way inferior to other phones.

Figure 3-7a (left): LG Optimus G2 with a rear key on the back of the phone (Photo: LG Electronis). *3-7b (middle):* BlackBerry Q 10 smartphone with a physical keyboard (Photo: BlackBerry). *3-7c (right):* Bartec Pixavi Impact X with four physical buttons on the front display (Photo: Bartec Pixavi). Reproduced with permission of Bartec Pixavi.

For several years, haptic interfaces have also been applied in the automotive industry. Automotive brands such as BMW and Toyota use haptics to provide drivers with interactions that are more intuitive and that improve safety by reducing visual distraction. By experiencing discriminable haptic sensations, users can manipulate several vehicle functions with a single controller, which in Toyota's case is similar to a computer mouse or joystick (see Figure 3-8a) and in the case of BMV is a control wheel (see Figure 3-8b). Vehicle interface systems consisting of haptic controller and high-resolution display enable drivers to manage the complexity of in-car information including navigation, communication, configuration, and entertainment.

Figure 3-8a (left): Haptic perception in a driving context: Remote touch haptic controller in Toyota's Lexus cars. The controller is similar to a computer mouse or joystick and enables one-handed operation while allowing the driver to concentrate on the road. *Figure 3-8b (right):* The BMW iDrive touch controller is designed as a control wheel and enables users to easily display and control in-car information while keeping attention on the road.

More recently, Hoff, Bjelland, and Cato (2008) reported on the development of a haptic interface for an in-car audio system that is placed between the gear lever and the armrest. Their touch controller concept consists of two rolling cylinders, a slider in front of the cylinders, and a button on the left-hand side. The slider slides along one of the cylinders and changes the sources, such as radio, phone, CD, etc. The cylinder scrolls through the chosen source. To inform the function, grooves are spaced along the source slider. The other cylinder controls the volume and turns the system on and off. It is designed with large knobs to make a good thumb-grip. The button is used for selecting options, e.g. phone numbers from the phone list (Hoff, Bjelland, and Cato 2008: 208-209). In their case study, the researchers wanted to make use of the haptic qualities of the hand.

Could the given examples suggest that tactile user interfaces might be superior to purely graphical user interfaces? Physical interfaces for intangible digital media have become a research area in recent years that has been looked at in different ways. Further approaches in the field of tangible computing can be found in research work with RFID-based interactions (e.g. Sneve Martinussen, Knutsen, and Arnall 2007, Sneve Martinussen and Arnall 2009), table-based interfaces (e.g. Ullmer and Ishii 1997, Magerkurth and Stenzel 2003, Microsoft 2012), and token-based interactions (e.g. Ullmer, Ishii, and Jacob 2004). This research shows an opposite trend to virtualisation, in which the real world is enriched and expanded.

The following sections illustrate the idea of tangible user interfaces as a way for dealing with the digital world in view of real-world activities of mobile individuals such as field operators. The idea will be briefly explained and examples presented.

3.5.1 The idea of tangible bits: TUI vs. GUI

Tangible user interfaces (TUIs) are design approaches for interfaces that focus on physical interaction and tangibility. They attempt to close the gap between our everyday life world — or, more precisely, the interaction with objects of everyday life that includes all senses — and the digital world. Hiroshi Ishii and colleagues at the MIT Media Lab in the mid-1990s presented the first independent concepts for tangible user interfaces. The original designation was graspable user interfaces, which should emphasise the tangibility and manual manipulating of graphical information. The change to the term *tangible*, however, emphasises tangibility and feeling, thus multisensory interaction (Hornecker 2008). The key idea of TUI and thus, the main difference to GUI[9] is to give physical form to visual information and computation. Ishii explains that the tangible representation is tightly coupled with the computation inside the computer, but the tangible representation is physical, allowing users to directly grab and manipulate the digital information. This allows users to better control information and contributes in collaborative situations where people work simultaneously

[9] The graphical user interface, short GUI, represents its components such as windows, menus, or icons as intangible pixels on the computer screen. Remote controllers, like mouse or keyboard, control this information.

(Ishii 2007). Moreover, while our visual senses remain in a sea of digital data, our bodies are still located in the physical world. While aspects of the real world were primarily replaced through graphical and virtual worlds until the mid-1990s (think of the replacing of paper files through computer software and graphical interfaces or of virtual environment software that is used by players to create environments in a virtual space), researchers today are trying to integrate both worlds by using familiar human actions and gestures; the human being himself, however, is staying in his everyday world. The interaction with the real world and, consequently, the sensory experience has moved back into the centre of interest for the past several years. And with it, the concepts of the life world in phenomenology and of embodiment move back into the centre of design considerations (see also Chapter 2.1: Phenomena of human experiences — the concepts of life world in phenomenology and embodiment).

Tangible interaction seeks physical interaction and thus provides greater contextual and social richness. In the following, three examples of tangible interfaces will be illustrated.

3.5.2 Examples of tangible user interfaces

One of the first tangible interfaces was the metaDESK that was developed by Ullmer and Ishii at the MIT Media Lab in 1997. It is an interface platform in the form of a table that gives physical form to windows, icons, handles, menus, and controls. The system is driven by interaction with graspable physical objects — at that time the objects were called physical icons; now they are called tokens — which are used on the desk's surface. In addition, Ullmer and Ishii introduced the application Tangible Geospace to illustrate the system. The application is an interactive map of the MIT campus that allows for interaction with geographical space. Different models of MIT buildings made of transparent acrylic serve as tokens. By placing these models onto the desk, the two-dimensional map of MIT appears and repositions itself in such a way that the models will be located on the map on the corresponding buildings. Simultaneously, an arm-mounted small screen displays a 3D view of corresponding map sections (Ullmer and Ishii 1997, Hornecker 2008).

Microsoft PixelSense[10] is another table-based interface that has been developed by Microsoft and Samsung and was released in 2011. The 40-inch Samsung SUR40 display enables experiences with a 360° degree interface that can be used by several people to share digital information at the same time from all sides of the table. Thus, it encourages face-to-face collaboration and social interaction. The display responds to touch (by supporting more than 50 simultaneous inputs) and physical world objects that can be placed on the screen. Instead of cameras, the PixelSense technology integrates sensors in the individual pixels that register and interpret what is touching the screen. Primarily designed for commercial customers to use

[10] Microsoft PixelSense is formerly called Microsoft Surface. It was renamed after Microsoft announced the consumer tablet Microsoft Surface.

in public settings, PixelSense enables multiuser, multi-touch, and tangible experiences (Microsoft 2012). The product's limitation is that although physical (tagged) objects can trigger a digital response, these reactions cannot be manipulated directly by the objects.

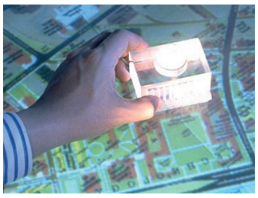


Figure 3-9a (left): Physical icon of the MIT's Great Dome used in the application Tangible Geospace (Ullmer and Ishii 1997). *Figure 3-9b (right):* Microsoft PixelSense. Users can interact with the surface by use of direct touch interactions and by placing objects on the screen (Photo: Microsoft).

Another interesting work presented by Ryokai, Marti, and Ishii in 2004 is the drawing tool I/O Brush (see Figure 3-10). The tool is aimed at helping children to explore colours, textures, and movements that can be found in everyday objects and materials. It has a small video camera with lights, bendable touch sensors, and optical fibres embedded inside the brush. When the brush touches a surface, the frames from the camera are captured and stored while the lights provide supplemental light for the camera. The optical fibres light up to indicate when the brush has picked up the special "ink" (in this case photons) from a chosen surface. For the canvas, the researchers used a large Wacom Cintiq screen at the time of the study. It has a built-in graphics tablet. To allow the system to identify the brush's presence on the canvas, the researchers embedded the coil of the Wacom pen tip inside the I/O brush's tip. On the canvas, children can draw with their special "ink" that they just picked up from their physical environment (Ryokai, Marti, and Ishii 2004).

Figure 3-10: The I/O Brush looks like a physical paintbrush, but it is augmented with technology (Ryokai, Marti, and Ishii 2004).

I consider this research work an excellent example of how physical information and digital information can complement each other. By picking up “ink” from the real world, children experience differences in textures, colours, and movements, which they are then allowed to arrange in an abstract and expressive way by support of digital technology. Moreover, children interact physically. They move a physical tool consisting of different materials and shapes over object surfaces that are located in their everyday life world, and they move it on the canvas. Arising from embodied practical action, the designed object and its meaning are sensually perceived. In other words, its gestalt, including content and function is aesthetically experienced (see also the discussion on cognitive processes in HCI in the second chapter).

Discussion: interaction is physical

Given the bodily interaction with real objects, the design should be more devoted to the potential of material things, both from a sensory perspective and based on their action potentials (Hornecker 2008). Importance lies in the movement of an object and the related possible actions. Linking device performance to human performance is necessary. Research has been carried out on this challenge in previous years. Apart from the examples given above, inspirations can be found especially in the game sector (e.g. games such as Nintendo Wii or Microsoft Kinect). However, the connection between devices and specific tasks is just as important.

The following sections will go into more detail about human motion and will describe the relationship between human performance and device performance, in particular in the context of execution of work on process plants.

3.6 Human-computer interaction and human motion

Most of us are familiar with it: to be able to read a message on a smartphone, one first has to dig the phone out of one’s pocket, unlock it, and start the corresponding application via touchscreen. This is quite inconvenient and annoying when we are pursuing another activity. If we use smartphones, we must thus interrupt our current activities. The main point of mobile devices, however, is the flexible usage on the move. Nevertheless, the fussiness of getting out the unit is not the only challenge. When current devices such as smartphones and tablets are used on the move, our limited vision must focus on both the interaction with the device and maintaining the perception of the surrounding environment. In particular, in the development of devices for work environments, where users move under difficult conditions and where they need their hands free for other activities, other sensory channels are of importance. This requires an understanding of the relationship among working individuals, their work environment, and their tasks, as well as the design of the technical means that are used. It is likely that many of the technologies used today are suitable for the private consumer market but not suitable for the industrial market since the context is much more comprehensive and several requirements must be met.

Mobile devices are used in different movement situations: seated or standing, walking (distances with and without obstacles), and sometimes running. Movement conditions can affect task completion times, error rates, and the user's degree of attention. Interacting with mobile devices under stationary conditions is similar to the use of a desktop computer, whereas non-stationary conditions increase the demands for attention significantly. This is due to the more complex context. Interaction with the device is not necessarily the primary user task. For example, on a heavily travelled road in the middle of the city, it must be the main task of the driver to concentrate on the road. The navigation of the integrated navigation system while driving becomes a secondary task. If it is a pure GUI, the driver's attention is demanded by several visual impressions, such as the interaction with the device and the act of driving, where both the equipment and the road environment must be captured visually.

3.6.1 Task performance and device operation

In the process industry, the dependencies between user task and device operation can be presented more clearly. Figures 3-11 and 3-12 show the complexity of human activity in a specific work context, with the human-machine interaction that must be subordinated to other tasks and adapted to the specific environmental factors. At the same time, the examples illustrate important aspects of the Embodied Mind Theory that is based on ideas of phenomenological philosophers such as Heidegger and Merleau-Ponty: namely that practical engagement is the core of human existence (see Chapter 2, section: Embodied practical action as the source of meaning, page 20). The human body is the bearer of a being that exists in the world. We perceive and act through our bodies and establish a relationship with our environment through practical activities (Øvergård, Bjørkli, and Hoff 2008). These activities (and thus our existence) are associated with the use of tools and technology. They gain their meaning through active use in a given context, which in turn includes all objects relevant in this context.

Figure 3-11: User tasks: In industrial process facilities, such as in the oil and gas industry, a typical activity of an operator often is to get from point A to point B. A primary task thus becomes to navigate through a network of pipes and valves, whereas the operation of a mobile device becomes a secondary task (Photographs: author).

Figure 3-12: Special environment factors: Usually equipped with protective clothing, tools, and technical safety devices, operators have to give attention to the requirements of their environment. Visual displays demand uninterrupted user attention; it is impossible to control the screen of a handheld device while attending to other activities. In addition, graphical information in terms of icons, symbols, and text becomes less visible as displays become smaller and are easily hidden by a touching finger, even more so when working gloves are worn. A pen, such as those used in some PDA devices, provides more precise input and more visual feedback, but it would occupy the second hand (Photographs: author).

The issue of how we act in our environment and how activity in it is coordinated is central in Distributed cognition and Activity theory, as was described in the second chapter. Following an important aspect of these approaches, maintenance work (activity) in plant operation would not only be intertwined with the use of mechanical tools and mobile devices, but also tools and devices should be understood as elements of the human cognitive system. They become integrated into the way operators control their activities and thus are part of the system of cognitive control. In line with Activity theory, these tools and devices — emerging from social and cultural development, which is determined by technological advances — mediate an object-oriented action. At the same time, they become functional extensions of the bodily action capabilities (ibid.). However, examples from special work environments, such as process plants, show current challenges in human activity systems.

3.6.2 Relationship between environmental conditions and task performance

One of the biggest challenges in complex user tasks where field operators of the oil- and gas industry are involved is the adaptation to environmental conditions on the process facilities. Given the complex infrastructure of such facilities and the weather conditions at the sea and on the coast, task performance becomes critical because the conditions affect feasibility, time effort, working comfort, and safety of an operation. Field operators are supposed to be flexible, both in terms of movement at the plant — by foot or with transportation devices — and in terms of performing tasks. In manual tasks, critical body postures and uncomfortable positions can be identified (see Figure 3-13).

Figure 3-13: Critical body postures: Field operators often perform actions that require different body postures. The photographs show the removal of CO_2-residues (to the left) and the controlling of valves (in the middle, to the right). In both cases, the involved operators are forced to take uncomfortable postures (Photographs: author).

In addition to using a tensed posture, operators must pay attention to the large amount of equipment carried in the field. Today, field operators are equipped with tools (primarily worn on a tool belt), technical safety devices (such as gas detectors), portable radios, headsets, push-to-talk adaptors (PTTs), measurement instruments, PDAs, mobile phones, and paper-based equipment (such as blueprints and work permits). Moreover, protective clothing must be worn. Due to the fact that process plants are huge facilities, operators must cover long distances. In addition, due to the ergonomic problems of wearing a large amount of equipment, challenges with the handling of the equipment arise. This includes the question of where to store a particular device when it is not in use (see Figure 3-14).

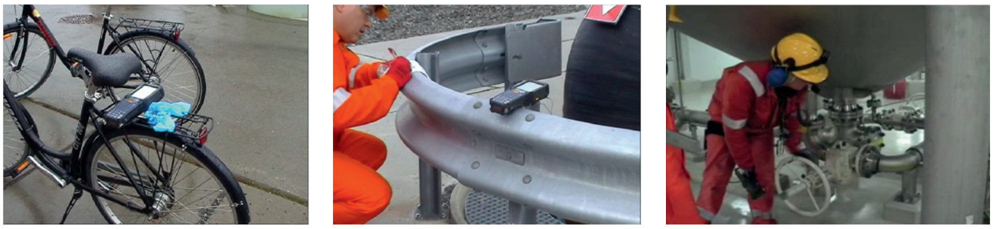


Figure 3-14: Where to store the device when it is not in use: The PDA used for collecting process data at Shell's process facility for Ormen Lange is too large be worn on the body. While operators execute other tasks, the PDA is placed on the rear rack of a bike (to the left), on a railing (in the middle), or kept in the hand (to the right) (Photographs: author).

For the design of mobile devices, this means that human-related factors, such as workplace factors (equipment, environment, etc.) and individual factors (ergonomic problems, stress, knowledge, expectations, etc.) have to be identified at the early design stages. In particular, ergonomic problems demand empirical data on human capabilities and environmental work conditions. In Chapter 6, I will report on empirical cases from two Norwegian onshore facilities and identify problems with respect to the above factors.

In terms of mobile devices, it is worth noting that today's computers already fit in the pocket, such as in the form of smartphones. Nevertheless, they still require the full attention of their users, both in the form of smartphones and tablets — the now customary forms. Wearable computing — technology which the user carries on his body — is currently an increasingly evolving category of devices. It expands the human body and connects it with electronic systems such as the smartphone. Due to the current Bluetooth standard, data transfer is more energy efficient, which allows for continuous connections between a smartphone and an external device. Thus, wearable computing no longer demands the full attention of the user and leads to more mobility. The following section shows a few examples.

3.6.3 Discussion: Does wearable computing support human interaction?

Wearable computing refers to small electronic devices that are worn on the body during use. The use of the device itself is not the primary action; instead, the device supports the action that is executed in the real world. Examples of wearable computing are headset computers, computer glasses, sport watches, and intelligent clothing with integrated electronics. However, probably the most famous wearables at present are activity trackers, smartwatches, and Google Glass (see Figure 3-15).

Figure 3-15: From left to right: activity tracker LG Lifeband Touch, smartwatch Samsung Galaxy Gear, and data glasses Google Glass.

The product examples are characterised by technical and fashionable features, which are increasingly appreciated in the private consumer market. In particular, activity trackers are among the most commonly used wearables (Schumacher 2013). Based on sensor technology that is integrated in smartphones, the device measures the steps of its bearers (possibly also the air pressure) and transmits the data via smartphone to the Internet. Smartwatches are also considered a trend, even though their operability is still difficult due to the display-size and the number of functions. Google Glass is the current product with the greatest potential for conflict, as its recording function can make Glass-users consider it to be a kind of mobile surveillance camera. Ethical behaviour is thus not secured, and the society still must respond with respect to this technology and must determine statutory rules. However, for many technology optimists it seems to be clear: wearable technologies will replace smartphones, just as smartphones and tablets have replaced desktop computers and notebooks. To operate a smartphone or tablet, the user needs two hands. Wearable technologies with their "always-on-displays" act as a "dashboard of the body" (Janssen 2014a) allowing for one-handed interaction and continuous monitoring of information.

However, a drawback of most miniature products is still their dependency on the smartphone. In order to build a mobile data connection to access online services, the devices need to be paired with a smartphone, which in turn must find a place, whether in the pocket or on the body. Another disadvantage of smartwatches is currently the low strength of the battery. Several companies are already working on solutions for both problems. For example, the sports watch manufacturer Timex has announced its first Smart Watch, which in contrast to other watches does not need a smartphone to allow a local Internet connection (Jurran 2014). In addition, manufacturers such as Samsung are integrating mobile radio chips into their newest watches and going for a better battery life.

In light of the special working conditions on industrial process plants, the current state of the art is of great importance. For example, Google wants to establish a stronger presence for its data glasses in the working world and to prove its benefits for areas such as service engineering, logistics, police, and the medical field with appropriate software (Janssen

2014b). According to experts, the technology of wearables is even supposed to have its first breakthrough in the world of work (ibid.). Previously, it was the opposite: new technology found faster acceptance in the consumer market than in the world of work, such as touchscreens. While mobile devices with touchscreens in private and public life have become indispensable, their use is not widespread in industrial contexts. In particular, the strict safety requirements in hazardous environments have an impact on the use of modern communication technology in outdoor areas. However, handheld devices such as PDAs, portable radios, mobile phones, and soon the first smartphones are already being applied in the oil and gas industry.

3.7 Ergonomics of handheld devices

Before going into the next chapter's theme, the state of mobile technology in the oil and gas industry, a few ergonomic considerations should be made in relation to handheld devices at this point. To do this, we must return to the hand and its property as a tactile tool.

Thanks to its anatomy, the hand has become an excellent gripping device in the history of evolution. Including the radius and ulna of the forearm, the hand consists of 29 individual bones that are connected by a ligament and tendon apparatus. This allows movement, but it also restricts movement (Wehr and Weinmann 2009: 62). Perhaps the most important aspect of the human hand is the powerful opposition of the thumb against the palm and fingertips. This anatomical development is called *opposition* and enables lateral and precision grips (ibid.: 63). Figure 3-16 shows different types of hand grips relevant for the handling of handheld devices.[11]

Figure 3-16: Hand grips from left to right: precision grip, grab grip, lateral grip, hook grip, and fist grip. Grab and fist grip are particularly important for the operation of handheld devices because the thumb in these positions is able to perform fine movements (Photographs: author).

[11] There are different names for the gripping types of the hand. The names used here are adapted from Wehr and Weinmann (2009).

Due to their anatomy, human hands are capable of operating and manipulating objects. On the other hand, more and more machines are replacing humans, both mentally and practically. While in the past human hands shaped the environment directly, since industrialisation, machines have taken over complex activities. Nowadays there are machines that manipulate objects. However, those machines require programming and control, both mental and practical. The hands, thus, indirectly manipulate objects. In this sense, the meaning of the human hand might have changed within our modern Industrial Age. Still, the hand is a tool of the mind.

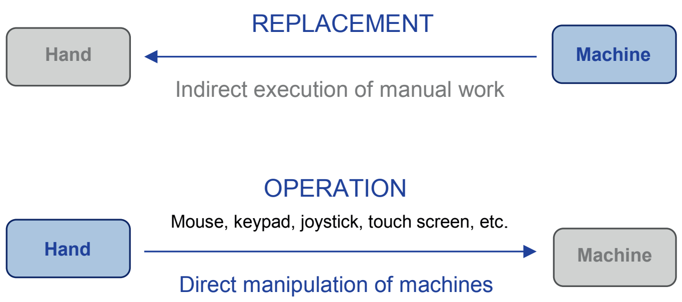


Figure 3-17: The hand has changed in meaning from an executive action organ to a control organ for machines. However, human cognitive processes are still involved because machines must be programmed and operated. The hand, thus, indirectly shapes its environment by direct manipulation of machines.

Handheld devices must meet several requirements to succeed in human-machine interaction. To begin with, the size of a handheld device must be small enough to enhance the mobility of its user and at the same time big enough to allow for comfortable and safe operation of the device. The relation between the dimension of a hand (small or large) and the operation of a device (positioning of the fingers on the object, hitting the right controls) must be taken into account. Limitations in use as well as critical situations emerging from extreme conditions of work such as harsh climate, work clothing, and stress, must be considered in product development in order to avoid incorrect handling of handheld devices. A user wearing gloves, for example, might send a signal or information accidentally while he is simply holding the device, or he might send the wrong signal while trying to operate a specific control key. Besides, in conditions where touch sense is constrained, users might tend to apply excessive force to hold objects, and thus they might have trouble positioning their fingers precisely on the object. Another challenge is "asymmetric handedness" — right-handedness and left-handedness. Even though most people perform better manual work by using their right hand, left-handed persons cannot be ignored.[12] Handheld devices therefore should allow use by left- and right-handed users, considering the thumb position in terms of an ergonomic operation.

Lack of space on small screens

In terms of requirements of the graphical interface of handheld devices, an important aspect is the lack of space on smaller screens. This leads to the need for a dynamic organisation of space and is one of the most difficult tasks of the design, since usually the amount of information that must be displayed on small screens is large. A brief look at the development of PDAs shows that developers quickly renounced conventional keyboards that were used in the first organisers (apart from a few function keys) in favour of a larger display. The British company Psion Plc. introduced what was probably the first PDA, Psion 1, in 1984. Emerging from programmable pocket calculators, this type of electronic organiser relied on the usability of a keyboard in a small device. However, soon the production was discontinued, and keyless PDAs that have been used with a stylus (and later by touch) were introduced on the market.

Figure 3-18: From left to right: Psion 1, 1984. The device allowed users to store contact information and a schedule and included a clock and calculator. Newton MessagePad100, 1993. Apple introduced the device. It was the first PDA with handwriting recognition. Palm Pilot, 1996. The device was economically more successful than Apple's product. Getac PS535F, 2009. The handheld device is a compact rugged PDA for industrial use that is based on the Windows Mobile platform.

The interaction with handheld devices comprises two main activities: entering information such as text or commands into the device and receiving the information presented on the screen. These input and output activities are impacted by any kind of motion. Although touchscreens became accepted long ago (especially in home systems), the challenges in terms of environment perception while moving still remain.[13] In particular, touchscreens are in use on PDAs, tablet computers, and smartphones and have largely displaced previously used styli.

[12] It is previously assumed that 10 to 15 percent left-handers in the general population (Zeh 2013).

[13] IBM Simon was the first smartphone that included computer functions and that introduced the touch screen. It was presented in 1993. Though many smartphones and PDAs had touch screens before Apple launched its iPhone in 2007; it was the original iPhone using a capacitive touch screen that changed the mobile device market.

Due to touch and gesture input options (for example, the Swype input method for smartphones), today's touchscreens allow for faster and more flexible interaction than former mobile devices. At the same time, touch input has constraints. It still relies on full visual attention.

Given the context of use of handheld devices in the current research case, we must not overlook the constraints of touch input on small screens. Especially in industrial settings, such as integrated operations in the petroleum industry, precise device interaction and errorless operation are critical. Thus, in the design process, designers and engineers must take into account both, graphical and three-dimensional product characteristics.

3.8 Discussion and conclusion

In reviewing relevant literature on current technologies, it becomes clear that we are facing a new era of mobile devices: body-worn technology, so-called wearables, has arrived in everyday life and will eventually replace mobile devices such as PDAs and smartphones. Computational miniaturisation will progress quickly. Soon, wearable technology will no longer be worn only on the body, but will be implemented within the body. For example, electronic contact lenses that show information directly in the field of view could make eye-catching data glasses unnecessary. In addition, dental implants could conduct sound vibrations through the bones to the inner ear (Google Glass employs bone conduction). Today, scientists are already talking about "body area networks", in which different wearable systems join and communicate directly (Schumacher 2013, Porteck 2014). Wearable technology, as is becoming apparent, will change our everyday life like smartphones and tablets did a few years ago. What this development will mean for everyday work remains to be seen. Scenarios for an easier workaday life, especially in the oil and gas processing industry are quite possible. With the photographs shown in Figs. 3-13 and 3-14 in mind, the issues with today's mobile equipment that is used in plant operation, become clear. Currently used devices are too large to be worn on the body, and thus they do not fit the way field operators perform actions. The mobile field operator, who is often forced to adopt unnatural postures, depending on the tasks, might benefit from smaller or more flexible solutions. The development and exploration of body-wearable interfaces such as data glasses or smartwatches could have positive effects for industrial applications.

However, research on future technologies for use in integrated operations in the petroleum industry should not fail to consider human factors. Modern information and communications technology (ICT) has its significance not only in the context of the special working conditions and complex work tasks in industrial process plants, but also against the theoretical background of human cognitive processes and the relationship of body and mind. The further development of handheld and wearable devices should aim to augment body and mind functions. It cannot be aimed at the replacement of human beings. For this reason, computer performance must be understood as computer assistance that is used meaningfully. Instead of continuing overemphasis on the virtual, certain actions and social interactions should remain in the real world. The acquisition of knowledge, and nothing else is action, requires a body, not an artificial body. Weizenbaum (1977: 276-277) provides an apt quote: “there are some things that people know not least because they have a human body. No organism who has not also a human body can know these things in the same way as humans do”. (translation of the author)

Our hands have a special role in the acquisition of knowledge, especially in man-machine interaction, in terms of the perception of tactile and kinaesthetic information. To be able to manipulate machines without error, visual, tactile, and kinaesthetic impressions are of importance for the experience of these machines. In particular, in the oil and gas industry, users of mobile equipment are in a situation where the purely visual recognition of information on small screens and the identification of buttons often are critical because of external work conditions. In a stressful environment like this, haptic object recognition can probably help to relieve operators from visual overload and stress. For this reason, tactile and kinaesthetic senses are important for the design and the layout of product details of mobile devices. Today, many small devices have touchscreens with complex graphical user interfaces that still demand the full visual attention of their users. On the other hand, relatively bulky equipment is currently used in industrial settings, which confronts users with both unnecessary functionality and non-ergonomic design.

A study of the literature has shown that a large body of research has been done on touchscreens and haptic-enabled touch interfaces. In recent years, actuators were produced that were capable of supporting tactile feedback in touchscreens ranging from small to large screens. Alternative technologies for haptic feedback in touchscreens, such as pneumatic actuation or pressure, have been explored and documented in several studies. However, most research work has given less attention to implications of user mobility on touchscreen interaction, particularly in industrial settings. The relationship between mobility and the effective use of ICT is crucial for the success of any mobile device. An important part of the problem is the context of use: the complex work environment that users of mobile equipment experience and the complexity of user tasks affect task performance and thus the effective use of the equipment. Current research in the field of TUI shows an opposite trend to virtualisation technology and demonstrates how to enrich the real world. By focussing on physical interaction in a real environment, TUI provides better contextual and social richness.

To summarise, touchscreens have become common in mobile devices and are currently applied in most industrial sectors. Exceptions are hazardous environments, such as those we find in the chemical process industry or in the oil industry. Here, there are special security requirements that only a few touch-based devices have met so far. The benefits of touchscreens are saving space on small devices, a dynamical simulation of controls such as buttons and switches, and a faster input rate based on a direct and high-level interaction. However, touchscreens themselves cannot supply sufficient tangible experiences and feedback. Moreover, the impact of motion on interactions with mobile computing devices used in industrial settings has not been sufficiently explored yet. Also, it seems that the complexity of the context of use for mobile devices in hazardous industrial areas has not yet been adequately covered. This includes a more comprehensive view of human factors. Despite adequate research on the subjects of collaboration in integrated operations on process facilities and modern technologies (including wireless solutions to support plant personnel), the perspective of the field operator has not yet been sufficiently reflected.

This provides the motivation for the first two research questions:

1. How does the product design of mobile devices affect efficiency and safety in Norwegian plants in the petroleum industry?
2. How do field and control room operators evaluate design and usability of mobile devices in support of field operation?

The next chapter will provide an overview of mobile technology used in the energy industry and will give examples from research studies on handheld devices that have been tested for gas processing plants and nuclear power plants.

4 ICT IN THE OIL AND GAS INDUSTRY

The purpose of this chapter is to present mobile technology used in the oil and gas industry and nuclear power industry. The chapter will give a brief overview of wireless devices and briefly address the requirements in hazardous areas. Moreover, it will report on research studies on handheld devices that have been tested for gas processing plants and nuclear power plants to support collaboration among operators. While several modern technologies have been successfully tested in recent years on nuclear power plants, only a few attempts have been made so far in the oil industry. This may be due to economic restrictions, in particular during the financial crisis, but security issues may also play a role. The operation of electrical equipment in hazardous areas must ensure security in terms of explosion prevention. This imposes special requirements on design and technology that only a few of the today's modern technologies meet. This chapter will draw on research work conducted by researchers from IBM and Statoil, the Institute for Energy Technology (IFE), and the Idaho National Laboratory (INL).

4.1 Interaction in Integrated Operations

Before addressing the issues of wireless solutions and mobile devices, the attention will again be briefly directed to integrated operations. As described in the introduction, IO means the integration of people, work processes, and information technology to support people in decision-making and work performance. In the oil and gas industry, IO is focussing on cooperation between the disciplines of reservoir management, drilling, production optimisation, operation and maintenance, logistics, and health, safety, and the environment (HSE). It further includes seamless cooperation between different parts of the organisation: offshore/onshore, oil company/supplier. Thus, IO goes far beyond communication between installations at sea and land bases. The primary objective is to enable new ways of working to achieve efficient and safe operations through the implementation of real-time data and innovative technology solutions and to make remote operation possible (Statoil 2013, IO Center n.d.). In terms of the people working in this sector, IO will result in the replacement of fixed teams by ad hoc teams with a frequent change of actors (Kaarstad et al. 2009). Thus, the traditional way of working will change:

- from serial to parallel
- from decision-making based on historical data to decision-making based on real-time data
- from the dependency of physical location to the independency of physical location
- from reactive to proactive work (ibid.)

In terms of instrumentation, IO means that new support tools, e.g. tools for data visualisation and communication, will be introduced and continuously advanced. Due to its advantage of mobility, wireless technology within so-called wireless-LAN networks has already become increasingly important in the process industry.

However, when human factors are ignored in the design development and adoption of wireless technology, users will experience problems. The largest challenge thus is not only the technology; the main challenge is how the actors are interacting. Collaboration and interaction in an IO context are discussed by Kaarstad et al. (2009). Focussing on communication processes in ad hoc teamwork (mediated by e.g. video technology), they point out that interaction in an IO setting may occur both across distances and face-to-face. For successful remote work, the authors explain, people need to have a common understanding and the willingness both to cooperate and to use technology that enhances cooperation. They need furthermore to cooperate in different time zones and must face the demands of cultural differences, different nationalities, and first languages, as well as different professional backgrounds. What applies to communication processes in ad hoc teams also applies to the work processes in the field. Interaction in the field cannot assume a common understanding of technologies used in the field, of spatial situations (e.g. infrastructure, spatial orientation on the plant facility), or of existing routines. Also, at the plant facility, operators have different cultural, national, and professional backgrounds. And often actors change due to different suppliers and contractors.[14] As Kaarstad et al. conclude, “Traditionally, collaboration has required the establishment of common ground or shared knowledge and understanding in the team prior to collaboration. Interaction must on the other hand involve the ongoing establishment of a common understanding during interaction, and requires a diversity of initial understandings and viewpoints”. In other words (and with reference to the theoretical approaches discussed in the last two chapters), shared understanding (and thus, meaning) is built during ongoing interactions. In IO, there are different interaction situations in which each individual contributes in different ways, based on his or her own position in the organisation, experiences, culture, attitude, feelings, and job satisfaction (ibid.). From a technology perspective, interactive devices must fit into the way operators interact, with all challenges that interaction in IO environments entails.

[14] Statoil for instance cooperates with different contractors. That means that many field operators are not employed at Statoil which in turn leads to situations where probably many first time operators work at the plant facility.

4.2 Wireless solutions

Among researchers in the field of process automation, there is general consensus on the benefit of wireless solutions for the oil and gas industry in terms of reducing installation, operating, and maintenance costs, faster installation and removal of the technology in remote and hostile areas, and mobile and temporary installations (Talevski, Carlsen, and Petersen 2009). Wireless solutions comprise wireless local-area networks (WLANs)[15], wireless sensor networks (WSNs)[16], wireless field instruments (e.g. pressure or temperature transmitters, flowmeters, vibration sensors), and mobile computing devices (e.g. PDAs, smartphones). Due to international standards such as the IEEE 802.11 standards[17] for WLANs and specifications of radio-frequency identification (RFID), applications such as asset tracking (e.g. warehouse logistics), monitoring, and control (e.g. mobile data logging of process information) have been enabled and have become increasingly common in the process industries in recent years. While the operating companies of hazardous installations were initially cautious because of the additional safety requirements for the design of wireless networks for wireless data transmission and for stationary and mobile devices, the demand for explosion-proof portable devices has risen sharply (Bartec 2013).

However, there are still challenges in applying wireless solutions in the oil and gas industry. Talevski, Carlsen, and Petersen (2009: 464) define the challenges as follows:

- the use of robust wireless devices and networks in remote and hostile environments
- the storage, structure, and retrieval of the tsunami of wireless sensor data
- the design of user interfaces for visualising, configuring, monitoring, and controlling wireless sensor networks and their outputs
- the use of middleware to seamlessly integrate devices, with existing process control and monitoring systems and operating systems and application convergence of technologies to deliver truly synchronised wireless voice, video, and data
- the provision of wireless network and device security

For remote operations, the use of sensor data through wireless sensor networks may enhance efficient operation and maintenance if the wireless technology is suited to oil and gas operations. At the same time, these processes aim to reduce the operational staff on hazardous production platforms. Ongoing research projects in the oil and gas industry even look into the development of completely unstaffed production platforms (ibid.: 468). However, the focus

[15] For transmission, WLAN uses the ISM band. ISM band stands for industrial, scientific and medical radio band. Other technologies using this frequency range are for example Bluetooth, WirelessHART, and ISA 100.11a.

[16] WSN refers to spatially distributed sensors for monitoring and recording physical conditions of an environment like temperature, sound, humidity, wind speed and direction, and pressure. It consists of a few hundreds to thousands of sensor nodes that include a radio transceiver along with an antenna, a microcontroller, an electronic circuit, and an energy source which is usually a battery (Janssen 2012-2014).

[17] IEEE stands for Institute of Electrical and Electronics Engineers.

here is on today's plant operators using mobile computing and handheld devices for plant operation.

Technical equipment for plant operators working in the oil and gas industry

Table 4-1 gives an overview of technical equipment available for the oil and gas sector. It is related to special tasks within plant operation and documents the product functions and the method of interaction (in terms of the device handling). As the focus of this thesis is on mobile equipment, the following overview is limited to portable or handheld devices.

Table 4-1: Overview of portable devices used in oil and gas plant operation. The overview includes Zone 1 and Zone 2-certified devices.

PRODUCT	FUNCTION	WAY OF INTERACTION
multi gas detector	gas measurement	two-handed
portable gas detector	detection and warning	one-handed
mobile computer for scanning barcodes and reading RFID tags	data gathering	one-handed, two-handed
portable TETRA[18] radio, headset, PTT[19]-adaptor	communication	one-handed, two-handed
mobile phone/handy	communication	one-handed
smartphone	combination of mobile phone, computer, and camera functionality	one-handed, two-handed
computer tablet	combination of computer and camera functionality	two-handed
digital camera	capturing images	two-handed

There are particular safety requirements for the application and use of mobile and stationary devices in oil- and gas plant operation. Because of the danger of ignition in hazardous areas,

[18] TETRA is an abbreviation of "Terrestrial Trunked Radio". It is a standard for digital emergency radio communication system. It is applied in different work domains, such as health care, fire service, police force, and industry.
[19] PTT is an abbreviation of "Push-To-Talk".

all equipment must comply with safety requirements and be labelled in accordance with ATEX[20] directives. The electrical equipment intended for use in Zone 1[21] is subjected to the ATEX RL 94/9/EG and must meet the requirements for category II 2G (Bartec 2013, Hauke and Schulz 2013).[22] Despite the state-of-the-art technology, the market for mobile devices for use in hazardous environments is still relatively small. So-called smart devices such as smartphones or computer tablets meeting the requirements for Zone 1 gradually appeared in the market. Figure 4-1 shows examples of ATEX Zone 1-certified mobile equipment.

Figure 4-1: Examples of ATEX Zone 1-certified mobile equipment used in oil and gas plant operation. From left to right: multi gas detector by Dräger, portable gas detector by Dräger, ATEX Handy 08 by ecom, ATEX Android Smartphone Innovation 2.0 by i.safe Mobile, ATEX Motorola Handheld Radio MTP850 Ex, ATEX Bartec MC 9090ex-K mobile computer.

As the examples show — particularly apparent in the examples of smartphone and mobile phone — the design of devices for use in hazardous areas differs from the design of their counterpart products that are used in everyday life. Due to the safety requirements, wireless equipment must be equipped with a flameproof encapsulation. Thus, a very thin design — as is typical in iPhone, Samsung Galaxy and Co — is rarely achieved. (I will discuss in more detail the design of explosion-protected devices in Chapter 6.) However, smart objects are

[20] ATEX is an abbreviation of "Atmosphères Explosibles ".
[21] The classification of zones depends on the frequency and duration of occurrence of explosive atmosphere (mixture of air and flammable substances such as gas, vapour or mist). In Zone 1, this explosive atmosphere can occasionally occur during normal operation. Zone 2 is the area where it normally not or only temporary occurs during normal operation (R. Stahl n.d.).
[22] Besides of hot surfaces, sparks, or flames, potential ignition sources can also be electromagnetic waves which are emitted by wireless devices. Therefore, they are subject to certain limit values which are described in DIN VDE 0848-5 / 2001 (Bartec 2013).

used in industrial contexts long ago. The following section addresses the idea of "smart devices" and their applications.

4.2.1 Examples of "smart" devices and their use

The Gabler Wirtschaftslexikon provides the following definition for "smart" devices: "IT-supported everyday objects that obtain additional benefit by sensor-based information processing and communication". (Springer Gabler n.d. Heading: Smart Devices, translation of the author) Today's language use in association with technology is not imaginable without the term "smart". We interact with smart objects, integrate automated and intelligent features in the new Smart House solution, or use networked information and communication technology for our future power system via the Smart Grid. In the oil industry, smart fields signify the installation of advanced technology to obtain detailed digital information on field conditions. Some terms are not clearly defined (e.g. Smart House); in literature, however, the term "smart" is often used.

To me, smart devices are characterised by supporting multiple tasks (e.g. phone, photography, gaming, playback of media, etc.).[23] They are usually equipped with information technologies (e.g. sensor technology) for identification, localisation, monitoring, and notification. Objects which are referred to as smart are thus capable of receiving information from their environment, processing and recording this information, and communicating with each other. Ergo, we live in a smart environment that is permeated by information technology. Today, digital technologies are embedded in the physical world. Through RFID tags, for example, information can be integrated into real objects, or through sensor systems, real-world properties, such as temperature, can be transformed into digital data. The physical and digital worlds are closely linked, which also has consequences for the design of space situations.

In the industry, the use of smart technologies has increased across many sectors over the past several years. Automatic identification, e.g. barcode and radio-frequency identification (RFID), is used for asset tracking in warehouses, food product markets, the automobile industry, the oil and gas industry, health care, etc., and WSNs have found their way into a wide variety of application domains (Petersen and Carlsen 2012). In addition, smart handheld devices such as computer tablets and smartphones have been applied in education, medical, healthcare services, and non-hazardous industries. In the energy sector, particularly the nuclear sector and the Norwegian petroleum sector, the introduction of smart devices is slow, however.

[23] In this work I use also the concept "smart", although it might be discussed against the background that the interaction capabilities of smart technologies are based on programed rules (and thus, they are predetermined). I like to consider smartphones, PDAs, and computer tablets machines, whereas the computer specialist writes their software programs in a smart and intelligent way.

The following two sections describe research studies and pilot projects on handheld devices that have been tested on gas-processing plants and nuclear power plants to support collaboration amongst operators. The focus of the description is on study goals and results; it is not on test situations and methods. Figure 4-2 illustrates when the individual projects were carried out, as well as the project initiators and the tested devices.

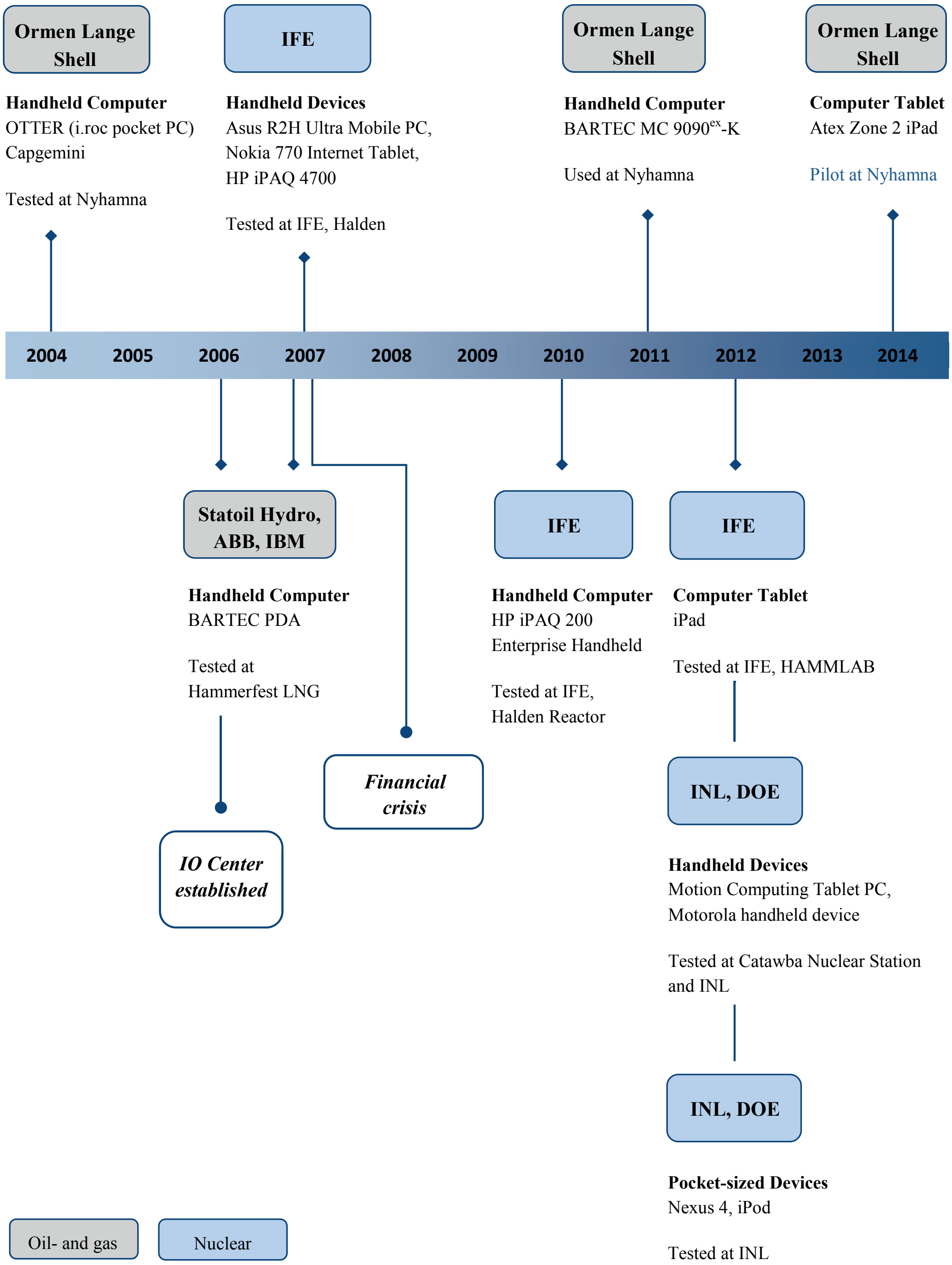


Figure 4-2: Timeline for the research projects on handheld devices conducted for the oil and gas industry and the nuclear power industry.

4.2.2 Research studies on handheld devices for gas processing plants

Wireless mobile solution for guiding operators through work processes on the plant

One of the first mobile solutions that was investigated at the processing facility for Ormen Lange at Nyhamna was the handheld computer Operational and Technical Tasks for Efficient Rounds (OTTER). It was developed by Capgemini in cooperation with Shell Global Solutions International in the context of Shell's Smart Field® program. The target groups are operators, maintenance technicians, and engineers in all parts of the process industry. The solution combines handheld computer technology with a software solution that allows for many tasks to be carried out by field operators on their rounds, such as monitoring equipment conditions, tuning of instruments, testing, and reporting to plant management (Capgemini 2004: 4). The application process is as follows: Tasks and task lists are downloaded from the OTTER database into a handheld computer. On the round, the device then guides the operator through the plant, presents tasks to him, and offers information on the spot. The information includes work instructions, previous observations, and task history. After completing the round, all information details, e.g. observations and measurements, are uploaded into the database for analysis and reporting (Capgemini 2004, 2006).

The benefits are summarised as follows:

- Tasks can be executed in a more effective and efficient way.
- Paperwork can be reduced through digital technology.
- The worker has control over which tasks were executed and with what results.
- Knowledge management is improved through keeping, developing, and implementing the worker's own and others' know-how.
- Information is instantly available to everyone in the business once it is in the database (speed).
- Communication is improved between different business units and between shifts.
- Operation costs are reduced (ibid.).

In the literature, little is documented about the disadvantages of the device. Although the developer stated that OTTER is a proven solution that is used in a number of Shell plants worldwide (ibid. 2004), Nyhamna has stopped the pilot. According to operators who were interviewed in 2011, the solution has not been introduced because of usability issues making users unable to execute their tasks in an improved way.

Wireless mobile solution for automatic testing of fire and gas detectors

At Hammerfest LNG, researchers from Statoil Hydro and IBM tested a handheld computer developed by BARTEC and were prepared to support fieldworkers in testing fire and gas detectors. The study was part of the TAIL IO project, which was initialised as a technology consortium project in January 2006 and jointly managed by Statoil Hydro and ABB (the consortium consisted of ABB, IBM, SKF, and Aker Solutions).[24] The project included a number of subprojects ranging from condition and performance monitoring, wireless communication, and mobile ICT infrastructure to robotics technology. Subproject F5 focussed on man-machine technology, work processes, and mobile ICT infrastructure that supports plant personnel. The result of the project is a handheld prototype for testing fire and gas detectors and simultaneously reducing manual work and dependencies between the control room and the field operator performing the tests. The solution is based on RFID technology that allows both for reading digital ID tags that are attached to all detectors and for asset tracking of containers. The application process is as follows: The PDA reads the ID on the barcode or RFID chips that are attached to the fire and gas detectors. The ID is then checked against the ERP system SAP,[25] which confirms whether the correct detector is identified. The operator then tests the detector and performs maintenance work. After the tests are completed, the results are reported back into the system using the handheld PDA (Vatland and Grimstad (eds.) 2007: 13-14).

The benefits are summarised as follows:

- reduced time for inspections by simplifying work processes and avoiding errors
- more efficient and secure operations by replacing manual work by automated procedures
- less paperwork, including less paper that must be carried in the field
- reducing interruptions by radio communication between field operators and control room operators
- direct communication with the Safety and Automation System (SAS) and connection to SAP
- improved information quality in SAP
- avoiding shutdown due to incorrect operations (ibid., Vatland 2007)

Also, in this case, little is documented about disadvantages and challenges of the handheld prototype. However, challenges might include human factors, such as acceptance of new technologies, and thus change concerns about personnel tracking, availability of WLAN at the facility, and issues of product design such as weight and dimension of the device, product and graphical interface, and functionality. According to informants at Hammerfest LNG, the pilot was completed, but the device has not been implemented.

Wireless mobile solutions for collecting process data and managing work permits

At the beginning of 2011, Nyhamna introduced a handheld computer device for use at the process facility. The device was developed by BARTEC to support field operators in collecting process data, such as data on temperature, pressure, and oil level, and to reduce

[24] The project period was set at three years.

[25] ERP stands for Enterprise Resources Planning. The term is used for software, such as SAP, that controls whole organizations. SAP provides specific solutions for different industries.

paper-based work. While in the past data have been used reactively, without controlling and analysing, the aim now is to use data in a proactive manner, for example in terms of monitoring trends. The device used is the mobile computer MC 9090ex-K for ATEX Zone 1 (shown in Figure 4-1). It is used for scanning barcodes attached to instruments and equipment in the plant. The application process is as follows: The tours are selected and transferred to the mobile device using PIML — a system for generating tours and their transfer to external devices. On the round, operators then start the device software PIML Mobile (used for collecting data), select the appropriate tour, scan the barcodes, and enter the data. If necessary, comments on individual tags can be entered. After completing the round, the data are transferred back from the mobile device to Shell's database PI using a desktop computer, and a report is printed out.[26]

The benefits are summarised as follows:

- more efficient plant controlling and collecting of process data by replacing paper-based checklists with mobile technology
- less expenditure of time and money
- control over inspections conducted after data transmission
- storing of data in Shell's database and access to it

A field study at Nyhamna (conducted in 2011) has shown that there are challenges and issues when it comes to the practical application of the handheld computer. These issues concern ergonomic aspects, GUI and functionality, scanning procedures, and in particular the impact of a demanding work environment on task execution. Chapter 6 provides detailed information on the design, functionality, and challenges of the mobile computer MC 9090ex.

Additionally, Nyhamna now focusses on a second wireless solution. Starting as a pilot project in 2014, the Ormen Lange facility (with support of Shell) has tested a computer tablet for managing work permits and has recently taken it in regular operation. The project delivers a solution to update SAP-based work permits via a wireless handheld device with real-time permit statuses. The tablet that was being used is an Atex Zone 2 iPad deployed for the initial pilot. (For the time being, computer tablets are available only for Zone 2.) The benefits include improving operational efficiency in terms of reducing plant radio traffic and risk of errors, improving operator capability to view and update permits, and improving handovers between operators compared to paper-based permits (Royal Dutch Shell 2013). As the project is in its early stages, there is little documentation on challenges or disadvantages of the tablet solution tested at Nyhamna. From a design perspective, problems could result from product interface issues, such as the lack of tactile qualities that has an impact on the operator-device interaction; from product size that has a direct impact on how to carry the device in the field; and from the complex graphical interface, which demands the full visual attention of users.

[26] PI stands for Process Information and PIML for PI Manual Logger.

4.2.3 Research studies on handheld devices for nuclear power plants

Handheld computing experiment to update process information

At IFE, several experiments on handheld computing devices have been conducted to study their usefulness for monitoring updated process information and visualising real-time process data in nuclear power plants. For instance, Kaarstad, Strand, and Nihlwing (2012) reported on a study performed with an iPad as a tool for monitoring process information for the shift supervisor in situations where he is located outside the control room. Additionally, the researchers wanted to identify potential users among the nuclear power plant personnel and determine concretely how the device can be used. Using online process information from the PWR reactor simulator[27] of the Halden Man Machine Laboratory (HAMMLAB), the researchers prepared the iPad so that access to continuously updated process information was provided from large-screen displays, alarm displays, and process display. The study results showed high usability ratings of the iPad and benefits for the plant staff.

The benefits for shift supervisors include:

- more efficient communication during turnover
- faster update after entering the control room
- better process overview and better overview of team member activities
- improved shared understanding within the crew
- less mental demand

The benefits for the control room crew include fewer interruptions, less communication, and a quicker achievement of process overview and shared understanding (Kaarstad, Strand, and Nihlwing 2012).

A few challenges have been outlined by the researchers. During interviews in which operators were supposed to give feedback on potential application areas of the iPad, it was mentioned that control room operators might feel monitored by the management if management staff at all levels will be a user group of the device. Another concern was that the process can be controlled by unlicensed nuclear power plant operators using the iPad. Therefore, it was stressed that it should only be used for monitoring activities.

Another study was conducted at IFE to test and evaluate the use of handheld mobile devices for visualising real-time process data as monitored on displays in the HAMMLAB and on the Halden Reactor's monitoring system. Using the Halden Reactor Project's own visualisation software, called ProcSee, and three different handheld devices, the researchers demonstrated the applicability of mobile technology. The products Asus R2H Ultra Mobile PC (Fig. 4-3a), Nokia 770 Internet Tablet (Fig. 4-3b), and Hewlett Packard iPAQ 4700 (Fig. 4-3c) were used

[27] PWR stands for pressurized water reactor.

during the testing. While the first product is capable of running the visualisation software on the device itself, the others run standard software on the device to view the displays and ProcSee on a server. In addition, the researchers implemented a soft-panel keyboard in the ProcSee-based application, as they experienced challenges with the built-in soft panel for this non-standard tool. The results of the study showed that the best performance was achieved with the Asus R2H running ProcSee. The researchers concluded that this device is too large and too heavy for operators to carry in their pocket, however. The dimensions of the Asus R2H are 23.4 x 13.3 x 2.8 cm, and the weight is 830 g, compared to 14 x 7.9 x 1.8 cm and 230 g (Nokia 770) and 13.1 x 7.7 x 1.5 cm and 186,7 g (Hewlett Packard iPAQ 4700). Hence, the researchers favoured the smaller device of Nokia (Jokstad and Rekvin 2007).

Figure 4-3a-c: 3a: Asus R2H Ultra Mobile PC. *3b:* Nokia 770 Internet Tablet. *3c:* Hewlett Packard iPAQ 4700.

The benefits are summarized as follows:

- reduction of potential misunderstandings in the communication between field operator and control room through personal viewing and controlling plant data
- instant access to updated plant data
- safer performance of field operations
- reduction of workload on control room operators by dropping the number of phone calls requesting data values (Jokstad and Rekvin 2007: 1)

Additional benefits of the soft-panel keyboard used in the ProcSee-based application:

- display of the keyboard on the screen anywhere possible
- reduction of occupied space when the keyboard is visible through a keyboard-configuration with inclusion of only the relevant keys (ibid.: 10)

Jokstad and Rekvin addressed one main issue in their report. In favour of a very good performance and acceptable ease-of-use, smaller devices have been preferred, as large and heavy products cannot be carried in the operator’s pocket. The limitation of the study might be that the researchers represent their opinion based on personal experience during the testing and on comments received from experts in HAMMLAB and the Halden reactor (ibid.: 12). Moreover, the study includes little testing on design-related issues, including gestalt-qualities and operator-device interaction. Because the researchers used customised displays from monitoring systems to fit the limited space on small screens, the study focus is less on design than on software technologies. Thus, further tests under realistic conditions of work are needed to be able to make conclusions on the suitability of the handheld devices tested in this research study.

In 2010, Jokstad reported on a further experiment aiming to assess "the effects of having access to real-time process plant data in your pocket" (Jokstad 2010: 1). Based on the positive response of the personnel at the Halden Reactor concerning the potential of handheld devices that were presented to them in 2007, the researchers at IFE conducted a test where a PDA handheld device was used for a pilot application at the Halden Reactor. The objective was to gain insight about the use of applications for handheld devices in a typical nuclear facility environment and to get ideas for improvements. The PDA being used for the testing was the HP iPAQ 200 Enterprise Handheld running the operation system Windows Mobile 6. (The PDA used the Microsoft Remote Desktop Client in order to connect to a remote server and to display the application interface while the pilot application itself was running on the server.) Its dimension was 12.6 x 7.6 x 1.6 cm, and its weight was 192 g. The pilot application presented user-configurable trend displays showing Halden Reactor process measurement values. Apart from slight modifications to fit the handheld device, no major changes were made compared to the workstation-based monitoring system. The PDA's soft keyboard and a stylus were used for the interaction. The study results in terms of user experiences showed that users generally rated the interaction capabilities rather poorly, that the use of a stylus was considered old-fashioned, and that the sensitivity and thus, the responsiveness of the touchscreen were unsatisfactory (brightness and contrast were perceived very well). In addition, instead of having the device in a pocket, some users would rather have a strap around the neck. However, the application was found to be highly relevant (Jokstad 2010: 4-5).

Similar studies have been carried out at the Idaho National Laboratory (INL), which is a representative for IFE's American partner DOE (U.S. Department of Energy) in the Halden project. Their results will be briefly described below.

Portable handheld devices for NPP[28] plant status control and fieldwork procedures

The DOE has been sponsoring a research and development programme, named Light Water Reactor Sustainability (LWRS) Program, which is aiming to extend the current operating licenses of American Light Water Reactors by adopting new technologies that improve reliability and support safety (Farris and Medema 2012, Oxstrand, Le Blanc, and Fikstad 2013). The programme comprises several milestones with which different research teams have been involved. For example, in 2012, an INL research team completed a project that demonstrated conceptual ideas to improve human performance and plant status control,

[28] NPP stands for Nuclear Power Plant.

reduce human error in routine fieldwork, and increase operational efficiency (Farris and Medema 2012). The research was conducted at Catawba Nuclear Station in Yourk, South Carolina, and at INL, and it focussed on the exploration of the potential use of portable handheld devices in the field. The technology selected was commercial off-the-shelf technology (hardware and software, along with software developed by INL): one tablet device by Motion Computing and one small handheld device by Motorola, as well as RealityVision software by Reality Mobile. It allowed for capturing rich data (e.g. video, voice, and annotated pictures), barcode scanning of component identification tags, and updating process information and task status in real-time. After running demonstration scenarios — involving research participants, plant operators, maintenance technicians as well as leaders and change agents from the commercial nuclear industry — the research team gained valuable feedback on their conceptual ideas and new tools.

The benefits are summarised as follows:

- portability
- precise following of operating and maintenance procedures
- advanced communication capabilities
- access to necessary information
- component verification by barcode use
- instant access to real-time or near-real-time plant data, along with rich data such as photos and video
- improved human performance, operating experiences, and decision-making
- reduction of mental workload and thus, more focus on task vs. focus on tools
- improved fieldwork efficiency
- improved plant status control

The INL research team also documented suggestions for improvement. Study participants addressed, for example, issues concerning the technology applicability to site conditions and user demands. Against the background of the objective of the present thesis, the following issues are of particular interest:

- The design of handheld devices must meet the demands of fieldworkers climbing ladders, which means it must be designed to be hands free, rugged, and sized accordingly.
- It is critical that the device features all equipment to carry out tasks in one device, e.g. tablet, camera, electric torch, and barcode scanner in one piece of equipment.
- Due to the fact that using touchscreen technology with gloves is difficult, gloves with conductive fingertips were suggested.[29]

[29] Latest screen technologies even allow for interaction with holders of usual work gloves. For example, Bartec Pixavi's smartphone Impact X provides a touch screen that can be used with work gloves.

- And finally, the idea of customising the technology to accommodate different levels of professional competencies, visual differences due to age, and personal preferences in viewing options is valuable (ibid.: 18-19).

Another long-term research project, which is a part of the LWRS Program, has been focussed on a computer-based procedure prototype for fieldworkers (Oxstrand and Le Blanc 2012, Oxstrand, Le Blanc, and Hays 2012, Oxstrand, Le Blanc, and Fikstad 2013, Oxstrand, Le Blanc, and Bly 2013). Aiming at the replacement of paper-based procedures, this project was conducted to develop guidance that helps the nuclear industry in its discussions with potential vendors of computer-based procedure technologies. The focus was on GUI design and on providing structure and content of procedures as they are transferred from paper-based documents to digital data. To provide guidance, INL researchers conducted an iterative process where current procedure usage in the nuclear industry was characterised and a prototype was developed, which was repeatedly evaluated and re-designed. The versions of the prototype have been developed for iOS and Android systems and were optimised for field operators. Considering the demands of operators who need to climb ladders, move through tight spaces, and have their hands free, the research team used an iPod and Nexus 4 to present the procedures — devices that are small enough to fit in the operator's pocket. However, the concepts demonstrated by the researchers are intended to be platform independent, which allows for alternatives for computer-based procedure systems. In terms of the presentation of the procedure, the prototype device provides guidance to the operator in the sense that only relevant parts of the procedure are displayed; that is, only steps relevant to the operator for the specific task and the current state of the equipment are presented. Thus, the operator will be guided through the correct path in the procedure based on the information given during the pre-job briefing.[30] In terms of conditions that are not determinable in the pre-job briefing (e.g. reading of a tank level), the prototype device will update the path through the procedure based on the entered value (Oxstrand, Le Blanc, and Bly 2013: 5-6). The researchers emphasise that, because of the dynamic nature of the technology, an ongoing procedure can easily be adapted, which is one of the main benefits, compared to paper-based procedures that include multiple procedure documents. The results of the evaluation studies also indicated that the human-system interface for the device prototype is intuitive and usable. Operators were able to perform and complete procedural tasks by means of the prototype with minimal training. In the second evaluation study, it was found that the computer-based procedure supported work performance better than the paper-based procedure for the same task. The researchers concluded, however, that handheld technology might create problems that do not exist with paper-based procedure documents if the GUI is designed poorly. Thus, the understanding of how technology changes work processes is a prerequisite for achieving the technology

[30] A pre-job briefing (PJB) is a work meeting between those who are involved in the work to ensure that those involved have a clear overview of tasks to be performed, know about their roles and responsibilities, about critical stages in the process, potential errors and their consequences, and about strategies in case of deviations from the plan.

advantages. This includes that design concepts for handheld devices are tested in realistic settings (ibid: 1, 38).

4.3 Discussion and conclusion

In general, modern wireless handheld technology benefits the optimising of processes. On the one hand, it automates processes and thus helps to minimise human intervention, reduce costs, and increase process velocity. On the other hand, it increases quality and service by eliminating errors that can arise through a lack of control, information overload in the workplace, or manual work performance.[31] In reviewing current information communication technology used in the oil and gas industry, and in presenting research studies on handheld technologies that have been tested for gas and nuclear power plants, it becomes evident that in the last decade, the use of wireless technology in the process industry has increased. Their big advantage over wired technology is beyond fewer technical and financial resources, mobility. However, in the energy sector, paper-based methods for task performance still seem to be common. In the nuclear field, it is mainly related to pre-job briefing procedures and work orders. In the oil and gas sector, it is related to work permits and working drawings.[32] There seems to be a gap between research on technology solutions and its practical use in this field. Several research efforts have attempted to address this gap by testing handheld devices for plant operation. The studies described in this chapter have shown similar benefits of the use of handheld devices in the field. The main implications of these studies for the special case of the present work are:

- Current work procedures performed by field operators need to be studied and characterised.
- Consideration needs to be given to the way in which the operators interact, rather than to just see the challenges in technology.
- The collaboration process between stakeholders has changed through the introduction of IO. For teamwork, this means that individual team members may enter and leave the team more frequently. This has consequences for the interaction in terms of both interpersonal interaction and human-device interaction. In view of the human-device interaction, attention must particularly be drawn to first-time users.
- User feedback on design concepts needs to be obtained during all design stages.

[31] What should be also mentioned, however, is that the increasing mechanisation and automation of work processes will change the future job market. Firstly, the areas of activity will change from manual actions towards controlling and logistical actions. On the other hand, jobs and professions will increasingly being removed, which will lead to increased unemployment.

[32] As reported in Section 4.2.2, in fall 2014, Nyhamna has taken a wireless handheld solution for managing work permits in regular operation. Nyhamna and Shell are thus pioneering in the improvement of traditional paper-based procedures.

The strength of the research projects that were presented in this chapter is the participatory design approach focussing on the end user rather than merely applying the newest technology. Improvements in human performance and plant status control can only be achieved by using iterative design and evaluation processes, detailed process mapping in order to better understand current work processes, and a focus on real-world challenges. However, in terms of design, the main consideration in the studies described above, has been given to the GUI part of handheld devices or to software technologies. Even if the aspect of operator mobility has been taken into account (e.g. climbing ladders), the concepts have mainly been applied to off-the-shelf technology with little focus on product interface qualities.

Designing future mobile devices, of course, depends upon the user task: operators required to control real-time process data (e.g. dynamic trends of process variables) will depend on devices with an optimal screen in terms of screen technology, dimension, and the GUI. The focus here is on visualising process data. However, operators required to scan barcodes and enter measured values, along with other maintenance tasks will depend on an optimal graphical user interface *and* an optimal product interface. In the light of the research questions asked in this thesis, the aspects of mobility and flexibility in work performance are of particular importance. In the following chapters, we will see that field operators who work in the oil and gas field are challenged by restrictions in everyday work. Hence, the development of interactive mobile devices must address issues of the overall device interface, including graphical and tangible issues. As Oxstrand, Le Blanc, and Bly concluded: maintain focus on the task. To keep the operator focussed on the task at all times, operator interaction with the device (and thus, the focus on the device itself) should be kept to a minimum to ensure that tasks can be successfully executed. The researchers suggest examples such as simple navigations schemes requiring a small number of actions to execute a task step, and easy access to information needed (Oxstrand, Le Blanc, and Bly 2013: 6).

I would argue that a minimal focus on the device itself is accomplished, if the device can be experienced not only visually, but also kinaesthetic, acoustically, and in a tactile manner. This provides the motivation for the third research question:

3. How should mobile devices be designed to meet efficiency and safety requirements?

As pointed out in the second and third chapters, challenges of ICT cannot be addressed only through designing high-functional devices and expansion of networks, but need to include the intended users in the first line. The chapters thus have provided the theoretical knowledge necessary to understand the methods relevant for research on work performance at Norwegian onshore facilities, operator interaction, and usability evaluations of mobile equipment in the field. In the next chapter, I will present the methods that have been used in the case studies of this thesis.

5 RESEARCH METHODOLOGIES RELEVANT FOR THE PRESENT STUDY

In Chapters 2, 3, and 4, the necessary theoretical background for understanding the complexity of the design task of human-computer interaction was presented, the basics for the appropriate research methods for the current case were covered, and the motivation for the initial research questions of this thesis presented. The aim of this chapter is to present and discuss the applied research methods. The case comprises the study of interactions and workflows on Norwegian onshore facilities as well as the evaluation of handheld devices carried in the field. Against the background of the theoretical concepts and conceptual frameworks and in view of the current state of the art, this chapter introduces the following methods: 1) qualitative interview, 2) participant observation in fieldwork, and 3) video in qualitative research. In addition, it identifies Activity theory as an inspiration for data analysis and leads us back to the literature reviewed in Chapter 2. Before going into the research methods, Figure 5-1 presents an overview of the methods used for data collection.

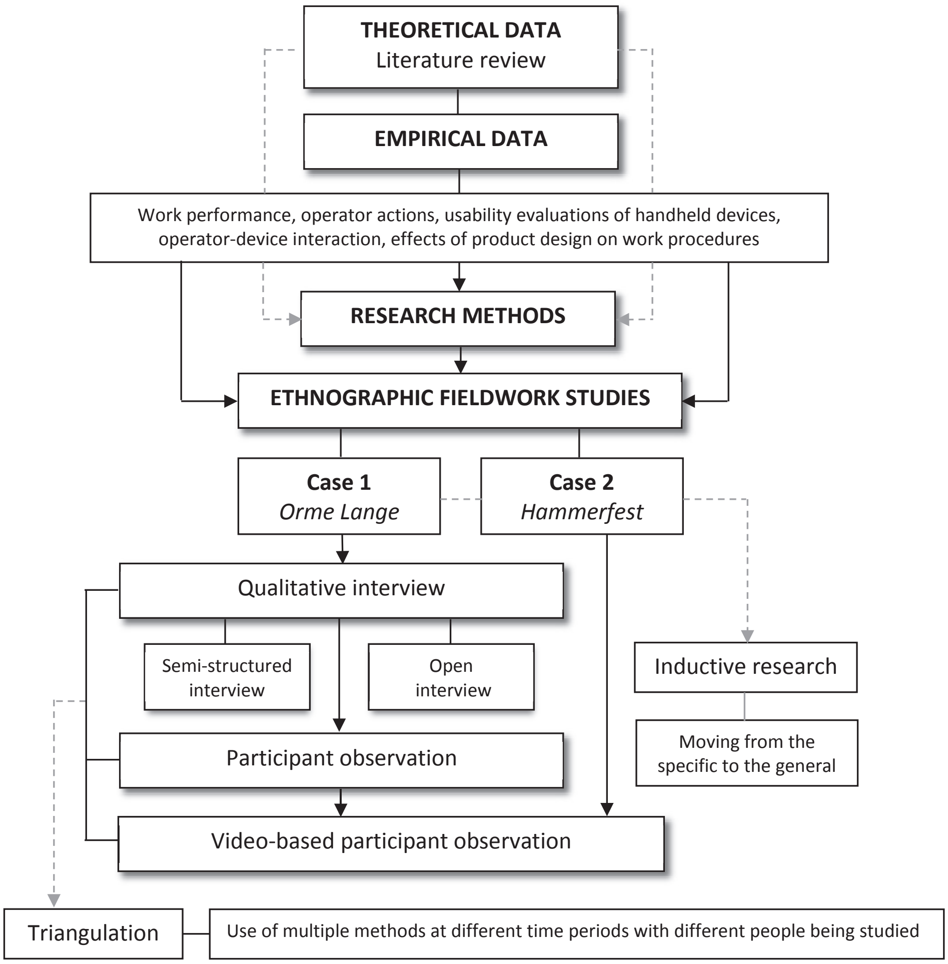


Figure 5-1: Overview of the research methods used in this thesis.

5.1 Data gathering — an ethnographic approach

Using an ethnographic approach involves going into the field — in traditional ethnography, this means going and staying there for a period of months, if not years. This is unrealistic for many real-world studies, as also claimed by Robson (2002), and in particular for ethnographic studies at oil and gas processing plants. Hence, this research used an ethnographic approach rather than a full-size ethnography. It includes participant observation that is according to Robson very closely associated with the process of an ethnographic study as well as ethnographic interview techniques.

In 2009, Heyer and colleagues conducted ethnographic fieldwork on the same subject: the oil and gas workplace. Participant observation and informal interviews were used to introduce this particular workplace and its work practices. The studied site was a refinery situated in a remote area of Norway, and similar to the two onshore facilities studied in the present research work, it is separated into the administration and plant area. The focus was on the shift team who worked in and across the industrial environment and the control room. Unlike the present work, the aim of the study was, however, to provide a descriptive account of the context, not to provide practical implications for design (Heyer 2009).

Fieldwork, as in the case reported in this chapter, is an approach to the collection of data that involves going to the site where handheld devices are used in order to study the circumstances of activity and task execution that the devices are designed to support. Driven by the assumption that the product design of handheld devices has impact on their user acceptance and hence on work procedures at process plants, ethnographic fieldwork including traditional methods of ethnographic research have been used to understand processes, activities, and interactions and to study the devices in the real context of use. Data collection has been prolonged over time and had three phases. As stated by Robson (2002: 188), it is common to focus on behaviours or events that occur frequently to be able to develop understanding of their significance.

For this research work, data triangulation was applied, which is the use of more than one method of data collection. The methods chosen were interviews, participant observation, and documentary video. The methods were used across multiple periods. According to Flick (2007: 89), triangulation can help to reveal different perspectives on one issue in research. In the present case, it can be knowledge about and practices with handheld devices used in hazardous areas. Thus, triangulation is a way to promote quality of qualitative research in ethnography (ibid.). Nevertheless, the nature of ethnography might introduce problems. In our case, the first problem was to get permission to study people working in a hazardous industrial setting. This was mainly due to safety concerns, administrational effort, and time. The second problem is that data collection in ethnographic fieldwork can pose ethical problems in terms of privacy protection of study participants. The following sections reflect on the individual methods used for data collection and discuss their reliability.

Ethnographic field methods

Traditional methods of ethnographic research, such as those applied in the present work, are still valid and as widely used as ever in scientific work. Participant observation is a qualitative method that has its roots in anthropological research. It is often associated with ethnographic studies in which the researchers through personal participation observe the practice of those whose activities are the subject to data collection. Ethnographic research differs in terms of different cognitive interests that will not be further discussed at this point (cf. Hitzler 2011: 48-51). All kinds of ethnography, however, have in common that researchers need to find the balance between “go into the field intensively” and “avoiding influence on the field”. This is what ethnographic research distinguishes from action research, in which active acting and modifying the field is central, and where researcher and researched are equal partners. The methods of data gathering in context of ethnographic fieldwork aim to collect and study materials (of all kinds) and to talk with interested parties (ibid.). Nowadays in field research, participant observation and interview techniques are often applied in parallel. Compared to most interview situations, where aspects of the reality are usually reconstructed, situated interviews as outlined by Sperschneider and Bagger (2003) are a promising way to gain empirical data of informants in their natural environment and in-situ. Additionally, film and video have been used in recent years to document research in social science and in particular in ethnographic field research.

The special importance of observational research to design arises from the fact that the research procedure is similar to the traditional design process. For the observation of the object of investigation, such as companies, users, procedures, problems, etc. is part of any analysis of a design project. Design is interested in the relationship between subject and object, which means how people communicate and interact in certain situations with products, systems, or services. Participant observation can provide a better understanding of people’s contexts, their intentions, and needs and can be more productive in terms of amount and quality of data, which serves as the basis for future design work, theories, and ideas.

Nevertheless, in the present case of field research in hazardous work environments, the traditional methods had their limits. This is especially true for participant observation and video-based studies. In the following, the strengths and weaknesses of the methodology are discussed in the light of the present research case. Before going into the method details, an overview is given of the activities conducted during fieldwork. The timeline shown in Figure 5-2 gives a chronological overview. Table 5-1 below gives an overview of the methods used, their purpose, the number of informants involved, the materials used during the activity, and the limitations of the respective methods.

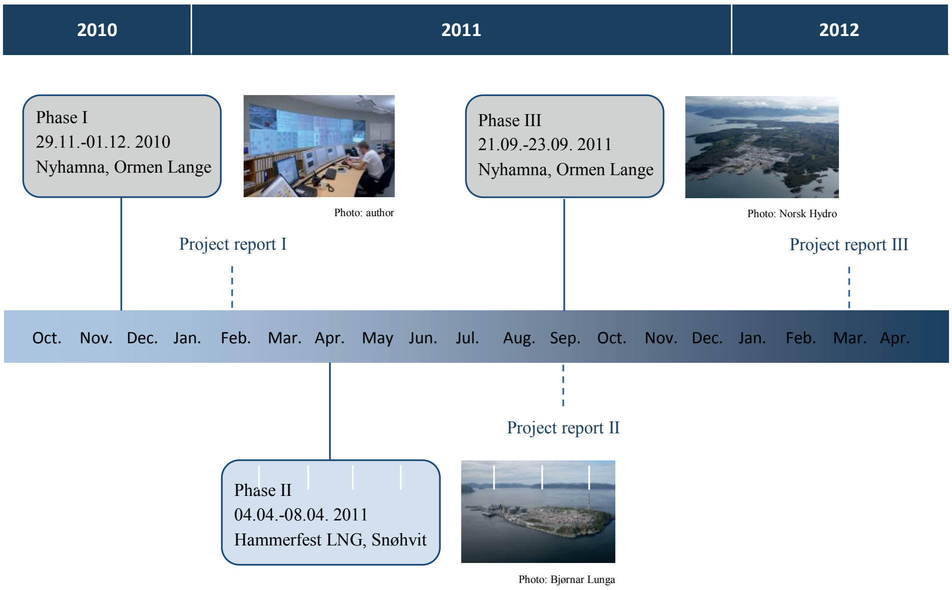


Figure 5-2: Timeline of research activities that includes three phases of fieldwork. The first phase was conducted in 2010 at the Ormen Lange processing plant located at Nyhamna, the second phase in 2011 at Hammerfest LNG processing plant located at Melkøya, and the third phase in 2011 again at Nyhamna.

Table 5-1 below shows the research activities conducted in three phases of fieldwork. The first phase includes interviews and observations of operators working at Ormen Lange processing plant. The second phase includes participant observation of operators working at Hammerfest LNG processing plant. The third phase includes interviews and video observations of IT engineers and operators working at Ormen Lange processing plant.

Table 5-1: Research activities conducted in three phases of fieldwork.

	Method	Participants	Purpose	Materials	Limitations
Phase I	semi-structured interview	five operators	usability evaluation of Motorola's MTP850 Ex-TETRA terminal	pictures of the product, list of interview questions, voice recorder, camera	a few interviewees, common interview situation (not in situ), limited interviewing skills
	participant observation	two operators	study of operator interaction and work performance	notepad	short-period observation, only one observer, no video camera
Phase II	video-based participant observation	three operators	study of operator interaction and work performance	video camera, notepad	ethical aspects of video observation, only one observer
Phase III	open interview/ collaborative forum	two IT engineers and one operator	usability evaluation of the handheld PDA MC 9090ex	interview guide, voice recorder, notepad	reconstructed reality
	video-based participant observation	four operators	study of operator-device interaction in the field	video camera, notepad	ethical aspects of video observation, only one observer

In the following sections, the methods used for data gathering on the Ormen Lange facility at Nyhamna and the Hammerfest LNG facility at Melkøya are discussed. First, the strengths and weaknesses of each method are described in detail. Finally, a tabulated overview of all methods and their corresponding strengths and weaknesses will be given.

5.1.1 Qualitative interview

The purpose of qualitative interviews is to gather descriptions of the life world of the interviewee with respect to interpretation of the meaning of the described phenomena (Kvale 1983: 174). The primary goal of interviewing engineers and operators working in the oil and gas industry was to get informed about their experiences with specific handheld devices used for plant operation and plant control and to learn about opportunities and challenges of operator-device interaction and current communication processes. While the semi-structured interviews conducted in the first phase of the fieldwork dispense with a verbatim interview transcript, the open interviews conducted in the third phase have been fully transcribed, documenting everything that is said in the recording. The following sections reflect on the strengths and weaknesses of the interview studies at Nyhamna and Melkøya.

Strengths of qualitative interviews

Kvale outlined 12 aspects concerning the mode of understanding in the qualitative interview (Kvale 1983: 174-179). I want to draw on five aspects which I consider to be most relevant for the case of this thesis and at the same time identify the method strengths.

1) The interview subject is centred on the interviewee's life world.

Work processes that are mediated by tools, information technology, and interpersonal communication determine the life world of field operators who work on oil and gas processing plants. During the field research, qualitative interviews (which are topic-oriented, not person-oriented) provided an understanding on key issues in task performance as it is experienced by operators. In the interview studies on Nyhamna and Melkøya, use and usability of handheld devices were central themes in the world of work of the operators, and the interviews focussed on these themes.

2) The qualitative interview seeks to describe and understand the meaning of central themes in the interviewee's life world.

Qualitative interviews describe facts as well as meanings. The interviewer is required to listen to the directly and indirectly expressed descriptions and meanings and is allowed to send implicit messages back to the interviewee or to ask follow-up questions. This way allows for obtaining details as well as confirmation or disconfirmation of interpretations of what interviewees said. I will give an example from the open interview about the handheld PDA MC 9090ex, conducted in the third phase of fieldwork, which gives an example of the importance of confirmation. During the interview, an IT engineer informed me about how the system is used and about the number of tags that have to be scanned on inspection rounds.

HJ: Det er to typer tagger, for å si det sånn. I hovedsak, det er de som vi kaller for digitale tagger som enten ... hvor du bare gjør en forhåpentligvis objektiv vurdering og sier at utstyr er enten ok eller ikke ok. Og så er det den typen hvor du da taster inn et tall, en verdi. Du leser jo et instrument (HJ viser et eksempel) ... hvor du da legger inn en overlast verdi. Og den tastes inn. Og en runde kan bestå fra 10 opp til over 80 tagger. Nå begynner vi å få litt erfaring og det vil skje at vi skal for det første redusere antall forskjellige turer og vi skal også prøve å få ned antall tagger innenfor hver tur. Det er alt for mange. Det er for mange både turer og tagger.

DB: En klarer nesten ikke alle tagger på en tur, eller?

HJ: Jo, det gjør man, men det kan fort bli litt uoversiktlig.

This quote shows that my interpretation of the engineer's explanation has been disproved considering the answer to my follow-up question on the meaning of what was being said. The problem was not that the inspection rounds cannot be completed in the time available (meaning) because of the high number of tags (fact); the problem was the complexity due to the number of tags in each round.

3) *The qualitative interview seeks to describe specific situations and action sequences in the interviewee's world.*

The purpose of the interviews with operators who use interactive devices to support their work activity in the plant was to obtain concrete descriptions of specific situations in operator-device interaction, how operators experienced them, and how they react, rather than general opinions on devices. In qualitative interviews, the interviewer may ask questions such as: *Can you describe an incident with the radio TETRA terminal where you could not achieve what you actually wanted to achieve?* By asking for stories on unexpected experiences in the use of the handheld radio, rather than only asking for general opinions on its use, qualitative interviews provide for a richer data set.

4) *The qualitative interview is focussed on certain themes of the life world of the interviewee.*

In both interview situations, the interviews were neither strictly structured with standardised or closed questions nor non-directive. During the first phase of fieldwork, a semi-structured interview technique was used to collect data about the MTP850 Ex TETRA terminal used at Nyhamna. After starting with a few standardised questions about the operator's residence, years of experience at the facility, and work task, open-ended questions were asked to keep the device and the operator's experiences in the interaction with the device in the focus of the interview. Here, a list of questions and themes was used to ensure that all themes were covered during the interviews with all operators, and the questions were largely asked in a similar order to make comparison between answers easier. The interview guide, however, allowed for probing of novel relevant information through follow-up or additional questions. The strength of the method is that the interview is directed towards certain themes, rather than towards certain opinions of interviewees about these themes.

5) *Qualitative interviews generate interpersonal situations.*

The qualitative interview is an interaction between people. As a form of communication that is jointly produced and conducted by the parties, the qualitative interview is in a manner similar to an everyday conversation. During the third phase of fieldwork, an open interview was conducted with two IT engineers and one operator who entered the room gradually. I was introduced in the functions of the handheld PDA MC 9090ex that is used for collection of process data at Nyhamna, before I got the opportunity to go out into the plant to study the device in use. By focussing on detailed descriptions of the professionals involved about their experiences with the device, due to the presentation of the system and the involvement of several persons in the conversation, the interview situation resembled a kind of collaborative forum. It was characterised by common curiosity on usability aspects of the device, challenges in procedures of use, and opportunities for improvement. Compared to standardised forms of interviews, a major strength of the qualitative interview is its interactive structure that allows for situated flexibility during the interview. In the course of the conversation, I was the interested listener, the committed conversationalist, and the curious consumers. That opened up paths of knowledge that were of importance, both in terms of empathy for the participating informants, as well as to own research interests. The method was the dialogue into which experiences and views of both sides fed. In this case, the mutual influence was, however, not a weakness but a strength of the qualitative interview.

Weaknesses of qualitative interviews

Despite of the strong points of qualitative interviews, there are also significant weaknesses. For example, interview results can be affected by the problem of interviewer bias, which can arise when the researcher is also the interviewer who expects the confirmation of his assumptions and hypotheses. In the case of semi-structured interviews about the TETRA terminal, which were carried out on Nyhamna during the first phase of field research, I noticed that the impression I gained from the first two interviews with operators, had an impact on later interviews. When asking later, I tried at the same time to address more intensely the problems of the terminal and thus I tended to ask biased questions.

Original questions: Have you ever experienced a situation in which the emergency button had to be operated? What do you think, how accessible is the button?

Biased questions: Have you also experienced a situation in which the emergency button was accidently used? Do you agree that the button can easily be misused?

The use of strict standardised questions might help to avoid interviewer bias. However, standardised questions also include weak points, as already discussed.

Another weakness of the qualitative interviews, as compared to participant observation, for example, is the loss of experience. In the interview, the prospects of the respondents can be grasped only in an approximate capacity. Because the most interview situations are characterised in that the object of the survey (which is being talked about) itself is not present during the interview. Hence, the reality needs to be reconstructed. Using the qualitative interview, it cannot therefore be clarified with certainty how exactly the real (original) situation was reflected.

In the particular interview case about the radio TETRA terminal, a further weakness might be the small number of conversations that were carried out. However, in qualitative interviews, a large number of performed interviews is not essential. It is more important to investigate some typical cases and to understand phenomena.

5.1.2 Participant observation in fieldwork

The understanding of participant observation appears to have changed in recent years. Where participant observation in those cases where qualitative data were collected was an independent method of qualitative research, it is now understood as a methodological approach within ethnography, according to Lüders (2011). It is one of several possible approaches, since ethnography has become accepted as a "general, method-plural, triangular research concept" (Lüders 2011: 151-152). Even with Robson (2002) we find that participant observation is a widely used method in qualitative designs, or as described by Robson, in "flexible designs", particularly if they follow an ethnographic approach. Drawing on the concepts of life world, embodiment, and Gestalt theory, the primary goal of the field studies in this research project was to understand work processes, tasks, and working conditions at two Norwegian gas processing plants and to identify routine practices of operators and associated problems. The further goal was to investigate how the design of handheld devices used in the oil and gas industry influences routine practices, communication between operators, and efficiency in work performances. The following sections reflect the strengths and weaknesses of participant observation on onshore facilities.

Strengths of participant observation

1) Operator activity

By participating in the practice of field operators and the personal experiencing of work situations, aspects of the operator's activity could be observed, which would not have been accessible through discussions or interviews alone or by studying documents about this work situations. Particularly in view of the extreme working conditions that have an impact on aspects of work performance in the plant, the method of participant observation contributed to a reliable data collection relevant to the research questions. It enabled studying ongoing work under realistic challenging conditions in critical environmental settings. During the observation of operators, I learned about challenges associated with the use of handheld technology in work contexts. The method of participant observation made it easier to look as close as possible at work procedures in the given work environment and thus to identify the reasons for the challenges that users have to face.

2) Interaction with the operators

Another advantage of participant observation was the opportunity for interaction with the operators during observation. The combination of observation and situated interview that is aimed at questions on in-situ activities provided a better understanding of how and why operators acted in this way. In some areas of onshore facilities, however, it was difficult to conduct situated interviews because of the high noise level. Additionally, I had to find the balance between when to ask questions and when not to interfere with work. Thus, questions were mainly asked on the way to different locations or in the plant offices. During the third phase of fieldwork at Nyhamna, operators were observed on their inspection round on the outside plant, and the bad weather conditions additionally had an impact on the number of questions asked during the observation.

3) Step into operator's role

Another opportunity for interaction was offered during the second phase of fieldwork where operators who performed maintenance work at Hammerfest LNG were observed. Inspired by a technique from user studies, "Apprenticeship – Teach me how" (Sperschneider, Bagger, and Buur 2006), I stepped temporary into the operator's role and underwent a special task when I tried to operate a lever. I experienced first-hand how hard it is to set a pump by hand.

Generally speaking, there seems to be no other method than in-situ observation to understand the nature of the operator's life world. Participation and observation were helpful in understanding the complexity of human interaction in the oil and gas industry.

Weaknesses of participant observation

1) Closeness and distance

Problems of participant observation generally refer to both the researcher and his role as an observer, and those who will be observed — in our case operators on gas processing plants. For the observer, the challenge raises how to get close to the field but to keep distance at the same time. Closeness is necessary for the appropriate data collection, and distance is needed to be able to actually observe within the field (Lüders 2011). Safety precautions are important at all gas facilities. The operators, to whom I had been entrusted, were responsible to ensure that nothing happens, and this fact determined in the end where in the plant I was allowed to observe.[33] However, the balance between closeness and distance also had to be found in terms of the observed subjects. The ethical issue involving trust, respect, and privacy protection must not be overlooked in fieldwork, even if it may mean certain limitations for data collection. The operators, who have been observed, may have felt my presence unpleasant, which in turn could have had an impact on their natural actions. Even though observing in daily life situations is an everyday act practised by all people — consciously or unconsciously — the feeling of being observed may have led operators to feel nervousness or tension, in particular at work. From the operator's perspective, the word observation might have had a more unpleasant meaning. Moreover, ordinary observation in everyday situations is often conducted without a specific purpose and reflection. Scientific observation is goal-oriented and a subject is consciously chosen. Therefore, the question must arise whether the operators felt impaired in their work activity.

2) Short period field studies

Secondly, another weakness of participant observation in applied research studies, such as in our case, is the relatively short period of data collection. In traditional ethnographic research,

[33] I completed a web-based safety course before entering the outside plant (HMS Adgang Shell / Shell HSE Access).

researchers would have spent several months in the field to collect data (which could also be a weakness). For applied research, this is not practical. Moreover, the strict safety precautions in oil and gas industry affect the duration of the research period on process plants. One could argue that this weakness has few consequences for the present work because the field research primarily focussed on the research questions. On the other hand, spending more time in the field could have resulted in richer data collection.

3) Only one observer
Thirdly, participant observation conducted by only one observer can be viewed as a further weakness. A research team consisting of two to three members can obtain much more detailed information in the field than a single researcher can. In our case, this in particular includes details (visible and hidden) on communication processes. Two researchers for example would have been able to collect data about the communication between an operator being outside in the field and an operator being in the control room, while they might have been observed at two different locations at the same time: at the plant and in control room. Thus, the way of interaction that is linked to a particular work task could have been documented in more detail.

5.1.3 Video in qualitative research

Documentary video is commonly used to support user research in interaction and user-centred design, and many researchers are familiar with this medium. In the participatory design tradition, which has its roots in Scandinavia, video has become a subject of study over the past few years. For the field research of this thesis, some proven approaches from video work have become valuable tools to support participant observation at Nyhamna and Hammerfest LNG. Video-based user study techniques have been discussed by Sperschneider, Bagger, and Buur (2006), Ylirisku and Buur (2007), and Buur, Binder, and Brandt (2000). Blauhut and Buur (2009) discussed the concept of styles in video studies. The following sections reflect on the strengths and weaknesses of video in qualitative research.

Strengths of video in qualitative research
By means of documentary video material from participant observations in field research, the reality or an extract from the life world of certain persons can be articulated, communicated, and reproduced. This is a key advantage over interviews. Compared to the observation with the eye alone, it is an advantage that the camera captures unfiltered information. Through the eyes, the world will already be filtered and information will be distinguished for relevance and irrelevance. The video camera can, however, capture the complexity of the observed actions unfiltered. The video method was therefore suitable for documenting the dependence of operators and handheld devices, the environmental dependency, and the relationship of operators to each other.

In view of the complexity of an industrial setting such as a gas processing plant, documentary video goes beyond a purely observational approach. Video studies can be performed in different ways and by means of appropriate techniques:

- *simulated use* where the observer may construct a task for the user to do or simulate a work situation
- *apprenticeship* in which the observer steps into the user's role and learns about work routines by doing it herself
- *acting out* where users carry out their work like in normal procedures
- *shadowing* where the observer follows the user in his daily routine (Sperschneider, Bagger, and Buur 2006).

I will give an example from Hammerfest LNG, where we tried out the technique of *simulated use*. In order to find out how far acoustic warning might be missed or ignored due to the extreme high noise level at the plant, operators simulated two very short alarm situations and demonstrated how portable gas detectors (carried in the field) and systems (integrated into control room panels) indicate alarm acoustically and visually. The alarm case has been made up but showed that acoustic warning cannot be ignored.

Another option offers video styles that can compensate for the difficult conditions of a critical industrial environment. Video studies can be carried out using different camera styles:

- *the surveying camera* that scans the space and provides an overview of the environment and people in it by following people at a respectful distance
- *the composing camera* that paints considerate, well-composed pictures of how people move and act in context, not mixing interviews with action
- *the engaging camera* that moves close to understand, sees other people's perspectives, and joins the conversations (Blauhut and Buur 2009).

The surveying camera | The composing camera | The engaging camera

Figure 5-3: Different camera styles have been used at Nyhamna during the observation of operators who performed their inspection round on the plant.

The three styles differed not only in how far the camera zoomed in or out during certain actions but in the composition of pictures and in how far the camera took action. The styles helped to establish the context between study purpose, applied camera technique, and the relation of the observer (and filmmaker) to the operators in front of the camera.

In terms of analysis work, video is also a valuable tool because it can have many roles in the design process: from studying users, to making sense and understanding phenomena, to giving users a voice, and finally in designing interactive user-centred artefacts. Lastly, designers are not forced to base their work on field notes and memories from observations. Videos can be repeatedly viewed and examined for the purposes of analysis.

Weaknesses of video in qualitative research

Despite the strengths of video in qualitative research, there are also some weaknesses, especially in light of field research on onshore facilities. To start with the requirements for communication equipment such as mobile phones, cameras, pagers, or radios, it is strictly prohibited to use such equipment inside the plant area, which is not EX-approved. Moreover, photography and/or filming with non-EX equipment with battery and/or flash are classified as "Class B ignition sources" as they can produce incendive sparks (Class B involves flammable gases or liquids).[34] My filming was approved by the corresponding area technicians, and I complied with the safety requirements in which I agreed not to use flash when taking pictures. (In administration buildings, there are usually no restrictions on the use of film and photo equipment.) Overall, the technical equipment was kept at a minimum, and video footage was captured with a simple Panasonic NV-GX7 camcorder.

Another limitation arises from the ethical question, as recording people requires adherence to ethical standards. This includes informing the potential informants about the research study and its purpose, obtaining permission for data collection, respect for the informant's privacy, and handing over the data to appropriate informants if requested. The potential influence by the presence of an observer has already been discussed in the context of participant observation in fieldwork (see Section 5.1.2). The presence of a video camera may influence situations and people being videotaped. What role does the camera play in building rapport with the studied operators? For the present field research, this question posed a challenge in terms of making decisions on which study technique to apply, whether recordings should be interrupted, and in terms of how to build rapport with the operators before and during the observation. Despite my efforts to observe and to record from a respectful distance, I had the impression that some operators felt uncomfortable when the camera was pointed at them for a long period, especially in quiet periods. Therefore, I turned the camera off from time to time, instead of letting it run continuously. This in turn had an impact on the analysis afterwards because it was no longer possible to create accurate timelines for individual operations.

[34] Statoil (n.d.). Facility specific HSE manual for Hammerfest LNG. Appendix to the GL1122 personal HSE manual, p. 15.

A further reason for not filming permanently at the plant is that studying operators who work at natural- gas-processing plants is quite a challenge. Gas-processing plants are large installations consisting of several plant areas that include a network of pipes, valves, and controls demanding attention from the people on the plant. Moreover, wearing protective clothing and carrying portable equipment such as radio terminal, remote PTT (Push to talk), and gas detector posed an additional challenge. When I entered the plant at Melkøya for the first time, I felt the need to become familiar with the location (including the noise around me) and to get used to wear protective clothing and equipment. In addition, I was overwhelmed by the amount of new information. Hence, I started to film the scene only after approx. one hour.

This leads me to video techniques and styles that have been described in the section on strengths of video in qualitative research. Despite the advantages of videotaping in critical industrial settings, such actions simultaneously reveal the technique's weakness. The dilemma is that documentary videos provide material *about* real life, but they *are* not real life (Aufderheide 2007). By making decisions about what kind of camera to use, what kind of video techniques and styles to choose, and how to tell stories, researchers (or filmmakers) give portraits of real life, where reality is technically and creatively constructed.

Finally, the method of video observation in the present research may have a weak point by the lack of a research team. As mentioned before, observation in field research — by means of a video camera or without — will probably result in a richer data collection and a more detailed data analysis if more than one researcher participates in the research study. I would conclude, however, that video media in qualitative research (even if time-consuming) reflects human activity.

The following table gives an overview of the methods discussed and their corresponding strengths and weaknesses.

Table 5-2: Overview of the strengths and weaknesses of the research methods used in field research on operator-device interaction in the petroleum industry.

	Strengths	Weaknesses
Qualitative Interview	• guided toward certain themes of the operator's life world • seeks for facts and meanings • seeks for specific situations, rather than general opinions • interactive structure that strengthens the interpersonal situation • allows probing and follow-up questions	• reconstruction of reality • data is mainly based upon interviewee statements about past experiences • interviewer bias • time-consuming transcription of taped material
Participant Observation in field work	• enables studying ongoing activities in situ • provides firsthand experience of action situations in the operator's life world • helps in understanding contextual factors • enables interaction with the observed operators	• ethical consideration • positioning in the field • short period of data collection compared to ethnographic research • best with a research team • time-consuming in organizing and realisation
Video in qualitative research	• videos goes beyond a purely observational approach • documents the complexity of operator-device interaction • records unfiltered information • video techniques and styles can compensate for constraints in the field • valuable for analysis work and design purposes	• ethical challenges • technical and creative influences on the meaning of what the material shows the viewers • best with a research team • time-consuming editing work

I will now turn the attention to analysing methods. Although the field studies of the present work are not considered as ethnographic fieldwork — in terms of a long-term participation in the community that is the subject of research — but were rather inspired by its principles, some of the ethnographic methodology's elements for data analysing are relevant to our case. Moreover, from a design perspective, the application of creative design techniques and tools seem to be a promising way to analyse data.

5.2 Data analysis

The method for analysing data in the context of ethnographic research includes verbal documentation of data, such as the transcription of interviews and recordings of natural dialogues, as well as non-verbal documentation by means of created films or videos, images or photos, graphic objects etc. It is advantageous, however, to also describe the non-verbal objectification of data verbally to allow a controllable and time-appropriate interpretation. In line with the literature reviewed in Chapter 2, two ways of analysing the interaction with handheld-devices used in the petroleum industry have been identified: 1) inductive category formation to get detailed insight into the operator's experience of task-specific device interaction and 2) qualitative observation and video analysis to understand the context and complexity of operator-device interaction. In the following sections, the methods for the data analysis are presented.

5.2.1 Interview analysis

The interview analysis of the evaluation of the TETRA terminal might be considered as relatively weak because it dispenses with an exact transcription of the conversations in terms of a social science context. Instead, it represents the audio recordings, arranged according to themes by numbering the answers of each interview according to the list of questions. The individual themes were then evaluated, summarized, and described in a project report. As an initial result of the interview study, the report outlines patterns derived from responses and defines key problems. However, in the analysis of this interview study, the focus was less on concrete language, but rather on content and thematic aspects. Therefore, the method of summarising content analysis for the understanding of task-specific device interaction can be sufficiently accurate.

The interview analysis of the evaluation of the handheld PDA began with the transcription of the conversation using the software tool Transana. Transana is a program designed to simplify the qualitative analysis of audio, video, and image data. It helps managing large data sets and provides useful functions for the transcription of interview data such as assigning keywords or applying notes. Additionally, the software tool includes features for arranging video clips. In our case, the tool was used to facilitate the analysis of audio data from the recorded open interview (collaborative forum) on the usability of the handheld PDA MC 9090ex. After the complete transcription of the conversation, the inductive category formation was used for the evaluation. The inductive category formation attempts to identify the evaluation aspects from the obtained material to gradually develop categories. To analyse the data, first a categorisation scheme was created (see Appendix E), which divides the problems identified into main and sub-categories, such as effects of the PDA application (effects on the user, effects on procedures, etc.). The categories have been numbered and have been added to the transcribed template, meaning that the corresponding numbers were assigned to the statements. (Figure 5.4 shows an extract. For the entire document; see Appendix D).

Samtale med Terje
• [**Mål** er at operatører går runder til å sjekke en del punkter og samle en del data på målinger **P 4.2**].
• [Regneark som bruket tidligere, list opp alt de skulle sjekket **P 4.2.1**].
• [Det som har vært tilfelle tidligere er at dem har gått runder, men det var ingen som har kikket og analysert data. Data bare havnet i en perm. Det som kanskje har skjedd av og til er hvis det noe har havarert, har man kanskje i ettertid gått inn og så kikket, dvs. man har brukt data reaktivt. **P 4.2.1**] [Ønsket nå er å være mer proaktivt, dvs. å samle inn data og kan bruke data til å gå inn i PI (Process Information, Shell`s standard system/database for lagring av prosessdata) for å ta ut historikken der **P 4.2**].
• [Hovedmålet som ble satt opp første gangen var å samle data på utstyr, manuelle måler, som brukes ute i anlegget til å måle for eksempel temperatur, trykk, en del manuelle målinger **P 4.2**].
• [En sideeffekt er at man har litte grann kontroll på at operatørene går runder (selv om det ikke er hovedhensikten). Papirarket kan fylles ut ved å sette seg ned på en plass, med en håndholdt enhet er man fysisk ut på plassen og gjør seg kjent i anlegget. **P 4.1**]
• [Hovedønsket er å samle data, få inn den verdien og kan bruke den proaktivt, følge med trender **P 4.2**].

Figure 5-4: Excerpt from the coded transcript of the main category “effects of use of the PDA [P 4]” and the sub-categories “effects on users [P 4.1]”, “effects on procedures [P 4.2]”, and “earlier procedures
[P 4.2.1]”.

The statements were then separated and grouped in appropriate order under their respective categories. The summary was reviewed and a tabular overview of relevant problems and their interpretation was generated (see Chapter 6). The overview includes the analysis of the interview and of video-based participant observation. Next, I will briefly describe the methods for the observation and video analysis.

5.2.2 Observation and video analysis

The point of video observation is to develop and present structures or features of investigated phenomena, which have been seen and heard. For social sciences, Marotzki and Schäfer discovered “that tools for film analysis in the context of qualitative research have not been developed”. (Marotzki and Schäfer, 2011: 66) The scientists refer to the current lack of visual analysis methods for film and video material. However, there are several techniques and tools available in the design field. For example, Sitorus, Donovan, and Jensen (2007) developed the “video wall” technique, which is a computer application that allows simultaneous viewing, moving and labelling of multiple video clips on the same screen. Buur and Søndergaard (2000) developed the “Video Card Game” that allows participants to group and regroup clips that are printed on a card and to identify differences and similarities of actions by clustering the clips.

In the present case, the analyses of qualitative observation and video material comprise field notes, transcription of audio data, and video editing inspired by the above-mentioned techniques. For documentation, visualisation tools of graphic design, such as design maps, images, and interactive infographics, are suggested. Additionally, descriptive methods such as case stories and tabular overviews are proposed.

For the transcription of audio data on the videotapes, the software tool Transana was used (see the description in Section 5.2.1). In addition, common video editing software was chosen. The focus in the videos was not on spoken language, but rather on understanding the context and any information on the complexity of physical activity and device interaction. Ulead VideoStudio 10 was used for editing the video material. Unlike Transana, Ulead VideoStudio provides typical tools for cutting, optimising, and presentation of film material. The features range from multiple overlay tracks to a variety of video filters and effects, as well as a montage of sound and images. Just like Transana, Ulead VideoStudio facilitates arranging and rearranging video data. The major difference is, however, that common video editing software does not provide corresponding tools for transcription and coding of video data. Figure 5-5 shows two screenshots of the different software interfaces.

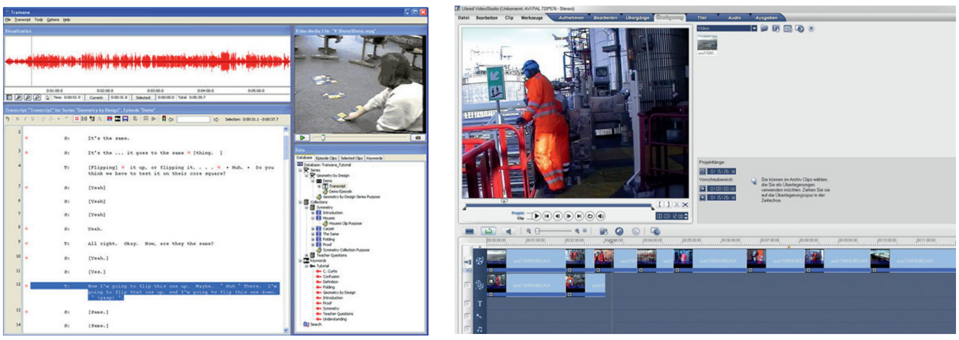


Figure 5-5: Left: Transana software interface showing the waveform diagram, transcript, video, and database windows (Woods n.d.). Right: Ulead VideoStudio 10 software interface showing video preview window, library, and project timeline window (Screenshot: author).

The video analysis began with cutting and arranging several films according to themes that arose from the observation. The data were then labelled in order to make sense of each clip and to integrate images such as maps. Additionally, several short clips were created to highlight phenomena of physical activities and device interaction. Seven films and eight small clips were created from the film stock recorded at Hammerfest LNG, and five films and eight small clips were created from the film stock recorded at Nyhamna. Later, the clips were arranged into two video collages, where each clip runs in a loop. This technique enables an accurate study and comparison of body postures during task performance and lets us look closely at operator-device interaction. Figure 5-6 presents a still image of a video collage from video footage captured at Nyhamna.

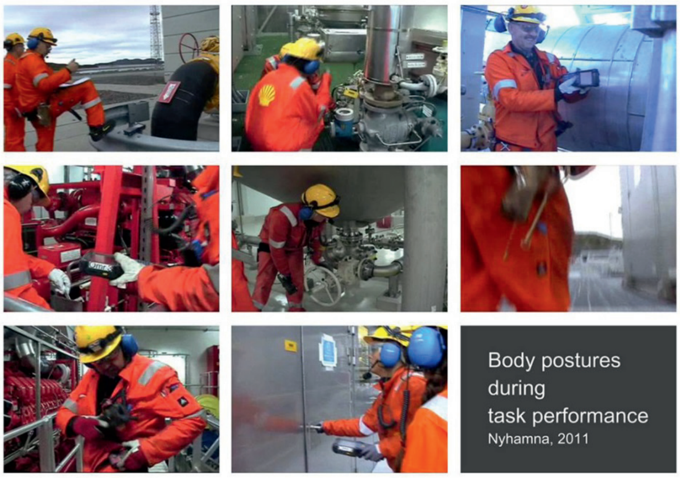


Figure 5-6: Video collage from video footage captured at Nyhamna. The collage consists of eight small clips of about seven to eight seconds running in a loop. The purpose of the collage is to show and study typical body postures during task performance. With this technique, the problems in handling the handheld PDA become more evident.

The edited video material was sent to all participants of the field studies to verify its correctness and, where appropriate, to respond to potential requests for rendering faces unrecognisable. After re-reviewing, the findings from the edited video material were incorporated into the documentation. The results of the case studies are documented in the next chapter.

Before presenting the cases in detail, the following sections will reflect the outcomes of the data analysis in view of design as research method and Activity theory as inspiring theoretical framework for the research analysis.

5.2.3 Design as research method — result visualisation

There are various ways to work with verbal and nonverbal research data as a design material. As section 5.2.2 has outlined, creative design techniques and tools such as those used for observation and video analysis may enable researchers to better visualise and communicate their research results. Against this background, design is not a traditional research method as those described in Section 5.1, but rather a method for analysing research data. Video artefacts (e.g. video collages), interactive infographics (e.g. video and citation enhanced graphics), and other forms of representations enable researchers to present and mediate their understanding of particular phenomena and to outline problems that have been identified. Figure 5-7 shows an example of an interactive infographic that encourages researchers to engage with the graphic by choosing and clicking on hyperlinks to get more information on specific situations. The hyperlinks point to video clips, larger images, and citations.

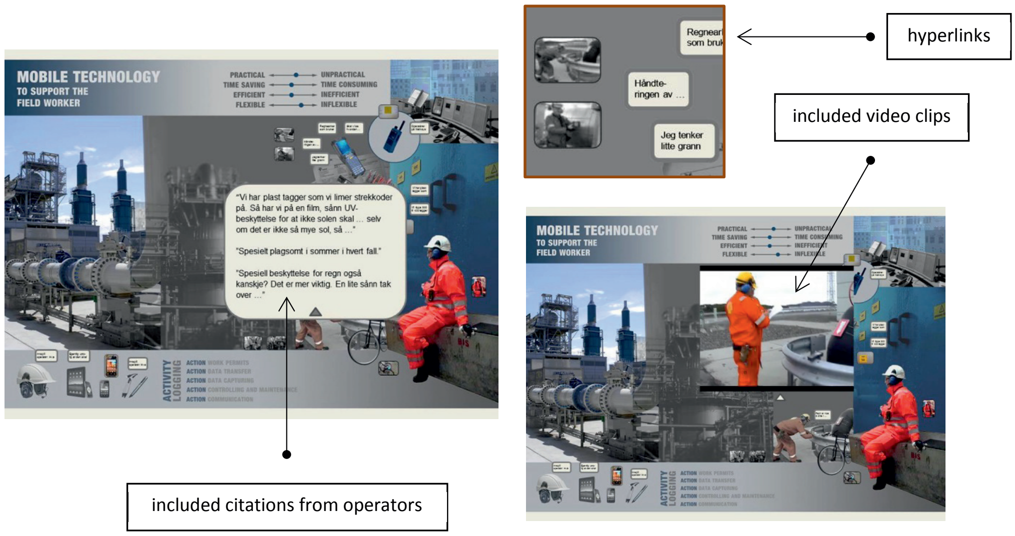


Figure 5-7: Example of an interactive infographic that includes citations and video clips to visualise parts of the data collection and outline problems observed in the field. This method allows researchers to put much information into one graphic without overloading the reader with information. Because of layers and sub-layers, not all information is presented at once.

Designing case stories as a method for contextualising observations of complex in situ activities can also be used for the analysis of research data. It is a way to involve researchers in comparing and contrasting details of the story and the problem presented in the research case. A good case story design should give researchers and readers the opportunity to be able to relate to the situation described. This includes the act and its background context, the agents who perform the act, the instruments used in performing the act, and the motives for the act. In the present work, designing a case story serves as a case-based resource for problem understanding (see Chapter 6). Additionally, the combination of video artefacts and case stories is suggested to support problem-solving.

On a three-dimensional design level, the approach of research through design takes a step forward from the stage of data analysings to the stage of problem-solving. Based on verbal and nonverbal material as discussed above, the design of initial product concepts mediated by mock-ups, prototypes etc. constitutes a research method for developing solutions for identified problems.

The present research must be limited to what is necessary for design as a creative way for data analysis and for outlining future scenarios.

5.2.4 Activity theory in HCI

There are many theories related to HCI, and many researchers have argued for certain theoretical approaches that are considered particularly relevant and useful for HCI. In the literature on cognitive processes, however, it became clear that there is no specific theory or theoretical framework for human-machine interaction. Different approaches in philosophy and cognitive science unfold on the other hand the entire complexity of human interaction. In view of the present research case, however, specifically Activity theory seems to be an inspiration regarding the implementation of field research and analysis of the research data, as it broaches the issue of the division of activity, action, and operation. (For more details on Activity theory; see Chapter 2.)

Due to the fact that Activity theory takes human activity as the unit of analysis — including a subject performing the activity, an object toward which the activity is directed, and a mediating artefact through which the activity is performed — it has been applied to a variety of research studies in HCI. For example, Bellamy (1996) used Activity theory to understand the relationship between technology and educational change. Engeström's work focussed on exploring innovative learning processes within and between work teams (1999). Kaptelinin and Nardi (2006) emphasised the application of Activity theory to the analysis and design of technology, and Badram and Doryab (2011) used Activity theory for analysing observations of medical work in hospitals. In view of video analysis, Activity theory has been applied by e.g. Bødker (1996) and Baumer and Tomlinson (2011). What their research studies have in common is that Activity theory was used as an approach to structure the analysis of video material in terms of the activity triangle developed by Engeström. The approach of Harris (2004) sought to complement this work by providing methods for the structural and functional analysis of video data that have their theoretical foundation in the framework of the systemic-structural theory of activity (SSAT).

For the present case, Leontiev's three-level concept of activity, which is the distinction between activity, action, and operation, is of particular interest. In elaborating on Vygotsky's theory, Leontiev has called attention to the distinction between individual action and collective activity. Whereas Vygotsky's initial model was in some way a simplified triangle model of mediated action (see Figure 2-9a in Chapter 2), Leontiev's concept distinguishes between collective activity that is driven by an object-oriented social motive and goal-oriented individual actions. In our case, the object-oriented social motive could be the profitable processing of LNG at Statoil's and Shell's natural gas processing. Goal-oriented individual actions are thus related to plant operations and are performed by plant operators. The tools and conditions for these actions determine the third level of operations.

Based on the data collection of the field research, Section 6.3 will report on the particular activity system of plant operators and illustrate the activity levels involved. It will further draw on Engeström's triangle model of an activity system (1999) as it is also found to be helpful for the research reported here.

5.3 Conclusion

Against the background of the theoretical concepts and frameworks that have been presented in Chapter 2 and in view of the studies and pilot projects on handheld devices described in Chapter 4, the research methods presented in this chapter have taken a User-Centred Design approach (UCD) by investigating challenges in current work procedures from the user's perspective. In order to understand the context of operator-device interaction, consideration needs to be given to the way of interaction and the environment in which operators interact, rather than to just analyse the challenges in currently used technologies. Moreover, the industrial work settings, and the oil and gas work setting in particular, are not yet sufficiently documented in the HCI literature. Therefore, for qualitative design research in the domain of oil and gas, traditional research methods are meaningful instruments to explore operator activity. In particular, the approach of video-based participant observation seems a promising way for capturing rich data in a challenging industrial setting. Participant observation can be even more effective when complemented with other methods. In the present research case, it has been shown that conducting interviews with experts before doing observation was a good way to get first insights into the domain, to learn about currently used systems and technologies, and to get a first impression of the operator's tasks. However, despite the undeniable advantage of being in the field, observing and recording how field operators act, it is important to find the balance between moving close to understanding and maintaining the required distance to show respect for the persons being observed. Building mutual trust and rapport with the informants requires a careful preparation of the fieldwork, including preliminary information on the study purpose, methodology of data collection, and the intended use of the data; it also requires a thoughtful execution of the study on-the-spot by showing empathy and respect for the informants and a responsible use of the collected information.

To summarise, traditional methods fit the purpose of the present research work as the focus is on operators and on context understanding. The field studies provide empirically valid findings. Their goal is to produce reports of experiences and to provide design criteria. In the data collection and analysis, priority is given to an ethnographic perspective. However, a comprehensive ethnographic fieldwork, as in traditional ethnography, is not intentioned here, but rather a general style that allows the investigation of the context and the descriptive and interpretative analysis of everyday work experiences and practices from the perspective of operators. In more detail, this chapter discussed the methods of field research and additionally suggests strategies for thematic data analysis that range from categorising information according to evaluation aspects found in interviews to strategies for editing video footage clearly and effectively. It also suggests the combination of nonverbal (e.g. video artefacts) and verbal (e.g. case stories) documentation of research results to support data analysings. Design as research method is a research approach that has been used for several years across the design disciplines. In our case, we draw on the experiences with video records as a tool for reflection and design as described by e.g. Suchman and Randall (1991) and Buur, Binder, and Brand (2000). We further draw on tools and methods used in the field of graphic design to generate graphic images of the obtained research data that can be easily interpreted. In this sense, knowledge will be developed through design.

On the theoretical side, we draw on Activity theory as an appropriate framework to inform the research analysis because it understands activity and action as being oriented by motives and goals, whereas operations are adapted to the conditions of the real world, which constantly change. Methods inspired by Activity theory are used here due to their opportunities for analysing different levels of operator-device interaction and their emphasis on users as actors.

This chapter introduced the research methods. Next, I will report on the empirical cases.

6 EMPIRICAL CASES FROM TWO NORWEGIAN ONSHORE FACILITIES

The purpose of this chapter is to present the results obtained from the field studies at the Nyhamna onshore facility and Hammerfest LNG at Melkøya. The studies were carried out in three phases in chronological order: Nyhamna I, Melkøya, and Nyhamna II. The chapter, however, initially reports about work performance and operator interaction at Hammerfest LNG to give general insight into the everyday work of operators. It will then describe the findings from the usability evaluations of handheld devices used at the Nyhamna facility and report on operator-device interaction. In doing so, this chapter addresses the questions of how the product design of mobile devices affects efficient and safe work procedures at Norwegian plants in the petroleum industry (research question 1) as well as how field and control room operators evaluate the design and usability of mobile devices in support of field operations (research question 2). Finally, I will look more closely at the activity system of field operators by drawing on key elements of Activity theory. Before going into the findings of the studies, Figure 6-1 gives an overview of the methods used for data analysis. They are based on the literature reviewed in previous chapters and on empirical data.

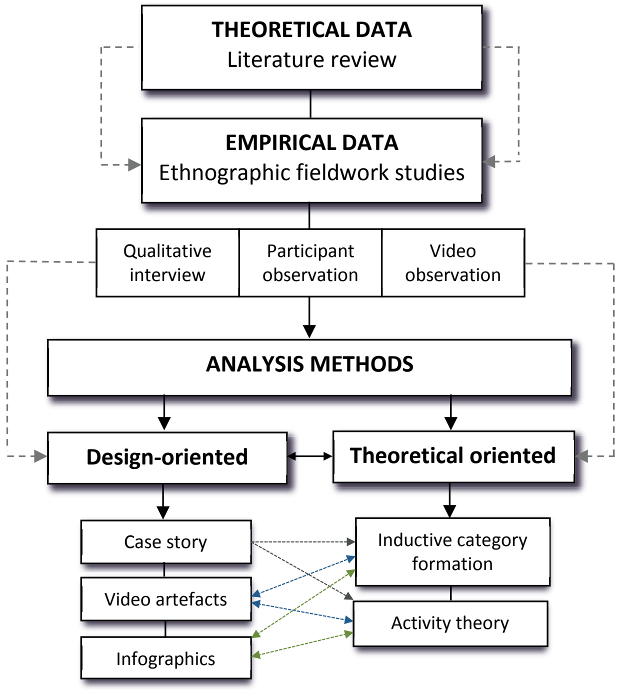


Figure 6-1: Overview of the analysis methods used in this thesis.

6.1 Field study at Hammerfest LNG plant

Before presenting the results of the field research at Melkøya, near Hammerfest, the following section will briefly provide background information on the Hammerfest LNG development.

Background information on the Hammerfest LNG development

Hammerfest LNG is located on the island Melkøya in Finnmark. It is Europe's first and northernmost export facility for liquid natural gas (LNG). The unprocessed wellstream is transported from the Snøhvit field, which lies in the Barents Sea about 140 km northwest from Hammerfest, through a seabed pipeline to Melkøya.[35] At the plant, the wellstream is separated into natural gas and condensate, and 5–8% of carbon dioxide contained in the gas is removed before the gas is liquefied by being cooled down to -163ºC so that it can be exported by tankers to Europe and the United States of America (USA). The carbon dioxide separated out at Melkøya is then returned to the Snøhvit field offshore through a separate pipeline for storage beneath the seabed. Thus, the emissions of greenhouse gases from Melkøya are

[35] The Snøhvit area development comprises the three fields Snøhvit, Albatross, and Askeladd. They were discovered in the period 1981-1984 in about 300 m water depth.

considerably reduced.[36] Snøhvit is under the operation of Statoil and began gas production in 2007. The injection and storage process of CO_2 in the Snøhvit field started in April 2008.[37]

The present field study was carried out in area 2 of the Hammerfest LNG plant. This area includes the process- and compression areas, the electric power generation area, the cooling towers for natural gas and nitrogen removal[38], and the process substation. Figure 6-2 shows an overview map. The next sections will outline the methodology, followed by a description of how work is conducted at Hammerfest LNG. It will then summarise the problems observed and discuss the observations thematically.

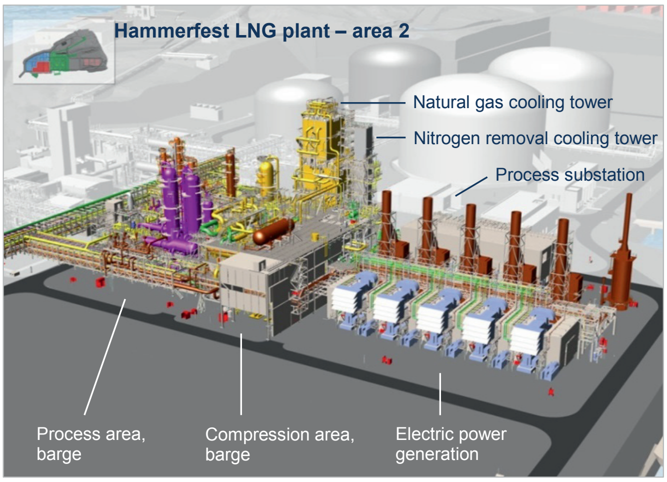


Figure 6-2: Hammerfest LNG plant, area 2 includes the process area and compression area, the electric power generation area, the cooling towers for natural gas and nitrogen removal, and the process substation. In the background, the storage tanks for condensate, LNG, and LPG[39] can be seen (Graphic generated by Petrolink as, provided by Pettersen 2010).

[36] However, despite the feasibility of carbon capture and storage at the Snøhvit process facility, the emissions from oil and gas activities in general, are too high. The oil and gas industry contributed with about a quarter of the Norwegian greenhouse gas emissions in 2013, according to Miljødirektoratet (Norwegian Environment Agency). From 1990 to 2013, the emissions from oil and gas operations increased by 81 percent (published on miljøstatus.no May 14, 2014).
[37] The information given here refers to the Global CCS Institute (2014), the Offshore Technology platform at offshore-technology.com, and Statoil (2007).
[38] Nitrogen needs to be removed from LNG in order to meet storage and transport specifications, fuel gas requirements, and LNG heating value requirements (Pettersen, J. 2008).
[39] LPG is an abbreviation of Liquefied Petroleum Gas.

Methodology

Video-based participant observation was conducted over a period of three days. The focus of the study was on two plant operators and on one operator in the central control room (CCR). However, other employees such as the team leader, operating coordinator, and further operators indirectly participated in the study by contributing information. The observations were conducted by shadowing two operators working in area 2 of the Hammerfest LNG plant (Figure 6-2) and by interviewing one participant in the CCR while observing the control room area (situated interview). The operators worked the day shift, starting at 7 am and ending at 15 pm. The video footage was captured with a Panasonic NV-GX7 camcorder. Additionally, notes and photographs were taken during observations both outside and inside, and during conversations in the administration centre or control room.

6.1.1 Work performance at Hammerfest LNG

Case story

The following section describes the work practices of plant operators by presenting a case story. As mentioned in Chapter 5, a case history is a useful tool for the contextualising the observations of in situ activities. It is a story about how operators interact in a real context. It reflects realistic work situations, presents operators and their work tasks, including opportunities and dilemmas, and describes factors that influence these dilemmas. The purpose of such a case story is to enable designers to identify with those involved in the story. The described phenomena provide valuable insights for further analysis.

OBSERVATION OF PLANT OPERATORS (I)
(Names are changed)

It is Monday 4th April 2011 at 12 noon at the Hammerfest LNG processing plant. Andreas and Kristian have their daily routines in the area 2 of the plant facility. Andreas has been working at Melkøya for one and a half years. Kristian is apprentice and has been working here for seven months. I have been permitted to follow Andreas' work with my video camera for two days.

Just like the operators, I am wearing protective clothing, including gloves and glasses. I am equipped with a gas detector that is clipped to my pocket, a remote PTT clipped to my jacket, a portable radio fixed on the belt, a video camera, a note pad, and two pens. The remote PTT has a connection cable to the radio. It dangles a bit. The way I move while wearing all the equipment is primarily influenced by the radio antenna. I feel that I have to move my arm out to the side away from my body trying not to get in trouble with the antenna. The operators additionally have tools in their insight pockets of the jackets and light on the helmet.

Area 2 includes the process area, the compression area, the electrical power production, the natural gas cooling tower, and the cooling tower for elimination of nitrogen. We entered the process area — a network of pipes, valves, and controls. I followed Kristian, who started to remove CO_2 residues using a tube, as the pump is not working. It is supposed to be replaced. Because of the extreme high noise level in the area, I was not able to get Kristian's explanations in detail while we were in the working area.

Later, Andreas and Kristian get informed by the control room that another pump is not working correct. That is why Kristian has to set the pressure manually using a lever. The operation of the long lever seems to be a show of strength. Kristian needs several short breaks. Then he asks me if I want to try. I try but was not able to move the lever at all.

During this routine, the control room deactivated the gas detector (otherwise, the gas alarm would have been activated). After the routine was over, the control room operators activated the detector again. Kristian used his handheld radio to communicate with the control room.

I followed the operators from 12 pm to 14.30 pm, trying to keep step with them, and at the same time trying to become familiar with the environment. I asked questions about operator tasks and needs while walking in the plant and following Andreas' inspection round (the noise level is lower than that in closed areas). I realized one of the main problems is the handling of work permits. Work permits (Norwegian: "Arbeidstillatelse", short AT) are paper-based forms that must be signed by a qualified operator before a work task can be executed. Later, the signee has to activate each work permit on the computer by use of SAP. Andreas is qualified to sign work permits. He tells me that it often takes a long time to complete the activations.

Anderas' shift ends at 15.00 pm.

It is Tuesday 5th April 2011 at 7 am. On my second day, I was braver to use my video camera when entering the plant. Little by little, I got used to the environment and to protective clothing, equipment, and the high noise level. Andreas, on the other hand, has gotten used to the situation of being observed and filmed. Nevertheless, I did not film all the time out of respect for the operators.

Andreas' and Kristian's shift started at 7 am. After changing clothes, the operators went to their desks located in the administration building. Half an hour later we are back at the processing plant and the operators start their daily routines. This time, Andreas keeps pencils, a small note pad, and engineering drawings with him. His first task is to sign work permits. We keep going across the whole area 2 for the next two hours to meet those operators, who need Andreas' signature and back to the plant office, where computers are available. Operators use the computers to activate work permits. (In between, Andreas controls the CO_2 tube.) Before Andreas signs a work permit, he has to check the order. Sometimes he is shown what needs to be done, sometimes operators explain their tasks. Andreas then lists the respective numbers of the work permits, using his note pad. He explains that the last five numbers will be entered into the SAP-system in order to activate the work permits. I ask for the meaning of the work permits. Andreas gives an example. He was asked to sign a work permit related to the maintenance and repair of a CO_2 pump that was leaking. As the pump would have been electrically deactivated, the control room had to make sure that the second pump would work during the maintenance. That is why Andreas communicated with the control room (using his portable radio) to clarify the situations before he signed the work permit.

Another case: A pump that is supposed to work during an operation is registered in a work permit by mistake. The document, however, affects another pump. Andreas is responsible and has to make sure that the correct pump will work. Not until the work task description is absolutely clear, he signs the document.

After a while, another operator called for a work permit. When we arrived, he did not know exactly, where in the plant he was. Andreas told him about the area and where they were standing right now. Later he tells me that the description of the area in the document was wrong.

I came across a problem while observing Andreas signing many work permits. To be able to write on DIN A4 paper sheets, he always needed a solid pad. He used his leg or any hard plane that was available. Moreover, paper sheets flutter in the wind and get wet when it rains. On the other hand, those operators, who have to ask for work permits must keep the paper sheets with them at all times.

I wondered about another problem, the noise. I was impressed how operators communicate with each other under the extreme noise at the plant. Face-to-face communication is often difficult and operators need to speak loud. They also use signals and gestures. When I expressed my concerns about the noise, Kristian told me that some of them are versed in lip-reading.

I was surprised and Kristian explained that you gradually adopt it. I asked whether it is possible to hear the acoustical signals of the portable gas detectors with which each operator is equipped. I wondered because of the noise. Kristian then simulated an alarm situation and I understood that the sound was clear enough. In addition, the detectors flashed and vibrated.

A while later, Andreas is called back for work permits and entry permits. This morning, he signed six of nine entries in area 2, and he must keep copies of all of them. I realised that it was difficult to handle the stack of paper over the course of time. (Once, Andreas was even forced to put some papers in the mouth because he had no free hand to hold it.) He mentions that operators communicate a lot during the work permit procedures both by radio and face-to-face communication. For direct communication, operators often use mobile phones available in the plant offices. The GP580 Ex portable radio used at Hammerfest LNG does not include a call function.

We are back in the office and I snap at the chance to talk a bit with the operators who are there right now. (There are six work stations in this office and operators are constantly coming and going.) Andreas informs me that any work permit will be valid from 7 am until 19 pm. Nevertheless, there are much more work permits to sign before lunch than after lunch. Today, two operators signed in the morning (Andreas and Gro) and three operators after lunchtime. (Gro has been working at Hammerfest LNG since 2008.) I am allowed to look at some old work permits to get an impression of the work tasks. For example, work permits relate to the construction of a stair tower within area G1, a leakage in valves, and work on a lift. Gro informs me that there are specific classifications of work. Category A, for example, includes operations with open flames such as welding. Category B involves crane and lifting operations. Moreover, there are two different levels of danger, whereof level 1 means most dangerous.

I am interested in the operator's experiences with their portable radios. They tell me that they mainly use three functions, the adjustment of volume, channels, and zones. The display is only used to control whether channels are set correctly. There is no need for the use of the keypad and for the programmable side buttons that the radio includes, apart from the PTT button.

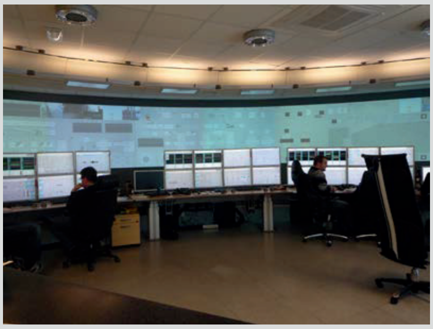
We leave the outdoor facility for lunch and meet again at 11.30 am. The afternoon goes uneventful. From 11.30 am to 14.00 pm, Andreas works at the plant office, checking work permits and reading work documents, messages, etc. From 14.00 pm to 14.30 pm, he is called for some work permits and one entry permit. We leave the plant at 14.35 pm. Andreas' shift ends at 15.00 pm.

It is Wednesday 6th April 2011, Andreas' shift starts at 7.00 am. First, all operators meet for an informal meeting in the control room. At 7.30 am, Andreas enters the outside facility starting his work with signing and activating work permits. Again, a work permit is wrong. An external electrician is instructed to connect a pump. However, on the connection order it reads "disconnect" instead of "connect". Andreas and one of his colleagues rewrite and reprint the order using a stationary computer that is available in the substation. The operators then execute the order and connect the pump. The electrician himself is not allowed to change the connection order. Again, I observe how many documents operators have to carry with them. They often use a cover for documents that keep connection orders and work permits safe.

Today, Andreas carries many blueprints, folded and put into his pocket because he has to control valves. He tells me that a specific valve will be replaced. But they have to measure gases and to remove hydrocarbon first. The valve would then be labelled by a sign (usually a red laminated sign) to indicate that the valve is changed. The blueprints are DIN A3 drawings of pipes and valves that look quite similar to me. However, according to Andreas, they show different pipes and valves. It often means to browse through the many drawings, states the operator. From time to time he must handle up to ten blueprints at once. While recording him, I realised how complex the system of pipes, valves, and controls is. Andreas must repeatedly look at the same drawings to make sure to find the right valves.

While we spend time in the plant office, I continue the conversation about the portable radio. Gro explains that they have had problems with the radios in the past. She believes that it might be due to the high humidity. Moreover, she mentions few areas, where radio range is not sufficient, for example in some substations. They had also problems in the offices of work area 2. But it has been improved now.

We leave the outside facility at 10.00 am. I finish my observation in the outside area and continue observing the central control room after the lunch break.



I am appointed with Lars, one of four operators who work shift in the central control room. Lars seems to have a usual working day. We chat a bit and he explains how control room operation is organised. There are always four operators working in the same shift, each operator controls one of the four control stations of the room. The operator, who controls station 1, is responsible for subsea activities, which include all operations related to the LNG ship. He uses two radios when the LNG ship is docked at Melkøya, one radio for communication with the ship's crew, the second radio for communication with the staff on the plant. (Earlier this day, another informant told me that the LNG carrier always has priority.) However, the operator's working area is quite large. He has to control several monitors at the same time, including the large screen, and often he moves or crosses the room carrying two heavyweight radio units. In response to my question, Lars tells me that they rarely use the large screen. Rather, they use the eight individual screens of each of the control stations.

I ask the operators for permission to videotape them and stay a little while in the control room, trying to capture the atmosphere of work. I observe that the operators' work places are equipped with many communication technologies such as phones with cord, wireless phones, and several radio units. However, it is a pleasant silence in the control room and there is a good atmosphere among the operators.

6.1.2 Problems observed

The case story revealed the following main problems in the current work procedures at Hammerfest LNG:

- Paper-based practices in industrial hazardous settings are cumbersome, time-consuming, and unsuitable considering work and weather conditions. However, A3-sized diagrams and blueprints, for example, are portable and do not constitute safety hazards in the plant where they are used to identify equipment and components. The most obvious use of paper is that of work permits, which operators also considered to be “a little messy”.
- The current work permit process poses a danger for incorrect information. The consequences are additional phone and radio communication, delays in information flow, the correction of orders and work permits, and hence the loss of time. Moreover, current processes require operators to run back and forth between the plant and plant office in order to handle signed work permits. Typically, the operators who are responsible for an area are radioed by other operators when they require a signature, and this can cause delays if the operators who are authorised to provide their signatures are some distance away.
- The lack of an orientation guide at the plant poses both potential dangerous situations for operators and time-consuming work processes. Statoil cooperates with different contractors — in particular, in the context of reparation and upgrade work. That means that many operators are not employed by Statoil and that first-time operators (e.g. vendors or assemblers) will frequently work at Melkøya. The design of the entire process plant is, however, logically and physically complex, involving compressors, valves, high-pressure pipes, and explosive materials. While experienced operators know their work areas, first-time operators who are not familiar with the plant will depend on local orientation aids to support their orientation perception and activities.
- The equipment that the operators carry has an impact on the operators’ mobility. This mainly refers to plant operators, as their total equipment includes — in addition to the radio unit — measurement devices, tools, and paper. Their work environment is also demanding in terms of the workspace design, distances, and climatic factors. However, certain CCR operators are temporarily required to carry multiple mobile devices and simultaneously control multiple monitors.

Figure 6-3: Usual equipment of plant operators including tool bag and belt, gas detector, measurement equipment, head set, light (left), blueprints (upper right), and radio (bottom right).

6.1.3 Discussion

Plant operators are very mobile and work in a hazardous environment where human error poses a high risk to safety and health in addition to potentially leading to financial loss. While plant operators are exposed to harsh environmental conditions under which work tasks are executed with the aid of various types of artefacts, and where constant radio communication with the CCR is required, the workload for control room operators can be particularly high when emergency situations arise or when the LNG ship is docked at Melkøya. Although the observed work domain is technologically advanced in terms of process automation, non-digital objects are still important in current work processes, often serving as a transmission link between the digital world and real world, which Heyer (2009) also observed at another Norwegian gas refinery.

For example, pocket notepads are used to write down information (e.g. numbers of work permits, part numbers, and notes) that will later be entered into a digital system using desktop computers available at plant offices and work stations. Work permits exist in digital form in the enterprise resource planning-system (ERP system) but are printed out in order to provide operators with paper-based documents. The documents will later be physical archived when work is complete and all required signatures have been appended to the documents. A3-sized pages showing technical drawings or diagrams are designed and stored on computers. However, in the field, printed versions are used to guide operators in identifying the correct plant equipment. Thus, it appears that paper versions are currently still common.

Non-digital signs are used to label verified or changed equipment in the plant. They indicate executed action and make the invisible visible by visually marking plant equipment. Considering the discussion on the sign function for design in Chapter 2, it can be determined that these simple artefacts involve a symbolic sign in an action context. They are part of a dynamic process that includes the use and interpretation of signs. Physical labels and notes (signs) are used in the operator's daily practice of communicating, and their interpretation is based on professional experience, routine, and explicit knowledge contained in the subjective stocks of knowledge.

Mobile digital objects for the purposes of communication and work execution are mainly related to measurement equipment and handheld radios. During the observation, it became clear that control room and plant operators not only depend on radio communication but also benefit from it, as it provides them with a shared awareness of processes, location, and activity. Nevertheless, it is worthwhile to explore and examine alternatives in order to reduce product weight and enhance operators' mobility. For example, headset solutions with integrated functions for radio channels and volume setting, or other portable solutions should be considered in future research.

Work permits are related to specific work tasks in the plant. They will be activated or deactivated in SAP and later completed in the same system. Although they are an important part in terms of safe work performance, the current paper-based procedure leads to unnecessary delays caused by a high error rate, the covering of long distances in the plant, and an enormous scope of communication — both radio and direct communication. These procedures could be made quicker and more efficient by using mobile devices or digital writing solutions that do not require notepads, pen, and radio communication. Optimally, mobile technologies would communicate with the company's ERP system to realise wireless data transmission. At the same time, false information in the documents would be avoided and unnecessary running back and forth reduced.

Mobile technology could also be used for guidance in the plant, and it could facilitate the identification of certain equipment in and components of the plant. For example, A3-sized prints of drawings or plans require an appropriate resolution and prevent operators from zooming in and out to see details. This is a key advantage of electronic devices, such as computer tablets.

To sum up, the oil and gas industry is one of the few industries that do not yet benefit greatly from mobile technologies. Handling and archiving large volumes of paper documents pose a challenge in terms of space, efficiency, and cost. However, it was important to study operators working on a (physical) process plant in order to gain insight into current workflows and actions as well as to understand the role of design in these processes. During their inspection rounds, operators physically experience the plant. They hear the noise, smell the gas leak, or feel heat and vibration. They take their gloves off to feel, for example, the temperature of an engine. Therefore, their presence at the plant is important for the perception of errors that cannot be displayed by tools. "Man hører som en pumpe hoste" ("You hear, like a pump coughs") was what an operator said when we talked about potential mobile solutions. What follows from this is that designers and engineers should draw attention to new artefacts, taking into consideration humans' physical activity and the need for a tangible design. The need exists for future concepts and new technical solutions that are designed to support the operator's expertise rather than replace it with technology.

6.2 Field studies at Nyhamna process plant

In the previous section, we looked at operation processes at hazardous industrial plants using the example of the northernmost gas processing facility, gained insight into the context and work environment, and understood radio communication as an important instrument in this context. The following sections present two examples of mobile devices, a radio TETRA terminal and a handheld PDA, which have been investigated for their usability. Because evaluations of handheld devices that are used in critical industrial settings are not yet sufficiently documented from the user's perspective, the present research study will focus on the opinion of operators by means of interviews and field observation. Before presenting the results of two field studies at the Nyhamna facility, brief background information on the Ormen Lange development is given.

Background information on the Ormen Lange development

The Nyhamna facility is located at Nyhamna in Aukra. The Ormen Lange field is situated 120 km northwest of Aukra in the Norwegian Sea, 3000 m below the surface of the sea. It is Norway's second and Europe's third largest gas field. The gas is transported 120 km through subsea pipelines to the land facility at Nyhamna, where gas and liquid (such as water and light oil) are separated and the dry gas is compressed. It is then transported to Easington in England through the world's largest subsea gas pipeline, called Langeled.[40] Tankers transport the light oil to refineries worldwide. Nyhamna's CCR is located in the administration building. Control room operators manage and monitor the entire facility from here. Ormen Lange is operated by Shell, and gas production from the Ormen Lange field started in September 2007.[41]

The present interview study was carried out in the administration building, mainly in the CCR. The subsequent short field observation was conducted in area 3, which comprises large parts of the process plant, including the compression area, mono ethylene glycol plant (MEG), and water treatment plant (the entire facility is divided into three areas). However, the

[40] Langeled consists of 100 000 pipes, each pipe 12 m long. 1,2 million tonnes of steel were used for the construction.
[41] The information given here refers to A/S Norske Shell, Nyhamna.

observation mainly took place in the plant's substations. Figure 6-4 shows the reception unit for liquid slug, called slug catcher, and the administration building.

Figure 6-4: Left: Slug catcher where the process of separating gas and liquid starts. Right: Nyhamna's administration building. The building includes a simulator, a laboratory, a workshop, and the control room (Photographs: Shell).

The next sections describe the methodology and the results of the interviews and field observations from Nyhamna. It is followed by a summary of various patterns and identified problems as well as a final discussion of the study results. However, it should be pointed out at this point that the data refer to interviews, which were conducted at the end of 2010.

6.2.1 Usability study of Motorola's MTP850 Ex TETRA terminal

Methodology

The participants of the evaluation study of Motorola's MTP850 Ex TETRA terminal included five operators who were interviewed and two operators who were shadowed and observed at the plant half a day. Further discussions with other stakeholders were included in the study. The interviews were primarily conducted in the control room area, using props such as printouts of the TETRA terminal in order to write down notations and comments in terms of functions and characteristics of the product in context. In addition, the operators took their radios with them. Each interview took about 20 to 30 minutes and was conducted as a semi-structured interview, where a list of questions was followed to ensure that all themes of interest were covered with all of the participants. The list included both closed and open questions that allowed for follow-up or additional questions on specific themes. During the interview sessions, a voice recorder was used, and notes were made. The observation was conducted by shadowing two operators during their inspection round in plant area 3. Notes were made both during and after the observation.

Semi-structured interviews

In the following, the interview results are presented, grouped according to their topics. The purpose of the interviews was to understand how the design of the handheld radios affects efficient and safe work performance at the Ormen Lange land facility and how operators evaluate their radio equipment. The interviews also included questions related to the introduction of the device and some technical issues. The digital TETRA terminal has been used at Nyhamna since 2009 and replaces the analogue radio communication. (For the product interface of the MTP850 Ex terminal see Appendix A; for the list of questions, see Appendix C.)

Work tasks and work experience

The work experience of the participants at the Nyhamna facility was between one and five years at the time of the interviews. Two informants worked in the CCR and at the outside facility, two at the outside facility, one informant monitored and controlled the process mainly from the CCR. The informants are trained in the areas of production-, process-, or electrical engineering or in instrument maintenance.

Intended use of the MTP850 Ex TETRA terminal

All informants use the terminal largely for voice communication between the CCR and the outdoor facility. Most of them only use the talk-function, whereas the telephone function is rarely used.

Introduction of the radio

Several participants reported that a user guide was handed out to the operators — a little piece of paper with illustrations and arrows [quotations: “a little simple instruction sheet”, “no more than a little piece of paper”]. No course was offered. One informant said that the unit was often re-programmed [quotation: “collected, delivered, collected, and delivered again”]. Still, the radios are programmed differently. Another informant explained that he simple learned to use the product by trial and error and that he got tips from colleagues. It took him a long time to figure out basic things, such as how to change channels quickly by using the side button instead of using the menu. One respondent even suspended the use of the MTP850 Ex radio as long as possible. He mentioned that they had learned from one another’s experiences in addition to learning-by-doing. Another informant stated that he had familiarised himself with the radio by trial and error, and that worked well. However, some of the operators in the CCR turned off the new radio and used the old radio instead.

Product acceptance

Several participants did not like the new digital system. They described problems with delay and echo (probably caused by minimal time consumption during the compression and transmission of the audio data), which lead to acoustic noise in the control room. As a result, a yellow information sign on the door of the control room requests that operators turn off their radios before entering the room. One participant described problems with echo and feedback both inside and outside of the CCR, pointing out that operators will thus not hear all of the information they need or may get the wrong information. As an example, he illustrated that an operator who works at the plant may ask for support regarding special instrumentation. If the wrong instruments are activated caused by a misunderstanding in radio communication, this could be a very critical problem. Other participants expressed that the device barely meets the operators' needs. However, two participants were generally satisfied with the product. One of them accepts the radio except for the low sound. He would prefer a higher volume because it is exhausting for him to hear when he is outside and wearing headset. The other informant explained that he had used other radios before, but he likes the new digital radio better, as it has more functions. (All informants had previously used analogue radios, where echo problems did not occur.)

First-time use

One informant stated that the first-time use of the digital radio, despite the skepticism, was not as difficult for him, as he normally only uses the communication function. Other informants, however, were irritated by the echo when they heard it for the first time.

Most frequently used function

All informants seemed to use the two-way communication function most frequently. At the outside plant, most operators use the PTT function and a headset. Two informants said they often use the programmable side button on the radio because they can thus switch between their favourite channels very quickly. While one respondent especially switches between the channels of production and maintenance [quote: "I like to press just one button."], the other one also uses the channel for work permits (Norwegian "Arbeidstillatelser", AT-channel) or the standby channel. In addition, the second respondent had called other people about five times using the radio.

Functions that have not been used so far

The integrated message function generally seems not to be used, and it turned out that several participants did not know how to use it. It was also emphasised that a text tool is not needed [quote: "There is little need for text messages."]. Some informants do not use the display of the radio, and therefore, they do not need a graphical menu. Moreover, the use of the keypad / buttons is mostly restricted to the side buttons, including the two programmable buttons and PTT button.

Expectations that have not been met

Several informants mentioned the tedious procedure to make a call using the radio. The operators would have to scroll through a long list consisting of several hundred phone numbers and would thereby repeatedly press the scroll button because there is no option to search or enter certain numbers. Therefore, operators use rather ordinary phones that are available in the plant's substations. One informant noted that the available functions of the device are not necessary because he largely uses PTT [quotation: "We use it in a very simple way, we do not need a very advanced radio."]. However, he mentioned a sort of misuse of the emergency button, which is located on the top of the radio. It was initially confused with the power function. However, when pressing the button, the alarm is activated in the CCR, and the whole system is locked.

Emergency

All participants indicated that they have not experienced any emergency that might require the operation of the emergency button. However, all of them mentioned the accidental use of the button, as already described. Due to the frequent misapplication in the beginning, all radios in use have been reprogrammed. According to the informants, this problem was discussed intensively with the supplier, Shell, and the representatives of employment protection, and a couple of changes have already been made. Interesting at this point is the explanation of a study participant who saw the potential cause of the misapplication of the button in the previous handheld radios, which integrated a similar-looking button in the same place but with this button having a different function. (Previously, operators would have called the CCR in an emergency.)

Teamwork and communication

All participants underlined the close collaboration between field and control room operators as well as the importance of communication among operators at the outside facility. This communication often refers to requests for work permits, and handheld radios are the dominant means of communication for the operators. The operators are accessible on different channels, depending on their professions (e.g. production, mechanics, electrics, or maintenance). One participant described how he changes the channel when, for example, an electrician should be consulted. He would use the menu and scroll through the channels. Another participant also said that operators are called according to their areas of work. For example, an operator who works in plant area 1 would call a colleague from this area.

Handling of the handheld radio device

Respondents generally evaluated the size and weight of the radio in a positive way. In addition, most informants had no problem with operating the device with gloves. Some informants, however, find it difficult to carry the radio clipped on a tool belt because it is a hindrance when moving, mainly because of its size and external antenna. One informant suggested there might be a smaller product that could be plugged into the front pocket of the protective overalls; another would prefer an integrated radio antenna. Other respondents are not bothered by it.

Accessories and additional devices
Plant operators are usually equipped with a headset and microphone by Peltor and mobile gas detection equipment by Draeger. Some operators additionally use a remote speaker/microphone to be able to talk without holding the radio. The use of additional tools depends on the work. At least two of the study participants prefer tool belts where tools and the radio terminal are fixed on the belt. One participant uses a hard leather case to protect the radio.

Radio range and coverage
The respondents in the study have different experiences with respect to the radio range. Some informants consider the radio signal range to be better than others do. However, at least two informants experienced radio interference within various substations, in the basement and in the quay area.

Battery lifetime
With one exception, all participants rated the service life of the battery as being positive (even in winter). The battery lasts about 12 hours. Several charging stations are available in the workshops, and several charging points are near the CCR.

Audio quality
The audio quality was evaluated positively. Apart from the echo problems, most informants were satisfied with the sound quality of the radio. The device is programmed so that the volume reaches its maximum at level 8, which is accepted by most. Only one informant would prefer a higher volume.

Robustness
All participants consider the radio to be a robust and solid device. In terms of robustness, radios from Motorola are generally appreciated [quotation: “I have never seen a Motorola radio that was destroyed by normal use.”]. Additionally, the hard leather case can protect the device against a potential fall.

Usability
Several participants have nevertheless clearly expressed that the handheld radio does not meet their needs, as it is too advanced [quotation: “We need only a small part of it, we do not need so many functions.”]. Many built-in features would increase the risk that a specific function is not running, said one of the study participants, who emphasised at the same time how dependent operators are on the radio. Even the acoustic problem with feedback and echo was mentioned again. Two of the respondents consider the usability of the device as being good, and they stated that they see benefits in the additional features.

Lack of functions

It was obvious that several participants would prefer a keypad (such as the analogue radios) that enables operators to make calls easily. Because information is transmitted over the entire channel, some informants would like to be able to call certain radios to share individual information. Furthermore, the need for a dual function of the rotary knob was mentioned, which would make it possible to adjust the volume control and change the channel using one knob (the knob is placed on the top of the unit). Some respondents again do not miss any concrete functions [quotation: “not spontaneous”].

Observation of plant operators

After interviewing field and CCR operators about the TETRA radio MTP850 Ex, two field operators were observed half of a day. The purpose of the observation was to study the practical use of the handheld radio. The operators’ work task was to check substation ventilation in the plant and to test ventilation flaps. They were equipped with headsets (with integrated ear protection), a handheld radio, a remote PTT, mechanical tools, and a stack of paper-based work permits. They wore safety boots, high-visibility protection clothes, gloves, and protective glasses and so did I. We took an electric car to get to the substations.

During the inspection work, the operators were always in contact with the CCR, where all processes are controlled, and they used the handheld radios. For example, one CCR operator directed the opening and closing of ventilation flaps for test purposes or gave the plant operators advice. The plant operators, in turn, reported back that everything was working. By using the external PTT control element, they were able to communicate without holding the radio. However, the existing work permit procedures had a strong influence on the overall inspection activity. Whenever we arrived at a certain substation, one of the operators called a qualified colleague to sign the work permit so that he would be allowed to carry out inspection work. He used the radio and selected the AT-channel, the channel for work permits. Because each substation or each task in one of the substations required a specific work permit, the operators had to again call for someone to get a signature at each new location. After the work had been completed in a particular place, the operators confirmed their work activities on the same form. When an inspection round has been completed, all confirmed work permits are delivered to the department head. In normal operation, the data are not transferred to the SAP system. Unexpected incidents must be reported.

It happened that we had to wait a long time before the relevant people were available to come and provide their signatures. The operators often used the time at the computer. Each substation is equipped with tables and one or two stationary computers that allow operators to follow the plant process. During the waiting period, the radios were often placed on a table. For those who are called to sign work permits, the requests are ad-hoc — that is, their current work must be interrupted. First, they need to reach the operators at their places, sign, and go back to their jobs. This constant interaction between the plant operators thus has an influence on the efficient operation of the plant. Although signing with pen on paper is relatively quick to do, the entire process can lead to delays, as observed in this case study.[42]

6.2.1.1 Patterns and problems observed

Interviews, discussions, and observation revealed the following patterns and problems:

Patterns of responses to questions about the radio device:

- Significant differences were noted in some answers to questions. Respondents who were not satisfied with the digital radio reported problems based on experiences within the CCR. CCR operators were critical in terms of design and technical issues. They also criticised how the new digital radio was introduced. Field operators, however, are generally satisfied and had not experienced any significant problems with the radio.
- Critical answers were given, regardless of professional background and experience at the plant. For example, the majority of the respondents criticised the long telephone list stored in the radio system.
- Identical answers were given to the questions on teamwork and communication. All respondents stressed the importance of the communication device and confirmed the close interaction with other operators, both in the CCR and at the plant.

Patterns derived from responses:

- Significant product features are available and easy to use; secondary functions are missing. For example, the voice communication is facilitated by product properties such as the easy-to-use PTT button and the programmable side button used to quickly change channels. Functions for the support of individual communication (individual radio talks) are missing.
- The function for emergency is critical and not adequately designed to prevent wrongful use (see Appendix A, number 1).
- Gloves, as they must be worn in hazardous areas, are no problem for the user-device interaction.
- There are critics and proponents of the product, amongst them strong critics but no enthusiastic proponents.

Patterns emerging:

- Respondents expressed little or no need for specific functions: No need for a text tool was expressed twice; no need for a keypad and display was expressed twice.

Patterns of behaviour:

- Field operators always carry their radios and a mobile gas detector with them, but apart from that, they use little advanced technology in the field. They wear a hearing protection headset with a PTT adaptor cable that serves as the link between the headset and radio.

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[42] As reported in Section 4.2.2, Nyhamna has in the meantime tested a wireless handheld solution for managing work permits. The test pilot was successful.

This puts them in a position to speak freely, while the radio is attached to the belt. During waiting periods in buildings or substations, the helmet-mounted earmuffs are often folded up, and the radio equipment is placed on tables so that operators can follow ongoing communication. However, the use of a remote PTT and headset at the outdoor plant make certain functions of the radio temporarily unnecessary — for example, the PTT side button or the top microphone.

Main problems:

- In general, changes are associated with stress because changes affect the way people act and manage information. In a work context, changes in systems and technologies can have a negative impact on the user if the technology is complicated, if problems occur, or if expectations are not met. Employees then quickly tend to reject new solutions. It is important that they understand how specific changes will help them to better perform tasks and manage information. Without a well-thought-out introduction process, new technologies can lead to more problems than they are supposed to solve.
- At the same time, changes require a transitional period during which users become informed about issues regarding the technology to ensure that these problems are avoided and functions can continue to be used. For example, acoustic problems, such as echo, can occur in the control room when a radio that receives a message is located in close proximity to a transmitting radio. Muting the sound in the moment when someone starts to transfer (as recommended by the manufacturer) could be a solution, which should be communicated to users throughout the transition period.[43]
- Many electronic devices today include a variety of features that are often not necessary with respect to their purposes. In some cases, it even turns out that devices can be more detrimental than beneficial to customers. The system of the digital TETRA radios from Motorola, for example, includes advanced optional functions such as a "Man Down" alarm, which were deliberately not ordered by the customer. In product advertisements, this function was promoted as a new function designed to increase operational safety; this product feature, however, has disadvantages. The "Man Down" function (and hence emergency) can be activated even when the radio is not moved for a long period of time — for example, if it is placed on a table for a while. Other features, such as the integrated text message tool, are difficult to understand because the device does not have a keyboard for text entry. Users have to rely on predefined messages in the menu.
- In Chapter 3, experiences and motoric habits are discussed in terms of tactile perception of mobile devices. We remember that human spatial memory provides us with spatial orientation in order to find what we expect to be the correct function or the correct button. In the case of the TETRA radios, it turned out that a particular button — the emergency button — was probably used out of habit and/or derived from certain expectations. These expectations were based on experiences with previous devices, not on the knowledge of

[43] A trunked radio system, such as TETRA, is a two-way radio system that can both transmit and receive information. As the compression and transmission of audio data take a very small amount of time, system delay, heard as echo, can occur.

the meaning of the button or its function. Depending on the programming, the unintentional activation of the emergency button can cost the company time and money.

- The physical design of large industrial facilities such as Nyhamna affects radio signals and range. The effective radio range depends on the layout of the facility, including its open and enclosed spaces, construction (e.g. number and thickness of walls, material, elevator shafts), and the number of the base stations on the plant. At Nyhamna coverage in certain enclosed spaces is bad. However, because radio communication is critical for plant operation, the loss of radio signals may pose a risk to health and safety.
- The design and size of the workspace also have implications for the efficient work performance of the operators. Considering the current work permit procedure, it is obvious that moving back and forth at the plant in order to sign work permits causes time delays, as work must be interrupted, distances must be covered, and work must be resumed. The duration and number of these movements depend on the intensity of the communication and interaction among the plant operators and their corresponding local positions at the plant. The current procedures do not improve efficient operation.

6.2.1.2 Discussion

In some respects, the results presented here clearly show a dilemma of radio communication. On the one hand, certain procedures, such as those of work permits, could be designed more efficiently with mobile technologies and would make radio communication superfluous. On the other hand, operators would then be unable to develop a shared awareness of ongoing plant activities, progressions, and local perceptions if communication channels are eliminated. In fact, the constant communication between the control room and field operators as well as the communication among the field operators can lead to time delays associated with waiting times and interruptions. However, work in hazardous work environments is of a critical nature, and therefore, interaction and close cooperation among operators in the CCR and those who work at the outside facility are essential for safe work execution.

The investigation of the TETRA radio used at Nyhamna has shown the impact of a radio's product design on work activity and, as a consequence, on user satisfaction. The presented study results are based on a relatively small number of interviews and conversations as well as a half-day observation of field operators. However, operators who work at Borregaard's biorefinery in Sarpsborg and who use the same handheld radio have also described similar problems.[44] In terms of product design, it became clear that user acceptance of the radio is not only a question of how users cope with menu structures and the way in which digital information is presented. Less sophisticated details, such as single physical buttons, can be a challenge for the collective work mediated by communication devices. Even more, these

[44] In 2013, students of the Østfold University College have interviewed operators who work at the bio-refinery Borregaard. The study was conducted as part of a semester project with the aim to improve the radio communication on Borregaard's process plant.

details can pose a risk with regard to efficient and safe task execution. In the operation of all technical equipment and instruments, that is, in every human-machine interaction, there is always a risk for human error, which engineers and designers must take into account. In our case, the risk involves different ways of using buttons — intentionally or unintentionally, but always based on experiences. In light of the review of the literature on the semiotic meaning of objects (see Chapter 2), the results of the study have demonstrated that design must mediate between object and need, construction and use, and function and meaning. The symbolic attributes of a technical device such as the TETRA radio are perceived by its users who have certain expectations and experiences, and who are characterised by their personalities as well as their social and cultural influences. These symbolic attributes relate both to the product as a whole and to each individual product item.

Also in Chapter 2, I have discussed the concepts of "affordance" (Gibson), and the "demand character" (Koffka) of an object respectively, against the background of Gestalt theory and I have elaborated on the affordances of devices used in plant operation (Section 2.4.1). Their importance for the product development of handheld devices for use in hazardous working environments lies in the knowledge of the human perception of gestalten and gestalt-qualities, which include physical object properties in terms of shape, size, and texture as well as symbolic attributes in terms of color and characters. The usability evaluation of Motorola's MTP850 Ex TETRA terminal drew a picture of a complex technology with advanced features that have never been used by operators, or that were not wanted by the customer. For example, a message function that enables users to send text messages (predefined or as a template) is rarely used because users either fail in the application or do not even know how the function is used. Specific questions about the readability of text and icons on the screen or on the application of the keypad were omitted during the interview sessions, as there is little need for visual information, according to the respondents. Conversely, the question arises as to whether there is little need for visual information as long as the display is as small as that of the radio. Irrespective of this, technologies overloaded with unnecessary features and properties are more complex and thus more difficult to understand, which can cause stress to the intended users. In particular, mobile devices for use in hazardous industrial environments should be simplified in order to be used in the task in hand. Drawing on Gaver's classification of affordances, as outlined in Section 2.4.1, the present case has shown that hidden and false affordances may lead to human errors in the use of technology. In the worst case, it leads to difficulties in plant operation in terms of efficient and safe work procedures.

The presented case further revealed critical issues regarding the technology introduction and transitional periods. As we have seen, the operators have experienced the TETRA radio in different ways. Some have no problems, while others continue to rely on the analogue radios. However, modifications of existing systems and technologies are always associated with the uncertainty and skepticism of potential users. A clear presentation of the issues that new technologies address, and their advantages compared to previous technologies, can help to generate a wider acceptance of those whose work is influenced by new solutions. In addition, a well-designed transition phase includes sufficient time for testing a new technology, involving the users, and reducing user resistance in a later application. Finally, instructions and training on the use of new technologies can prevent abuse.

Finally, the study has shown that the design of the physical workspace affects the efficiency of work activity, as it demands operators, among other things, to cover long distances after being radioed. On the other hand, the working space design can have a negative impact on adequate radio coverage in some areas of the plant. Drawing on Section 2.3.2 on Activity theory, the operator-device interaction (subject-object relationship) always incorporates the aspect of the working space in which subjects and objects are located. In the present case, the impact of the working space on collective cooperation becomes significant. Given the identified problems and the current discussion, we can conclude that the design of human-machine interactions includes the design of new products and systems, the design of the environments in which these products are applied, and the design of processes (introduction, transition, and utilisation processes).

6.2.2 Usability study of the handheld PDA MC 9090ex-K

The previous chapter examined the MTP850 Ex TETRA terminal, which is used for radio communication at the Nyhamna processing plant and between control room operators and plant operators. The following chapter presents the results of the evaluation study of the handheld PDA MC 9090ex-K that is used to collect process data on Nyhamna plant. The study comprises an open interview that was conducted in a meeting room of the administration building along with video-based participant observation that was carried out in plant area 3. The main objective of this study was to investigate problems of operator-device interaction, with a focus on issues of usability and workflow improvements.

The following sections briefly describe the methodology and present the results of interviews and field observation. It is followed by an overview of suggestions for improving the logging routines (proposed primarily by the experts) and a discussion of design issues of usability as well as some technical aspects.

Methodology
The study included a one-day investigation of the use of the handheld PDA MC 9090ex-K at Nyhamna. In the beginning, an open interview with two IT engineers and one operator was conducted, with the goal of obtaining background information on the functionality and intended purpose of the device as well as gaining basic knowledge about typical workflows supported by the mobile device. The engineers then presented the device and explained how it works in theory. In addition, they showed me the Shells database PI (process information) that is used to store the process data so that I could understand how the collected data are

presented in the system. The interview lasted about an hour. It was taped and later transcribed. (As described in Section 5.1.1, the interview situation was similar to a kind of forum, which was characterised by a common interest in the results of the study.)

The second part of the study focused on the actual data logging in the plant and had the goal of getting an impression of how the mobile computing device works in practice. For this purpose, two operators were observed and video-recorded during a demonstration round, and two operators were accompanied on their official round during the afternoon shift. The operators involved in the study already had experience with the data logger and provided valuable feedback on the application in practice. The main objective of the observation was to investigate the extent to which the data logger MC 9090ex-K simplifies tasks, including administrative work or paperwork. The video footage was recorded with a Panasonic NV-GX7 camcorder. In addition, notes were taken during the observation and following discussion with participants.

This study differs from the study of the TETRA terminal in its study design. While participants in the radio study were interviewed in succession, using an interview guide to ensure that the same topics were covered in each interview, the format of the interview on the handheld PDA was social and conjointly because the study participants themselves were interested in the improvement of the device. Thus, the interview served as preparation for the following field observation. As a result, the analysis of the interview and the video data are merged into one documentation.

Case story

Before the problems are discussed in more detail, a short case story is presented to provide an insight into PDA-mediated task execution in a demanding work environment. The handheld PDA MC 9090ex-K was introduced in 2011 with the aim of collecting process data in the plant by means of technology that replaces the paper-based procedure and thus leads to more efficient task execution and safer plant operation.

OBSERVATION OF PLANT OPERATORS (II)
(Names are changed)

It is Thursday 22th September 2011 at 15 pm at Nyhamna. I am allowed to follow and tape Gunn (operator) and Elisabeth (apprentice) during their logging round at the gas processing plant. During the round, equipment will be inspected and values or observations will be recorded on the device. The data will be marked with the date and timestamp.

It is a rainy and windy afternoon. Gunn, Elisabeth, and I cycle to the plant because the cars are in use. For me, it is quite a challenge to ride a bike with relatively heavy helmet and headset on my head, video camera over my shoulder, and exposed to rain and cold wind. We are on logging round, and Gunn and Elisabeth are equipped with tool belt, gas meter, radio, and flashlight. Gunn additionally carries the PDA. Before she starts logging, she talks to some of the operators and signs a work permit. In the meantime, the PDA is placed on the rear rack of the bicycle. When we want to continue biking, Gunn almost forgets the device.

During the work, Gunn keeps the device in her hand, all the time. It seems to become heavier over time. In addition, the wind blows strongly and I notice that it becomes more difficult to keep the device steady in hand to scan. Visibility is poor and the scanner window of the device and the surfaces of the barcode labels (also referred to as tags) must sometimes be wiped dry before scanning. Additionally, I notice that Gunn sometimes presses the scan button several times before the red laser line appears and tags can be scanned.

Gunn has been working at the gas processing facility at Nyhamna for three years. She has been working within plant operation and maintenance and has a background in chemical process. She tells me that she would prefer the logging round to be a separate task. Currently, it often happens that operators do not constantly take the device with them because it is far too heavy. Hence, operators are forced to drive back and forth to get the device when it is needed.

Gunn believes that operators have to scan too many tags. Especially in the pump station, the number of tags could be reduced, she states. She explains that there are currently three tags on each pump. She would prefer to enter a comment into the device rather than to scan three times. Moreover, double checks on some equipment are performed, where both the control room and plant operators verify pressure. I ask how long the longest logging round would take. Gunn replies, one and a half to two hours.

(Earlier the day, another operator told me that there are currently loggers who have to make the entire tour alone. To him, it would be nice to share the tour with a colleague.)

I understand that a tour contains 50 to 150 barcode labels at the time of my plant visit, and that operators complete two tours the day, one tour during the afternoon shift and one tour during the night shift. I notice that the tags are labelled with the letters “E” or “N”, or “E” and “N”. Gunn explains that certain tags are only scanned during the afternoon shift (Norwegian: Ettermiddags-skift), certain tags only during the night shift (Norwegian: Nattskift). Some tags are scanned either in the afternoon or night shift, and some tags are scanned in both shifts. Apart from that, loggers must occasionally search for tags, as barcode labels are usually attached to equipment with structured surfaces that is not always easy to identify.

Gunn and Elisabeth have found all tags and cycle back to the administration building, wet and slightly shivering. So did I.

6.2.2.1 Problems observed

The short case story presented here has already indicated some of the main problems of barcode scanning in demanding work environments, by means of a handheld PDA. The following tabular overview summarises and reflects on relevant problems of the handheld PDA. It describes the relevant issues in detail and puts them into context through their categorisation and interpretation. The overview is based on a categorisation scheme derived from a set of evaluation aspects of the collected interview and video footage. (See Appendix D for the coded transcription of the material, Appendix E for the categorization scheme, and Appendix B for the product interface of the MC 9090ex-K.)

Table 6-1: Results of interview and field observation.

1. PDA USABILITY PROBLEMS	INTERPRETATION
Ergonomics	
One of the most obvious problems of the handheld PDA is its size and weight. When working, operators normally hold the PDA in the hand all the time. Strong wind can affect scanning procedures, as it becomes more difficult to steady the device in order to scan.	The product is designed for use in harsh environments, which means its design is rugged and compact. This inevitably leads to a bigger product. However, this device weighs over 1 kg and its dimensions are 231 mm x 91 mm x 105 mm (length x width x height).
Hitting the barcodes depends on how operators hold the PDA in their hand. In some ways, there is a risk for not aiming the scan exit window correctly at the barcodes.	The product design and the positioning of the scan exit window have ergonomic impact on users. As the device is somewhat bulky, it can have effects on the user's wrist and arm and can lead to fatigue of the arm when using the device over a period. Additionally, many barcode labels in the plant are vertically attached, and therefore, the logger must rotate the device to hit the barcode.
Some of the operators control the screen with their fingers; others prefer the stylus because wearing gloves makes the operation with fingers more difficult.	The screen can be controlled with the fingers and the stylus. The gloved operation is possible but can be cumbersome.
The keypad is too small, especially the alphabetic keys.	Usually, it is more difficult to hit the keys with gloves.
It may happen that operators forget the device somewhere in the plant. Operators often need to complete and sign work permits, or they carry out other tasks for which they need free hands.	Because of its weight and size, operators cannot simple wear the PDF with or on top of their clothing. It will not easily fit in a pocket, and it cannot be simply clipped to a belt, as operators have many other tools on their belts. Handheld vs. wearable computer?
Operators are often tempted to put the device down when they work in the plant because the PDA is big and somewhat bulky. Therefore, they must often back and forth to get the device back.	Unnecessary back-and-forth in the plant or from the field to the office is time-consuming and stressful for operators.
GUI	
Operators reported on challenges in reading the display when the sun is intense. The light intensity of the display is insufficient, and therefore, it is difficult for users to read the display clearly under direct sunlight, even though the screen backlight was adjusted to maximum.	The legibility of the display depends on light incidence and light intensity. Many screen devices cannot be clearly read under sunlight because of the displays' insufficient light intensity or due to screen reflections. Anti-reflective coated films for smart phones, laptops, and tablet PCs are used today to avoid glare and reflection on screens and to improve sunlight readability.

	Readability in direct sunlight depends on the type of the screen. Resistive touch screens, such as used in many handheld devices, are known for their poor legibility under direct sunlight. Compared to capacitive screens that transmit over 90 % of the light from the screen, the light transmittance for resistive screens is only about 75% (Braue 2011).
There are concerns about the screen text. IT engineers found out that the electronic text could be somewhat misleading.	
The graphical user interface of the PDA was considered as not being intuitive for users.	However, simple mistakes, such as scanning of tags, which are not registered in the corresponding logging tour, can be easily corrected by users.
GUI/Functionality	
Scan procedures can become cumbersome if operators cannot see whether they are aiming the scan exit window at the right position or not. They cannot see whether they have hit the barcode or not.	Both, legibility of the display and the identification of the red laser line depend on visibility and lighting conditions. The visual feedback during the scanning process is insufficient.
Operators are often forced to push the scan button several times until the red laser line appears.	time-consuming and exhausting
The touch screen of the PDA seems to be less sensitive than other screens, and it often responds slowly. Hence, operators must touch the screen several times to get response.	Again, screen sensitivity depends on the technology. Capacitive screens, such as used in smartphones, are generally much more sensitive to touch input than resistive screens. However, capacitive screens can usually not be gloved-operated, whereas resistive screens can.
Rainfall has negative impact on the use of the device because the barcode labels and the scan exit window of the device have to be clean and dry to perform scanning successfully.	Scanning can become time-consuming if operators first must wipe barcode labels and scan window dry. A discussion about barcode technology vs. RFID technology might be beneficial.
The PDA does not include an integrated camera.	It could be advantageous to share relevant pictures of plant components, equipment, etc. with colleagues in the CCR and in the field.
Operators miss a lock feature that enables users to lock the device if necessary. Now, users must either remove the battery or completely turn off the device, and turn it on again, when the device automatically locks.	time-consuming and not user-optimised

Use of functions	
The keypad functions are rarely used.	Does the PDA meet the needs of its users? What kinds of functions are necessary to perform the intended work task? A re-design of the keypad could lead to a smaller and user-centred product.
The MC 9090ex-K is not equipped with a trigger, whereas the MC 9090ex-G version includes a pistol grip with a scan trigger to enable users to better capture barcodes with only one hand. IT engineers and operators do not believe that the grip is important.	Although a device equipped with a pistol grip and integrated scan trigger would have ergonomic benefits, it would result in more weight (although only slightly more), and the device would be larger. The MC9090-K weighs approx. 1. 3 kg (without trigger). The MC9090-G weighs approx. 1. 4 kg (with trigger).
2. LOGGING PROCEDURE PROBLEMS	**INTERPRETATION**
Positioning and number of barcode labels	
Operators and IT engineers are dissatisfied with the positioning and the number of barcode labels in the plant. A total of 300-400 barcode labels are placed in the plant, with most barcode labels in plant area 1.	There is need for reconsidering the large number of tags and the number of its registrations. This includes unnecessary checks of several levels when machines are not operating, unnecessary double-check carried out by plant operators and the CCR, and reducing the number of tags at certain locations, such as the pump station, where up to three tags are placed at one pump.
In addition, the various logging tours are divided unfavourable because several tags attached in close proximity relate to different tours. This requires operators to go back and forth and spend more time on logging than necessary.	The general composition of tours may be improved because operators are faced with unnecessary work and unnecessary long ways.
Moreover, it happens that loggers must search for the barcode labels.	The barcode labels are placed at many different locations in the plant and attached to certain surfaces.
Types of tags	
The PDA solution is based on barcode technology. Barcode labels are exposed to heat and sunlight as well as harsh weather conditions, and will be reprinted from time to time.	Barcode tags require clean and dry surfaces in order to be scanned correctly. RFID tags are more rugged. Additionally, the information of barcodes cannot be changed, whereas RFID tags can be rewritten many times, and new data can be added.
The tags consist of plastic. The barcodes are affixed on the tags. In addition, special UV films are used to protect the tags against sunlight during the summer months.	RFID tags are available in different materials and designs, depending on application requirements.
3. PRODUCT EFFECTS	**INTERPRETATION**
Psychological effects on users	
Some operators are very skeptical about the PDA solution because they feel as though they are being	Social and psychological aspects of using information technologies for recording data must be considered in

controlled. In a sense, the practical application of the PDA in the plant contains a control over inspections carried out as well as the opportunity to follow a tour precisely after data have been transmitted.

launching new systems. The use of the PDA is a matter of safety for people and environment in a hazardous work domain because it ensures that inspection will be conducted. It is important to communicate the purpose and the benefit of the technology and to provide the users with context information.

Effects on procedures

The purpose of using the PDA is to collect data of equipment in the plant, such as data of temperature, pressure, and oil level, and to reduce paper-based tasks. A secondary effect is that operators actually take measurements and inspect locations in the plant. Operators made their rounds also in the past, but the data were not subsequently analysed. The data has been archived in a folder and analysed in case of an accident. IT engineers described the process as being a "reactive use of data". The aim now is to collect process data that will be saved in Shell's database PI (process information) and to provide operators access to the database. The PDA thus enables operators to use the data proactive.

In the past, operators used paper-based forms (spreadsheets) that listed all checkpoints. (Positioning and number of tags as currently installed in the plant are based on this spreadsheet.) However, paper forms can be completed independent of the location. Using a handheld device for data capturing means to be on the spot and to get familiarized with the plant. Moreover, the handling of paper sheets, especially in bad weather, is challenging. A PDA is supposed to improve procedures, save time, and make operations more efficient.

4. SYSTEM PROBLEMS | INTERPRETATION

Transfer of data

The PDA cannot directly communicate with the SAS system or check and update data in SAP. The systems are running on an independent desktop PC, meaning that the PDA device is not integrated in Shell's IT-network.

After finishing the logging tour, the collected data is transferred via a docking station that is placed next to the control room. In doing so, operators must leave the software program that runs on the PDA, put the PDA into the docking station, and start the software that runs on the PC. The entire process of data transmission takes quite long time.

Wireless communication between the operating system of the PDA and the systems being used by Shell (SAP, SAS, and PI) would simplify the work process in terms of data transfer and data access. The use of the handheld PDA for direct reporting and updating of SAP would save operators time and effort and contribute to safe plant operation.

Double check of data

Some of the process information is automatically read by the system, meaning that special data measured by transmitters, such as temperature or pressure, is automatically stored in SAS and transferred to PI. Plant operators capture, however, much of the same data. In addition, the control room records much of the same data. Examples are double checks of special pumps, where both control room and plant operators check the pressure as well as double checks of different levels. According to operators and IT engineers, there is no need to store these types of data in PI.

Automatically updating of existing systems can reduce unnecessary checks and documentation of process information and allows for efficient use of resources.

5. OTHER ASPECTS	INTERPRETATION
AT-procedures	
The operators criticised paper-based equipment because paper sheets are not suitable for operations in the plant. The most obvious example for paper-based procedures in the field is the signing of work permits (AT). Once signed, an AT-coordinator who has the overview over all permits activates or deactivates the documents. Plant operators usually use radio communication to call the AT-coordinator. For this purpose they must change the channel and use the AT-channel. Afterward, they must change back to the original channel.	The current AT-procedures at process facilities are extremely time-consuming and exceedingly unsuitable in view of the work conditions in the field. Plant operators wear protective clothing, including gloves. They are equipped with several devices, and they must work under demanding weather conditions. It is challenging to work with paper sheets in windy, wet, and cold weather. Moreover, operators spend a lot of time waiting for qualified colleagues who are allowed to sign the work permits. On the other hand, those operators who have been called to sign have to go back and forth and must interrupt their work.
Operators reported that the work task also includes a risk for errors. Operators have actually experienced frustrating situations caused by errors associated with AT-procedures.	This type of administration effort might be improved by using modern wireless technologies and integrating manual work tasks into existing systems that are already used. The process around work permissions needs to be simplified and digitised in order to avoid unnecessary paperwork, to save time, and to increase safety for people and environment.

The following table summarises suggested improvements regarding logging procedures that came up in the interview and in later discussions.

Table 6-2: Overview of suggested improvements by the study participants.

	SUGGESTIONS
Improvement of the GUI	IT engineers want to improve the displayed information (textual feedback) because of its equivocality. Focus is on the type of information users get when a question comes up on the screen.
Improvement of functionality	IT engineers consider the embedding of a menu function that gives access to predefined measurement readings. There is need for improving interchange and direct communication among the different systems — including automatic notification in SAP — to make logging less static and data transfer quicker and efficient. This may include the embedding of predefined measurement readings and error codes to give operators easy access to data. Operators suggest the inclusion of a software application for AT-procedures in the handheld device.

Improvement of ergonomics	One participant mentions the idea of arrow keys to control the display instead of using the stylus.
Improvement of procedures	The study participants like to phase out several measurement readings because the SAS system records the same data. Instead, they want to have some control on cooling and more manual measured data. Moreover, engineers plan to further develop the mobile system with respect to control of filters. Engineers also plan to reduce the number of tours and tags. Too many logging tours are being conducted today, and operators have to scan many tags. Logging tours can thus become confusing. Moreover, engineers and operators want to reconsider time intervals for data logging, as several checkpoints do not need to be inspected as often as now.

6.2.2.2 Discussion

Routine checks on oil level, temperature, or pressure are particularly important in the gas industry. The emergence of mobile devices is increasingly making it possible for plant operators to collect process information in a more efficient way and thus to save the company time and money. Undoubtedly, routines have improved with the mobile data logger MC 9090ex-K, through the replacement of the previously printed checklists with technology. However, the study results still show potential for improvement. It has been shown that the design of human-machine interaction involves much more than the aspects of product usability. In the following, some of the issues will be discussed.

Designing for small screens – graphical user interface (GUI)

Display legibility depends on surroundings, lighting conditions, and not least the screen technology. Nevertheless, a well-designed graphical user interface (GUI) is of great importance to ensure that the device can be used effectively. Text presentations and the design of visual content on small-screen devices pose a special challenge, as several factors can affect their readability. As the field study at Nyhamna has shown, environmental factors — in particular, direct sunlight and rain — play an important role in the device application. This result is not surprising and may be observed under normal outdoor conditions. The point in this case is that the users are working in a hazardous environment, which makes it necessary to carry out activities in an efficient and safe manner. Designers and engineers must therefore develop product concepts that address the specific needs of operators working in demanding environments. Another challenge concerning the interface and software design is the lack of space on smaller screens. This leads to the demand for the dynamic organisation of space, which is one of the most difficult aspects of design, as the amount of information displayed is usually high.

The overall product design of the handheld PDA – human factors

The data analysis of logging procedures at Nyhamna has shown that end-users struggle with a quite clumpy handheld device that is difficult to handle because of its weight, its size, and the design and arrangement of individual elements (e.g. scan exit window). The product is rugged and compact because it is supposed to be used in harsh environments. In addition, it must comply with the ATEX directives defined for Ex-zones to make it intrinsically safe for explosive environments. However, the field study shows that the MC 9090ex-K is too massive in size and weight, and thus, it has a negative impact on the operators' mobility. By means of the video artefacts, how operators move in the plant and what body postures they adopt during maintenance work can be identified. Against this background, the question arises as to whether or not the design of future mobile devices for use within integrated operations in the petroleum industry should be based more on the design criteria for wearables (see Section 3.6.3 for examples of wearable computing). The main difference between mobile devices, such as a handheld PDA, and wearable devices is that wearables are worn on the body during use (for example, under, with, or on top of clothing), and they support action in the environment rather than action on the device. Of course, many questions remain unanswered, such as the size, information content, and connection with other devices. Nevertheless, it is worthwhile to pursue their approach in further research, which focusses on actions taken in the real world with the aid of mobile devices instead of focusing on the pure operation of mobile devices. Operators mentioned that certain features of the handheld PDA, such as the keypad, are rarely used. We obtained similar results in the investigation of the TETRA terminal. That should be reason enough for designers to reconsider the product design of handheld devices.

Procedures

Although the implementation of the mobile data logger has improved previous inspection procedures (by replacing paper-based checklists), there is still room for improvement to make work execution more efficient. The field study at Nyhamna was followed by an evaluation of the entire data logging project on the part of the responsible people in the organisation. The research report on the study and the created video artefacts that document the data analysis served as an inspiration and basis for improvement. The handheld PDA MC 9090ex-K is currently still used for data recording. However, after completion of the study, the number of logging points was reduced, and changes were made with respect to the logging rounds. In addition, the study has confirmed what we had already documented in previous studies; the current work permit procedures are time-consuming, error-prone, and not suitable for activities in process plants. The entire administrative effort associated with the work permits could be improved through the application of wireless technologies and intercommunicating IT systems. In 2014, Shell Ormen Lange started a pilot project with a computer tablet with the purpose of making the administrative effort required to give work permits to operators efficient and with the purpose of improving operational efficiency by reducing radio communications and reducing errors. The pilot was successful, and the tablet has recently started to be used in regular operation. At the time of writing this chapter, about 60 work permits per day are issued, and the engineers involved in the project are working to integrate the project into the system and to increase the number to about 200 work permits per day.

Psychological effects on users

In the sections on the TETRA terminal, the psychological impact of new technologies on users has already been discussed, and the importance of the introduction of new technologies in order to achieve better user acceptance has been stressed. In this case, it has been shown that some of the operators have been concerned about the possible side effects of the PDA on the individual user, in the sense of a controlling effect. However, the main purpose of the device application is not to monitor its users but to ensure that facilities and equipment are inspected periodically and hence to ensure that the plant is operated in a safe manner.

Design of the workspace

We have also discussed the extent to which workspace design affects human activities. In the observational study on processes at Hammerfest LNG, we found a lack of clear orientation guidance for operators who are not familiar with the plant (such as suppliers or first-time operators). The study of radio communication by means of Motorola's MTP850 Ex TETRA radio showed, however, that the physical space design can affect communication due to inadequate coverage and that the long distances at the plant affect task executions. Finally, the present study on data logging processes at Nyhamna has shown that barcode tags are not always easy to identify. They are mounted on different components and equipment that are arranged in a physically complex environment, in which construction, assembly, and surface structure determine each object (see Figure 6-5).

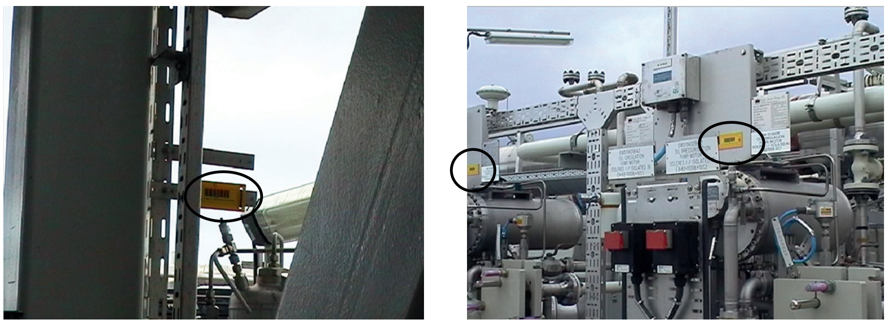


Figure 6-5: Examples of barcode tags that have to be identified and scanned by operators on their logging tours (Photographs: author).

To sum up, I argue that the lack of user acceptance of handheld devices currently used in the process industry is due to our poor understanding of the complexities of human activity. This activity includes human-machine interaction in a challenging work environment, such as the oil and gas industry. Drawing on the theories reviewed in Chapter 2, the literature on the sensory perception of objects reviewed in Chapter 3, and the research examples on handheld devices given in Chapter 4, the design task of future handheld devices for use in hazardous working environments should be considered on a (physical) activity level and on a technological level. Technology development must take into account the way in which users interact, rather than focusing only on technical issues.

The final sections of this chapter will take a deeper look at the activity system of plant operators based on the empirical data that have been presented above.

6.3 The activity system of plant operators

In the previous chapters, a number of relevant analysis techniques were discussed, ranging from Distributed cognition and Activity theory (chapters 2 and 3) to user and usability studies (chapters 4 and 5). For the present research, activity analysis that builds on Activity theory is emphasised. Activity theory considers human activity as a unit of analysis and differentiates among activity, action, and operation. This is an essential point of the observations presented here. As I will explain below, it has been shown that handheld devices are often suitable for a specific operation at the process plant, but at the same time, they affect other actions (and operations) within a complex activity.

Activity levels

As mentioned in Chapter 5, the three-level concept of activity is of particular interest to the present research case because it distinguishes between individual action (qualified by individual operations) and collective activity. Against this background, we can consider the activity system of process operators as a set of three different actions that can be divided into units of specific task executions — the operations. Based on the fact that human activity is performed at the three levels of activity, action, and operation, we can look at onshore gas production as an overall activity that consists of the actions of *plant operation, communication*, and *administration*, which, in turn, include concrete operations, such as maintenance work and data logging (*plant operation*), communication on work permits (*communication*), or data transfer (*administration*). These operations are performed according to a specific context in which the operations (and hence the actions) occur. They are always executed using different tools and are often routines. For example, the handheld PDA MC 9090ex-K is used in the context of data logging routines at Nyhamna with the aim of collecting and analysing the process data of the plant. Figure 6-6 illustrates the three action-based activity systems of plant operators, which include the operations of data logging, radio communication between CCR and plant operators, and data transfer regarding work permits and process data.

Figure 6-6: Plant operating, communication, and administration (actions) are performed as part of the overall activity — in this case, onshore gas production. Each action includes concrete operations enhanced by the use of physical artefacts, such as paper and pen, and by IT, such as stationary equipment, a handheld PDA, and a TETRA terminal.

Referring to Figure 6-6, certain handheld devices are used to perform certain operations (such as the handheld PDA for scanning barcodes or the TETRA radio for radio communication with the control room), and corresponding devices simultaneously affect every single action and the operations incorporated therein. Because plant operation, administration, and communication are interrelated processes, the applied technical devices will also usually be present at all levels of the activity. Thus, they not only mediate a specific operation but rather a set of operations that concern different actions. A device may barely or not be used at certain levels of the activity system. Nevertheless, operators must still handle it (see Figures 6-7 and 6-8). This applies not only to the handheld PDA but also to other devices and tools because field operators are usually equipped with portable gas detectors, portable radios, tool belts, and writing utensils (see Figure 6-8). For the design of future devices, the question arises as to how comprehensive the context of use must be understood. However, this question is not aimed at a high complexity of integrated functions, but at the device application or handling (which involves the carrying of devices) as part of a complex human activity system.

Figure 6-7: Operators performing data logging mediated by a handheld PDA. During the logging procedure, operators will perform other operations that will not require the PDA. These operations can either relate to the same action (e.g. maintenance work as part of plant operation) or to another action (e.g. signing of work permits as part of administration).

Figure 6-8: Plant operators are usually equipped with a set of tools, including formulas, a radio, a gas detector, and in the case of Nyhamna, a mobile data logger. The equipment is present at all levels of the operator's activity system and hence has impact on different actions and operations.

For an action to be carried out in onshore gas production, designers and engineers must take into consideration the resources and conditions of the plant environment when developing artefacts. The bodily execution of actions, which comprise low-level operations that, in turn, include human-device interaction, must be understood against the background of the conditions given in the situation of action. These conditions and the artefacts determine the level of operations. For the task of designing instruments and tools, this means that interactions cannot be considered in isolation from contextual aspects of human activity and the motives of action. With Engeström's model of analysis of the human activity system, we can illustrate the nature of human actions in the context of gas production and represent their context and motives in order to give them meaning.

Structure of the activity system of operators

Given the idea of the activity theorists that artefacts mediate human activity, Activity theory provides a framework within which we can understand how handheld devices mediate and affect operator activity in gas processing plants. Engeström's model of the structure of a human activity system can be used to describe the specific activity system of plant operators.

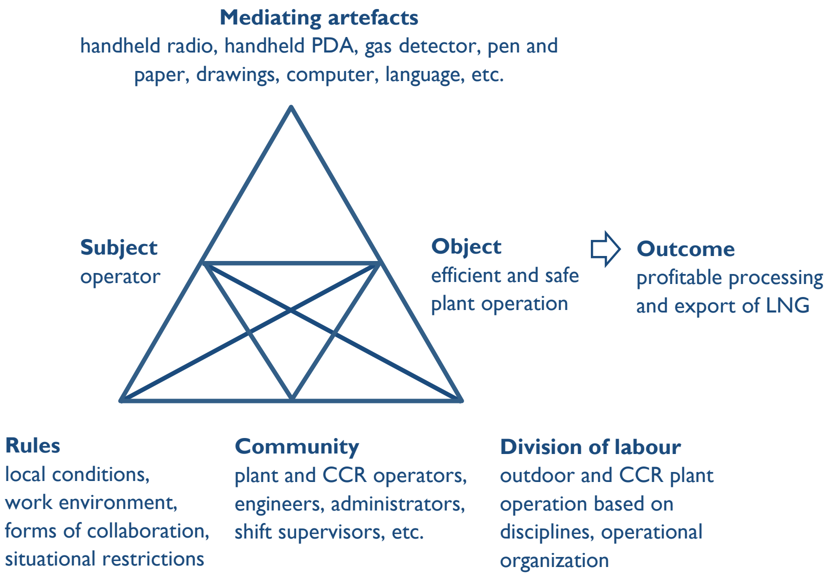


Figure 6-9: Application of Engeström's model of the structure of a human activity system to the activity system of gas plant operators.

The activity system of process operators includes a community consisting of field and control room operators, engineers, shift supervisors, and administrators. This community works according to rules that determine individual work performance and behaviour. For example, local conditions (including extreme weather conditions, plant structure and plant design, hazardous areas within the plant, and high noise level) lead to regulations for protective clothing and equipment, a code of conduct for working within the plant, and the organisation of work processes. The forms of collaboration are regulated by work permit procedures, by the interaction between the CCR and field operators, and by communication processes in the field. Situational restrictions are those that are imposed by the plant and that have an impact on human mobility (see the reflections on embodied practical action as the source of meaning in Chapter 2). The division of labour signifies the roles that individual subjects have within the activity system. For example, CCR operators control and monitor all processes from the central control room, while field operators perform maintenance work, data measurement, and the management of work permits in the field. It also reflects structures and responsibilities that individuals have in the community. The object of the activity system is efficient and safe plant operation to ensure health and safety for people and the environment. It is mediated by various artefacts — digital and physical — that help subjects to achieve the outcome of the activity: the processing and export of LNG.

According to Engeström, this projection from the object to the outcome is what serves as the motive of the activity and gives meaning to the actions involved in the overall activity (Engeström 1999).

Structure of the activity levels to describe the activity system of operators

In the next step, the three-level concept of activity and the model of the structure of the operator's activity system will be illustrated in a new combined model.

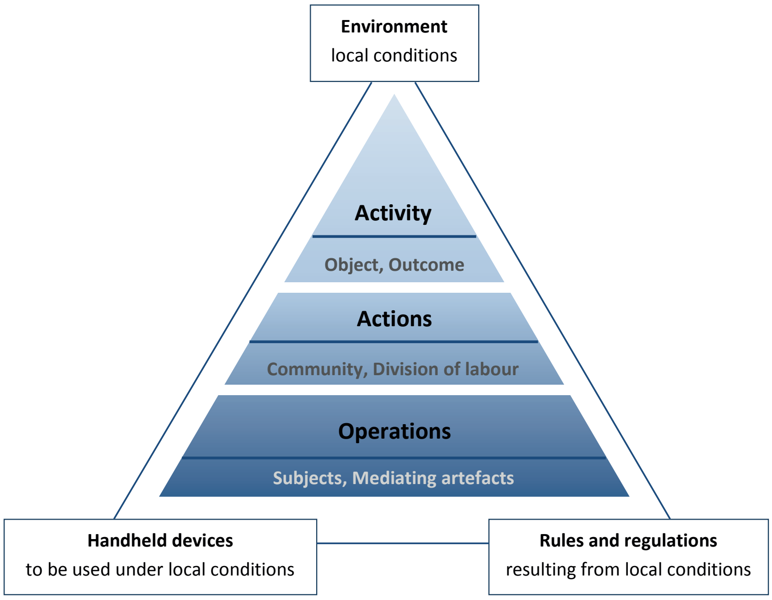


Figure 6-10: Model of the structure of activity levels to describe the activity system of plant operators. It includes the impact of the dependencies among the local conditions of the environment, rules, and handheld devices on the activity system. The model transfers the concepts of a three-level activity and the structure of a human activity system into the specific context of operator-device interaction.

The illustration combines the idea of the three-level concept of activity that distinguishes among activity, action, and operation, with the model of the structure of the activity system of operators that focusses on the interrelations among the individual subject, his or her community, and the object. The object of the collective activity — in this case, efficient and safe plant operation — and the outcome of processing and exporting LNG are what connect individual actions and operations to this activity. The actions are those of plant operation, communication, and administration, where people from different disciplines and with different responsibilities are involved. These goal-oriented actions are related to plant operations performed by individual plant operators by means of mediating artefacts such as language, handheld devices, and tools. Additionally, the illustration shows the dependencies among the environment in which the activity takes place, the rules and regulations (e.g. protective clothing) that result from local conditions, and the handheld devices that are to be used under the existing environmental conditions. These dependencies affect the entire activity system of plant operation and hence each level of activity.

6.4 How handheld devices change environment, subjects, and object

So far, we have described how 1) the environment, 2) subjects, and 3) the objective — which are elements of the activity system of plant operators — affect interactive devices. We have illustrated (1) how weather conditions, plant design, protective clothing, and rules of conduct affect the use of interactive handheld devices; (2) how field and control room operators use devices by means of certain functions, controls, and graphical interfaces; and (3) how the objectives of efficient and safe plant operation and the profitable production of LNG have an impact on the future implementation and application of wireless technologies [for the last item, see Section 4.1 Interaction in Integrated Operations (IO) and 4.2 Wireless Solutions]. Moreover, we have illustrated the dependencies among the environment in which the activity takes place, the rules that result from the conditions of the environment, and the devices to be used under the existing environmental conditions. From the field study results, we concluded that these dependencies affect the activity system of plant operators. The following section will illustrate how future interactive handheld devices can change items (1) to (3). By placing handheld devices into the centre of the triad of subject-object-environment, we can first describe both directions of the influences.

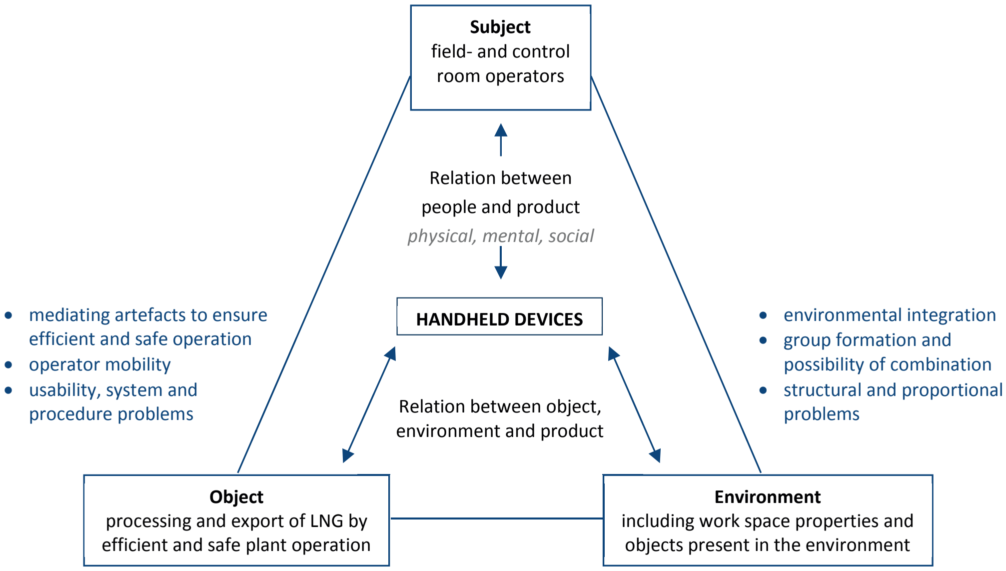


Figure 6-11: Relation between handheld devices and the construct of subject-object-environment.

The relationship between products and their users is characterised by physical, mental, and social aspects. On the one hand, users act directly on equipment. On the other hand, technology can change its user psychologically and socially. Smartphones, computer tablets, and the Internet determine the daily lives of most people. These devices have changed social structures and patterns of behaviour and have influenced interpersonal communication significantly. On the other hand, future handheld devices must take the environment and the objects already present in it into consideration. This has consequences for the environmental integration of future devices, group formation and combination as well as structural and proportional problems. Following the concept of the life world in phenomenology, the world is already structured and meaningful. Hence new technologies have to be embedded in these structures. What modern technologies such as handheld devices change is the way in which people act in the world. The purpose of handheld devices for use in the petroleum industry must therefore be to support meaningful action in a structured, hazardous environment. The objective of the activity of onshore gas production might not be apparent until new technology ensures increased mobility and flexibility amongst plant staff that leads to increased efficiency in plant operation. If new devices are difficult to use and system and procedure problems occur, the collective objective of an activity is not achieved.

To sum up, a handheld device is usable only when it fits into the relational context of subject-object-environment.

6.5 Summary and conclusion

This chapter aimed to answer the questions of how the product design of mobile devices affects the efficient and safe work in Norwegian plants in the petroleum industry and how field and control room operators evaluate design and usability of mobile devices in support of field operation. At the beginning of the chapter, the results of the three empirical field studies carried out on two Norwegian onshore facilities were presented, with an emphasis on work performances and the interactions of operators as well as the usability evaluations of handheld devices. It was suggested to follow key elements of Activity theory to inform our understanding of the activity system of process operators. The three-level concept of activity and Engeström's model of the structure of a human activity system have been found to be useful for illustrating the dependencies among different actions in plant operation. Based on these two approaches, a third model was developed (Figure 6-10) that stresses the dependencies among the environment, the rules resulting from the conditions of the environment, and the interactive handheld devices to be used under these conditions, with respect to current rules and regulations. The main point of this model is to emphasise these dependencies as a permanent concomitant phenomenon of the particular activity system of plant operators who work in the petroleum industry.

From the results of the study analyses, we can conclude that the improvement of work performance at LNG facilities towards efficient and safe actions and operations cannot be solely achieved by mobile technologies designed to support certain operations executed by operators. Process operators are only one part of the activity system. At the plant, they must complete numerous routine tasks while they collaborate simultaneously with other members of the same system. For design, it is important to take into account the dependencies among the individuals in the work community, the dependencies among different actions, and the interdependence of mobile technology and action execution. Our study showed that there is an urgent need to address many aspects of the gas production situation, which includes the rules that result from factors of the work environment, situational restrictions, and cultural and social influences on collaboration.

To be able to design new mediating artefacts in terms of future mobile technologies, not only must individual artefacts be considered in an analysis but also the entire complexity of plant operation must be taken into consideration. This is what Activity theory suggests. This chapter documents only a small part of the whole process. However, it already shows how complex the activity system is. The next chapter will recommend design criteria based on the empirical data presented here and on the theoretical knowledge provided in chapters 2, 3 and 4.

7 DESIGN CRITERIA — IMPLICATIONS FOR PRODUCT DEVELOPMENT

In Chapter 6, the results of the empirical studies were described. This chapter aims to answer the question of how mobile devices should be designed to meet efficiency and safety requirements at Norwegian oil- and gas facilities (research question 3). The chapter presents theoretically and empirically grounded criteria and their values for designing future handheld devices for use within integrated operations in the petroleum industry. Finally, drawing on the results summarised in Table 7-3, a hypothetical evaluation of three different design approaches will be made in order to identify the opportunities and challenges of modern mobile devices.

7.1 Design criteria and criteria value

Based on the findings presented in the previous sections, the following section suggests criteria and criteria values for designing handheld devices to support task performance in the petroleum industry. The main findings are summarised in Table 7-3.

Extend the design process

As the previous chapters have shown, the design process of human-computer interaction comprises design theory, research in the field, research analysis, and product development. Design theory gives information on the research methods appropriate for conducting field research, and it provides theoretical frameworks and approaches for data analysing. For the current subject of operator-device interaction in the oil and gas industry, designers and engineers must draw on design principles and theoretical knowledge about cognitive processes to succeed in developing future mobile technologies. In chapters 5 and 6, I have shown that traditional research methods such as qualitative interviews and video-based participant observation are suited for research in this field (video observation in so far as it is possible). For research analysis, the key elements of Activity theory are proposed to describe the activity system of plant operators, and design methodology is suggested to verbally and nonverbally describe research results. Figure 7-1 shows an example of how to combine verbal and nonverbal data using design methodology.

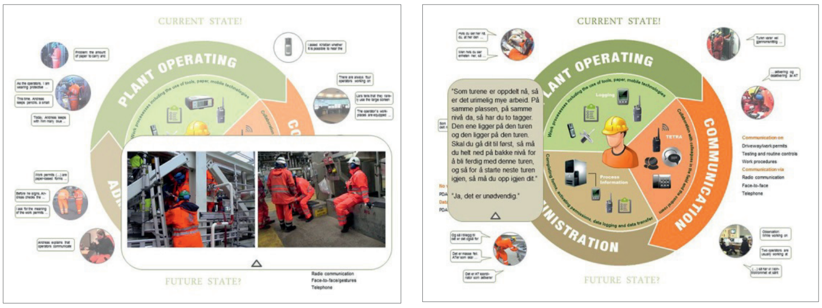


Figure 7-1: Example of an interactive infographic that includes photographs (left) and citations (right) to provide researchers with detailed information from field research. The infographic allows for selecting individual items of the graphic in order to be able to study, for example, human motion in more detail or to become informed about user feedback.

Further, the research on handheld technology should be oriented towards the user's goals and should therefore apply a user-centred design approach that includes methods of participatory design. This will address challenges in operator-device interaction from the user's perspective.

Pay attention to behavioural patterns and experience

Berger and Luckmann explain: "All human activity is subject to habitualisation. Any action that is repeated frequently becomes cast into a pattern, which can then be reproduced with an economy of effort […]. Habitualization further implies that the action in question may be performed again and again in the same manner and with the same economic effort". (Berger and Luckmann 1967: 53). In chapters 3 and 6, I have argued that humans are provided with spatial orientation in order to find what we expect to be the correct function or the correct button of a handheld device. For future design, this means investigating potential consistencies in current product designs (e.g. standard positions of buttons or controls) and studying the expectations and habits of users. At the instance of the misapplication of the emergency button included on the top of the MTP850 Ex TETRA terminal (described in Section 6.2.1), we can illustrate a pattern of use with Figure 7-2.

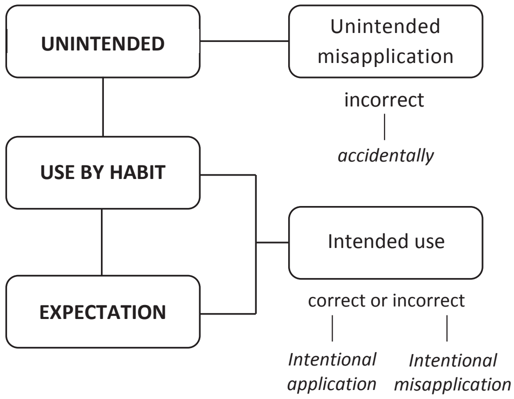


Figure 7-2: The figure shows a pattern of use using the example of a control element included in a handheld device.

A control element might be used correctly or incorrectly. In the case of correct usage, the control element will be consciously operated (intentional application) — for example, the emergency button of the TETRA terminal used to send an emergency alert in the case of an emergency. In the case of incorrect usage, the button might be accidently operated (unintended misapplication) — for example, by an unfavourable movement — or it might be consciously misapplied (intentional misapplication) out of habit or because of the wrong expectations regarding the button's function.

It is the primacy of use

A key challenge in the development of handheld devices involves succeeding in finding a design solution that prioritises the practical use of the device. Hückler states that "if a product cannot be used because it is incomprehensible and because it interferes or even prevents its application, then it cannot work technically — it will not even be put into operation: the primacy of use is essential". (Hückler 2000: 153, translation of the author)

In the light of Gestalt theory, which is discussed in Chapter 2, this thesis wants to challenge design in order to capture product qualities as a whole, for design applies the idea that the whole is greater than the sum of its parts. This is also emphasised by Hückler, who says: "This 'more' to find out is the special service that cannot be provided professionally from other disciplines". (ibid.:154) Further, in Chapter 2, I suggest that aesthetics should be understood based on the gestalt of a product because satisfaction with a device results from its real use, not from its appearance. Whereas the gestalt of a product provides actionable properties for correct operation, its appearance may involve semiotic structures regarding functions. The connection among the characteristics of devices indicating their proper use and affording action, their visual and non-visual perception, and the clues from the experiences with devices is important in the design process.

Design product interfaces including graphical interfaces

Non-visual perception can help in the localisation and identification of object or product components, especially if a product is to be used in mobile contexts, such as in the outside plant areas of gas refineries. In recent years, it seems, the most important improvements have been made in optimising mobile applications in terms of battery life, weight, size, and the GUI of small-screen devices. At the same time, the number of functions has increased. In this thesis, I argue that information about certain product functions can be perceived via multiple senses, including the sense of touch. There is an appropriate quote from Aristotle: "While humankind is far behind many animals in respect to all the other senses, he far outdoes them in the refinement of the sense of touch. That is the reason why humankind is the cleverest of all living creatures." (Aristoteles, cited in form+zweck 18, 2001: 36) In Chapter 3, I argue that haptic object recognition can help to relieve users of mobile devices from visual overload in an environment where visual recognition of information is critical. The problem with touchscreen devices is that they utilize only a few of the capabilities of perception and sense, and they require the user to look at the screen at every point in the interaction. As proposed in Chapter 4, mobile devices should support in focussing on their tasks rather than on the device. Haptic effects as well as kinaesthetic, acoustical, and visual properties can help to create a more intuitive user experience and to keep the focus on the device to a minimum. For the design task, this means the product should activate multiple senses in order to improve the experience of a technical device by means of more effective device feedback. That includes physical information provided by materials, surfaces, shapes, and the component's layout, which, in turn, requires designers to focus on product interfaces rather than merely on graphical interfaces (Figure 3-4 in Chapter 3 suggests a broader view on interface design).

Support task performance rather than device performance

Following the argument that the main focus of interactions in work contexts should be on tasks rather than on devices, I discuss in Chapter 3 how wearable computing supports activity in the real world. We found that, in light of operator-device interaction in challenging work environments, meaningfully designed wearable technology supports the actions executed by operators in the plant, as the use of the device is no longer the primary action. In his article "The Paradox of Wearable Technologies", Norman (2013) argues that wearable technology can enhance our abilities significantly when applied mindfully. He raises the question of whether the stream of messages from wearable technologies will divert people from work or increase people's abilities. The response, according to Norman, cannot be to place the burden on users alone, in the sense that they have to use technology in a responsible way. Instead, the providers of these technologies — and this includes designers — must share the burden of responsible design (ibid.). In order to focus on and augment operator activities, wearable devices should therefore conform to the actions, motion, and conditions of the environment.

In his book "*Moving Wearables into the Mainstream: Taming the Borg*", Dvorak (2008: 103) suggests design principles that broach the issue of "non-use obtrusiveness" — in addition to setup effort and interaction complexity. Principles are, for example:

- to use body-conforming shapes
- to conform to the body's contours and motion in all planes
- not to impede the normal operation of the body limbs
- to reduce opportunities for conflict with the physical environment
- to attach wearables to the body or clothing in a non-invasive manner

The author further made up four factors affecting the acceptance of wearables:

- Wearability
- Functionality
- Operation
- Aesthetics (ibid.: 103-105)

Kitagawa (2014) proposes additional rules. Two of the most relevant are:

- to base the design of interfaces for wearables on how consumers will use them, not on reproducing smartphone or computer tablet experiences (ibid.: Rule 1: Augment, don't replicate)
- to ensure multiple layers of security, such as device security regarding operating systems and applications, link security regarding data transmission between wearables and a central hub, and cloud security with regard to the storage of information (ibid.: Rule 5: Security above all)

Even if we cannot deal with the issue of information and network security in this thesis, it is nevertheless very important for the development of new systems, especially when it comes to critical applications, such as in the petroleum industry. Considering the research findings on operator activity, and drawing on previously published knowledge — in particular, on Dvorak's work — the following criteria might be relevant for wearable devices for use in hazardous work settings:

(1) Device placement on the body is important

Devices should be placed on body areas that are not moved very much during the course of the operator's working day, and they should adapt to individual movements (e.g. climbing, bending, or rotating) in order to avoid causing discomfort to the operators. Moreover, heavier devices should be placed closer to the centreline of the body, e.g. on the waist, as placing them far out on a body limb may result in muscle fatigue.

(2) The device should fit the body contour

The device's shape and surface should fit the body's contour in the area of attachment. This includes considering the curvatures of inner and outer shapes in relation to the body area and conical shapes in terms of a stable positioning on the body. Moreover, sharp edges should be avoided for better wearing comfort.

(3) Device attachment should be stable

Affixing forms to the body should follow the body's contour throughout its lengths and widths, rather than using single points of attachment that may be more unstable. The device should move in accordance with the body movement; it should not develop its own dynamic.

(4) Consider variations of body sizes

Wearable devices should be adjustable to fit the operator's different sizes and shapes over a period. Modular product structures could provide some adjustment.

(5) Provide easy physical access to control elements

Physical access to the control elements should be intuitive and not require intensive user attention. Wearable devices are supposed to be used during operators' task performance. Hence, operators should be able to focus on the task usually associated with motion.

(6) Provide interaction modalities

The user interface should provide multiple interaction modalities, such as visual, audio, tactile, and speech modalities. Operators could thereby be able to switch between modalities according to the current application context and could be more effective in performing tasks.

(7) Ensure information and network security

Due to the sensitive nature of the data in this sector, network levels need to be protected from intrusion, and operating systems and applications need to run securely. This requires secured architecture and data protection.

HCI is also a concern of ergonomics

Ergonomic factors do not just concern the weight and size of a handheld device. They also relate to given anatomical facts of the human hand with regard to directed movements and hand grips, left- and right-handedness, the limitation of tactile perception through gloves, and visual overload (see also Chapter 3.7). The study on the usability of the barcode scanner has shown that scanning procedures can become cumbersome because of the relatively bulky design of the device and the positioning of the scan exit window, which make hitting the barcode labels sometimes difficult. If operators will use the unit over a longer period, it might have an ergonomic impact on the arms and wrists. In addition, limited visibility and low contrast can affect the readability of the display and the laser detection on surfaces. Therefore, design should also look at the quality of device feedback — in addition to a natural adaptation to arm and hand postures. Moreover, operation complexity and operation logic in interactive systems are closely related to ergonomics. The design of HCI should be aimed at making device operation processes accessible to users through product semantics. However, the overall purpose should be to leave use-intensive complex technologies behind and turn towards context-oriented and coherent technologies.

Designing HCI is multifaceted

The support and improvement of HCI in the oil and gas industry does not refer only to the design of handheld devices. The HCI design task is much more complex and includes equipment, space, and procedures. As the research results of the field studies that were presented in Chapter 6 have shown, the usability of handheld devices is determined by factors that go beyond those of the GUI. The context of the use of mobile devices in industrial process plants seems to be particularly complex due to local conditions, the resulting rules, and social aspects. Based on the findings of the present research, it is suggested to include the aspects of:

- an orientation guide for first-time operators at the plant
- processes for the introduction of new technology and transitional periods

On the product interface side, important aspects are:

- the purpose of use
- the gestalt perception of objects
- ergonomic criteria to support operator mobility and flexibility
- the application of design and gestalt principles of visual perception, such as the principles of colour, proximity, similarity, closure, and continuity
- the inclusion of different human senses to improve the perception of product interfaces

Industrial requirements for devices used in hazardous areas

In the present case, mobile devices are used in hazardous areas. Therefore, additional safety requirements apply to all devices. As explained in Section 4.2, electrical equipment for use in Zone 1 are subjected to the ATEX Directive 94/9/EC and must meet the requirements for the category of equipment II 2G, which is the category for surface industries with a high level of protection and therefore a high degree of safety (Bartec 2012, 2013). On the design side, protection methods prevent equipment components such as batteries from becoming an ignition source. The methods relate to appropriate materials or the protection of components with an enclosure that prevents explosive mixture entry into or contact with sources of ignition (Bartec 2012). Encapsulations may have an impact on the size and weight of handheld devices. However, the example of Bartec Pixavi's smartphone Impact X presented in Section 3.5 shows that today's explosion-proof products do not have to be bulky.

The following section and tables are not to be understood as criteria; they only provide technology evaluations and directions for solutions. In light of the requirements for environments where visibility is often low and time constrained, technical aspects of RFID systems and aspects of screen technology are, however, important factors in designing handheld devices.

Technical aspects I: the benefits of RFID systems

In Table 6-1 presented in Chapter 6, I have raised the problems of barcode technology briefly and identified the advantages of RFID technology. RFID is a system that consists of rugged readers and tags that transmit detailed information about locations, equipment, or services. RFID identification has been used for years in logistics, production processes, animal identification, tracking and tracing at airports, or for access control, to name just a few examples. The main advantages include reading speed, durability, and insensitivity to external influences such as weather conditions. A further advantage of RFID systems is that no visual contact is needed; the data are transmitted by a transponder (tag) without visual contact with an RFID reader, and vice versa. Thus, the transponder can be read when there is fog, snow, ice, paint, or dirt or in difficult construction conditions. In addition, data from RFID tags can be much more detailed, and the tags are rewritable and offer flexibility that cannot be provided by other forms of identification. Table 7-1 summarises advantages and disadvantages of RFID and barcode technology.[45]

Table 7-1: Overview over advantages and disadvantages of RFID and barcode technology.

Advantages of RFID versus barcode technology	Disadvantages of RFID versus barcode technology
• radio transmission without visual contact • re-writable • fast identification in less than a second • simultaneous capturing of great number of transponders possible • resistance towards most of environmental influences • penetration of different kind of material • transponders can be integrated into objects • capturing of RFID tagged objects is significant faster compared to objects with barcode tags • the RFID chip is a data storage • the placement of RFID tags is not as complicated as the placement of barcode tags	• more expensive than barcode labels • higher integration costs • concerns over data privacy protection of the population
Advantages of barcodes	**Disadvantages of barcodes**
• low priced • worldwide standardisation • common technology	• direct line of sight required • read errors through dirt, humidity and wear • static information • limited memory capacity

[45] The information in Table 7-1 refers to: RFID-Basis. Das RFID Informationsportal (n.d.) and Sharma, T. (2008).

Technical aspects II: resistive versus capacitive touchscreens
Another technological problem is the use of resistive touchscreens, as they are less sensitive and responsive than capacitive touchscreens are. This is due to its technical characteristics. Table 7-2 summarises the advantages and disadvantages of the two technologies.

Table 7-2: Overview over advantages and disadvantages of resistive and capacitive touch screens.

Advantages of resistive touch screens	Disadvantages of resistive touch screens
• cheaper to produce	• lower resolution
• work with a gloved hand	• more bulky appearance
• longer lifetime	• emits less than 75 % light from the screen
• due to the lower sensitivity, more precise selection of functions possible	• less sensitive
• common type of touch screen	• due to lower sensitivity, less responsive
Advantages of capacitive touch screens	**Disadvantages of capacitive touch screens**
• high resolution	• sensitive only for finger touch
• emits more than 90 % light from the screen	• does not work with non-conductive gloves or stylus
• sharp images, clear screen	• more susceptible to interruption from dirt and grease
• more sensitive	• due to the high sensitivity, accidentally selecting of functions possible
• due to the high sensitivity, more responsive	• more expensive to produce

However, the growing popularity of devices such as smartphones and computer tablets has entailed a rapid development of touchscreen technologies. Future handheld devices may therefore be equipped with sunlight readable and more sensitive displays.

The design criteria presented in this section are primarily based upon the theoretical and empirical findings of the present research project. An important activity in this project was the observation of operators in everyday task performance using different tools and handheld technologies. These observational field studies formed the foundation of the design criteria. They are summarised in Table 7-3.

Table 7-3: Summary of design criteria for handheld devices for use within integrated operations in the petroleum industry.

	Summary of criteria for handheld devices
General criteria	• Extend the design process beyond the product development. • Support task performance rather than device performance. • Do not limit HCI to devices alone; consider physical space and current procedures. • Meet ATEX Zone 1 requirements for electrical devices.
Product design	• Make handheld devices wearable and tangible. • Focus on the practical use of the device. • Pay attention to behavioural patterns and experiences of users. • Take account of the requirements for hazardous areas, Zone 1.
Product interface	• Focus on product interfaces rather than merely graphical interfaces. • Design ergonomic interfaces to make products accessible to users. • Simplify operating complexity and logic.

7.2 Examples of approaches

Next, I want to refer to four examples: one conceptual approach developed by third-year bachelor's degree students at the Østfold University College and three examples from the industry that are currently in use. The aim is to show how mobile devices could be designed to better meet user requirements to some extent.

Conceptual approach

The research presented has shown that operators working in the process industry currently use handheld devices equipped with multiple functions, of which only a part is actually used. Drawing on Norman's concept of perceived affordance that has been discussed in Section 2.4.1, and using the example of the digital handheld radio used at the Borregaard and Ormen Lange facilities, I found that operators probably use the radio in a way inspired by the most salient perceived object affordances (cf. Gaver 1991 and Norman 1993). They fail to use some of the available features, partly because they do not know about them or do not need them. Students at Østfold University College[46] have tried to address the problem and developed a design concept based on the existing digital radio MTP850 Ex and commonly

[46] The students are Karine Mile, Gitte Kalsvik, Trine B. Kalsson, Odd G. Eriksen, Oddgeir Johannessen, and Håkon Torgrimsen.

used headsets. Assuming that process operators are at times working under harsh conditions in an industrial setting where they are required to be mobile, wear protection clothes, and communicate in noisy places, the project aimed to improve radio communication at the Borregaard facility.

The portable TETRA terminal MTP850 Ex is approved for gas and dust and is designed to ensure high reliability. Nevertheless, after the radio device was introduced, some challenges occurred, and operators seemed not to be very satisfied. This may be due to the total weight of the entire system consisting of the components headset, TETRA terminal, remote PTT, and connecting cable as well as the device placement on the body. It may also be due to sound quality, functionality and operability. The goal of the semester project was thus to develop a communication system based on the operator's needs and working context. The system should include all relevant components mentioned above. Moreover, the students were required to base their design decisions on a context and user understanding including current communication practices, a critical analysis of the present product solution, and the problems related to it. From the criteria presented in Table 7-3, they were required to take into account:

- task performance rather than device performance
- a focus on product interfaces rather than merely graphical interfaces
- wearable and tangible aspects of devices
- simplification of operating complexity
- requirements for hazardous areas.

After visiting the facility and testing the MTP850 Ex TETRA radio, the students interviewed one operator and distributed two questionnaires among 34 operators. The questions focused on the use and operability of the radio unit and the headset as well as on the frequency of mobile phone use. The results showed that many respondents assess a headset and radio as heavy and large equipment with an annoying antenna, and they think individual buttons, such as the button to change channels, are easy to use accidentally. Besides, respondents reported on challenges with regard to coverage and sound quality. Still, the study participants evaluated the headset and PTT button as being positive, as they need to be able to work hands-free.

Perhaps the most obvious common result from the interview studies at the facilities of Borregaard and Ormen Lange is the limited use of device functions. Operators at Borregaard reported that many functions (e.g. phone calls, the sending of status and text messages, or the menu key to enter a main or context-sensitive menu) have never been applied. The functions in use are volume control, changing channels, and the PTT button. In Section 6.2.1, I reported that operators working at Ormen Lange do not use the radio's message function. Moreover, the application of the key pad is mostly restricted to the side buttons, including two programmable buttons and the PTT button. Given these insights, the primary goal of the semester project was to simplify the present radio by reducing the complexity of functions and by including particular features in the headset. Figures 7-3 and 7-4 show some details of the design process. Figure 7-4c shows the proposed concept.

Figure 7-3a-c: Use of simple mock-ups for testing possible positions of control elements on the headset. The students' idea was to make the features of volume, channels, and PTT button available on the headset in order to improve operators' experiences with these devices.

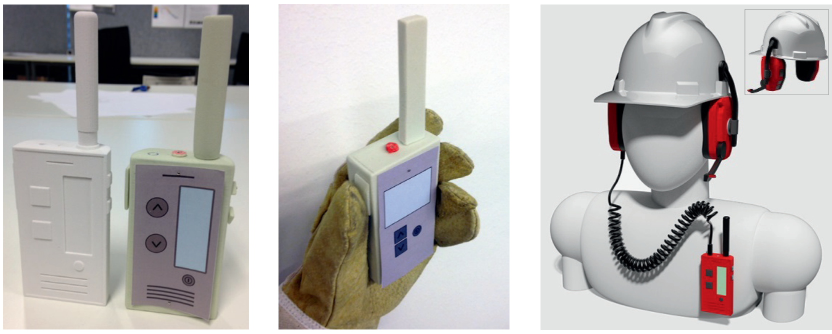


Figure 7-4a-b (left and middle): Simple mock-ups of the radio unit for testing size, shape, and inclusion of functions. The students reduced the number of functions and focussed on the primary task of voice communication. *Figure 7-4c (right):* The 3D design of the headset with an integrated microphone arm that acts as a switch to activate the PTT function; a volume setting and channel change button on the back side of the earmuff; a cable to connect the headset and radio; and a radio unit with integrated functions for volume setting, channel change, PTT, emergency, and power.

In view of the criteria presented above, the handheld radio has become more wearable and tangible, and operating complexity has been simplified. However, it must be noticed that this is a concept study developed during the course of one semester. The aspects regarding the extension of the design process beyond pure product development and the inclusion of physical space and current procedures were not sufficiently considered. Moreover, technical aspects and safety requirements are not yet entirely clarified.

Industrial examples

In chapters 4 and 6, I mention the test of a wireless technical solution for approving and completing work permits at Ormen Lange's process facility at Nyhamna. Using an iPad that is certified for ATEX Zone 2, field operators can now update SAP-based permit statuses directly via a handheld mobile device. Additionally, facility status report deviations are graphically displayed on information panels in the control room and permit office. Thus, the work permit coordinator in the permit office and field operators spend less time communicating via handheld radios, field operators carry less spreadsheets around with them, and status visibility in the plant is improved. This, in turn (along with the fast mobile data transfer offered by fourth-generation [4G] mobile networks), save operators time and administrative effort and contribute to improved plant operation. According to an information source, it can be assumed that SAP is currently developing their Android platforms, which will lead to future Android devices available on the market, including mobile devices certified for ATEX Zone 1.

Another example of the use of computer tablets in the process industry are the Samsung Galaxy Tab 2 tablets, the slightly smaller and lighter Tab 3, and Sony Xperia Z2 tablets, which are used at Sarpsborg Avfallsenergi AS. The tablets are used for process control and include alarm functions that have been developed by Predictor AS. The mobile solution relieves operators from covering long distances between the plant and control room and reduces the amount of work they must do, especially if a single operator is working a shift. Discussions with the facility manager and two operators have shown that the Samsung Galaxy Tab 2 best meets the demands of the users in terms of screen sensitivity, response, and navigation on the screen. However, the response time of the screen does not allow for process operation (information from Jørgen Karlsen, facility manager at Sarpsborg Avfallsenergi AS). Moreover, until now, three tablets have been destroyed, all because they have been lost and the tablet screen shattered.

Finally, Bartec Pixavi has launched the explosion-proof Android smartphone Impact X in 2014, which can work in hazardous areas. As reported in Section 3.5, the company headquartered in Stavanger has — on behalf of Shell — developed a device with a focus on product design and user satisfaction. It is equipped with two cameras; physical rubber buttons for navigation, power, and volume; a glove-friendly touchscreen, and video conferencing application software that allows operators to conduct live video conferencing sessions and stream video from the field. The smartphone is additionally certified for ATEX Zone 1 and is rugged due to its protective case — a thick one-piece aluminum case. On the wearable side, Bartec Pixavi has developed accessories that enable the device to be worn on the wrist (see Figure 7-5).

Figure 7-5: The explosion-proof smartphone Impact X can be mounted on a wrist cradle and enables hands-free working. (Photo: Bartec Pixavi)

In spring 2014, the Impact X received the Award for Design Excellence in the category of industrial design. The award was given by The Norwegian Design Council.

Unfortunately, no detailed usability studies on mobile devices in use are available yet. Initial evaluations from analysts at Nyhamna and operators at Sarpsborg Avfallsenergi AS have been positive, and to date, their expectations have been met at most points. The mobile products developed by Bartec Pixavi are under testing. However, drawing on the results summarised in Table 7-3, a tablet, smartphone, and wearable device can be evaluated to identify opportunities and challenges in light of the proposed criteria.

7.3 Evaluations

As mentioned in Chapter 4.3, the applications of mobile devices as well as their design depend upon the user task. Plant status control, global positioning system (GPS) navigation, or the treatment of digital forms will imply a higher amount of information and hence require larger devices with an optimal screen. In contrast, scan procedures or radio communication processes are less dependent on larger screens. However, the research findings of this thesis have shown that operators must fulfil multiple tasks during a shift, which means that devices that are carried at the plant affect multiple actions and operations (see Chapter 6.3 on the activity system of plant operators). Therefore, design has to deal with the question of how broad the context of use of mobile devices is.

The following table exemplifies four operator tasks and tries to evaluate the mobile devices: 1) a smartphone such as the Android smartphone Impact X, 2) a computer tablet such as the iPad and Samsung Galaxy Tab, and 3) wearables such as the suggested headset with a tactile user interface.

Table 7-4: Evaluation of three concepts of mobile devices regarding their practical use and their wearable and tangible design qualities.

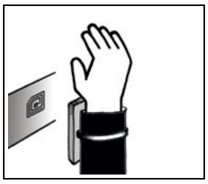
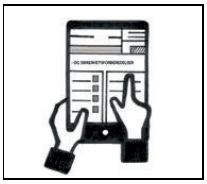
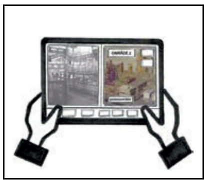
		RFID equipped smartphone mounted on the inner wrist	*Android tablet with mobile application to manage work permits*	*Android tablet with facility navigation app to guide first-time operators*	*Headset with tactile user interface for radio communication*
EXAMPLE TASKS					
EXAMPLE TASKS		Operators collect field-based process data via mobile device and report directly into Shell's database that is automatically updated.	Operators update SAP-based work permits via mobile device.	First-time operators orientate themselves on the plant via mobile device and navigation software.	Radio communication between control room and field operators via wearable device.
EVALUATION	Practical use	**Mobile performance** Operator mobility and flexibility is supported and task execution is improved. The hand strap makes the device usable and ergonomic. It is small and can be body-worn, which enables hands-free operation. The touch screen is glove-friendly.	**Operational efficiency** Replacement of paper-based task. Waiting time and administration effort are saved and error rate is minimized. Real time permit status is provided; radio communication is reduced. Difficult to wear close to the body, e.g. on the belt or arm. Readability may be affected by external conditions.	**Overview at a glance** Relieves experienced operators from unnecessary radio communication. Provides inexperienced operators more security in the orientation at the plant. Reduces confusing situations and risk of errors. Improvement of HSE and process safety.	**Easy to use device** The complexity of functions is reduced and operating complexity simplified. Operator mobility is supported. The mobile system is ergonomic. It enables hands-free operation.
EVALUATION	Wearable design	**Reduced content** Content must be reduced and image and text items are mostly placed one below the other to make them readable on the smartphone. Structured user guidance as in previous computer screen designs is not possible.	**Mobile vs. immobile** Relatively large device that neither can disappear in the overall pocket nor be clipped to the belt after the work task is completed. Size and weight have an impact on how to carry the device in the field.	**Mobile vs. immobile** Relatively large device that neither can disappear in the overall pocket nor be clipped to the belt once the correct location is found. Size and weight have an impact on how to carry the device in the field.	**Mobile and wearable** Wearable, lightweight device. The interaction system is included in the hearing protection equipment and there is no need for an extra device. Motion is hence less affected.
EVALUATION	Tangible design	**Quicker orientation** Visual and non-visual affordances indicate actions to the user. Dedicated, tactile buttons for primary functions are possible (e.g. scan function). Included physical rubber buttons stick out so that they are easy to press.	**Screen-based** No tactile product qualities are provided. Users are required to navigate through a graphical interface and to look and tap at on-screen text. Cognitive load on the users' visual attention.	**Screen-based** No tactile product qualities are provided. Users are required to navigate through a graphical interface and to look and tap at on-screen images and text. Cognitive load on the users' visual attention.	**Tactile qualities** Integrated physical buttons provide tactile and kinaesthetic impressions and inform about certain features. Users can focus on the task rather than on the device.

Table 7-4 shows opportunities and challenges of mobile devices when applied for specific purposes. For example, a wearable and RFID-equipped smartphone with integrated hardware buttons may support operators in executing data logging procedures in the field. Tasks can be performed more efficiently because the solution is practical, can be worn on the wrist, and includes tangible qualities for easy access. The ergonomic hand strap enables hands-free operation and more mobility during work activity. On the other side, the information content on small screens must be reduced and adjusted to the screen size. Good design is, however, not only about adjustable screen resolution and variable images; the challenge is to design an information architecture in a mobile context that clearly guides the user.

Computer tablets may be applicable for tasks such as managing work permits or supporting navigation for first-time operators. The amount of information needed is higher, and hence devices with larger screens are more suitable than smartphones are. Opportunities with these devices compared to paper-based procedures are data exchange across systems and real-time information, which will save operators waiting time and administration effort and make them more independent on radio communication. Navigation software will provide inexperienced operators with more orientation at the plant and relieve experienced operators from unnecessary radio communication. This will improve efficient and safe plant operation. However, computer tablets are relatively large and thus cannot be worn on the body. Their size and weight may have a negative impact on human motion. Moreover, today's tablet solutions do not provide tactile product qualities. Operators are required to navigate through a graphical interface and to look at the screen at every point in the interaction.

Finally, a headset with a tactile user interface such as that suggested by design students seems to provide opportunities for improved radio communication. The device would be easy to use in an industrial setting, as functions are reduced to the primary task of voice communication, and operating complexity is simplified. The user interface is integrated into the headset, allowing for hands-free operation and better mobility in the plant area. Moreover, the tangible design of the interface supports users in concentrating on the task rather than on the device. Challenges can be met if the size of physical buttons becomes too small and their shapes and surfaces too similar to be distinguished — in particular, if users are required to wear gloves.

To summarise, the examples described above are facing both opportunities and challenges, as mobile devices for use in process industries must meet various requirements. Depending on operator tasks, they must be wearable and lightweight and at the same time provide rapidly perceivable information. For designers and product developers, it is important to understand exactly how smartphones and computer tablets for use in hazardous environments are different from the same mobile devices used in daily life.

8 DISCUSSION

This chapter consolidates and discusses the results of the present thesis. It explains how the results support the answers to the research questions asked in the introduction and how they compare with existing knowledge on the research subject. Shortcomings of the research process are critically addressed here. The chapter further summarises the contributions of the thesis and explains how the results of the research are important in terms of our understanding of how handheld devices are used within integrated operations in the petroleum industry and what role the product design of handheld devices plays in efficient and safe plant operation.

8.1 Main findings

The research aim of this thesis was to explore how the product design of handheld devices affects working routines in the oil and gas sector in terms of the efficient and safe operation of process plants, and to what extent mobile devices could improve current procedures and satisfy the user's needs. The thesis was especially concerned with the following research questions:

1. How does the product design of mobile devices affect efficiency and safety in Norwegian plants in the petroleum industry?
2. How do field and control room operators evaluate design and usability of mobile devices in support of field operation?
3. How should mobile devices be designed to meet efficiency and safety requirements?

To respond to these questions, an ethnographic research approach was chosen, and two Norwegian onshore facilities have been studied as case examples. Fieldwork and the collection of data included studies of the site in order to explore devices being used in a real context and situational circumstances of activity and operator-device interaction. To conduct the study, three classical ethnographic field methods were applied: qualitative interview, participant observation, and video-based participant observation.

The main findings of the research work are:

(1) The design of handheld devices plays an essential role in ensuring efficiency and safety at Norwegian gas processing plants, as it can affect users, procedures, and environments. Design creates meaning and thus contributes to the understanding of products. In this research, I found that perceptible product qualities as well as the level of complexity of functions are critical for error-free device operation and hence for efficient and safe plant operation.

(2) Operators working in the petroleum industry are partly critical about the handheld devices they are using in field operation. The lack of user acceptance of existing handheld devices used in the process industry is probably due to the lack of product usability and the overall product design that does not attract the target group.

(3) Designers and product developers of mobile devices for use in the petroleum industry are faced with an increasing complexity in the design of seemingly simple products. Even though mobile devices are small, they open up an enormous dimension for design in order to meet the requirements of work activity in hazardous areas. This relates not only to graphical user interfaces but also to product interfaces that include physical product qualities.

(4) The absence of well-considered technical design solutions may be due to our little understanding of the complexity of human activity — in particular, human-machine interaction in a demanding work setting, such as the oil and gas industry.

(5) Finally, technology development must focus on human aspects rather than only on technical issues. Context-oriented and coherent wearable solutions may support the actions executed by operators in the plant, as the use of the device is no longer the primary action.

8.1.1 Research process and possible shortcomings

Although valid, and as widely used as ever in scientific work, classical ethnographic field methods have their weaknesses — particularly when applied in hazardous work environments. Chapter 5 introduced the research methods used in this thesis and discussed in detail their strengths and weaknesses in light of the present research case. This chapter will take a broader view on the possible shortcomings of the research process and explain why some findings, however, may be valid and why others are not.

Does the literature support the arguments of the thesis?

The thesis holistically examines HCI, and design theory is broadly defined. In order to respond to the research questions, scientific material has been chosen, ranging from theories that identify the phenomena of human experiences with respect to the users of mobile devices to theories on the interaction between humans and objects in terms of the practical use of mobile devices. Also used is material on the perception of the gestalt of an object as well as the complex activity system of human beings. On the product side, the semiotic meaning of objects is elaborated as well as the aesthetic experience of objects and their gestalt-qualities. On the user side, cognitive aspects of understanding are described as well as bodily aspects that play an important role in the practical application of objects.

Now, one might ask why the sign function in design is important for the research questions of this case, or why the aesthetical experience of gestalt is relevant. Moreover, how is the reference to philosophers such as Kutschera relevant? The answer lies in the application of devices. In the present case, this involves the safe and proper use of devices. There are two approaches. The first is that the user of a device experiences it aesthetically because aesthetics seeks to identify the relationship among structure, function, and gestalt (cf. Hirdina, H. 1978, published in Nehls, Staubach, Trebeß (ed.) 2008 and Hirdina, K. (2006). On the other side, Kutschera argues that users experience objects from outside, leaving out the fact that objects are used in practice. Unfortunately, the reduction of gestalt (form) on its outer appearance seems to be a widely held belief, and that is why Kutschera is mentioned at this point. Designers are often faced with making things to look nice in the end and to give objects their outer appearance. However, design should not be reduced to this. In response to the first research question, we identified that the product design of handheld devices can affect efficient and safe work performance in Norwegian gas plants in a negative way. The determining factors are not just related to the outer appearance of the devices — though the user's eye may first be caught by the often rugged and bulky product designs. They refer to the entire cognitive activity of operators, which implicates external factors and circumstances in the contemplation of human activity. In response to the second research question, it turns out that many field and control room operators are critical of currently used mobile technologies, as they do not feel being supported according to their needs. In the design of interactions, the interest may therefore not only be directed towards the operator-device interaction but also must be directed toward the interaction with other people and the environment. Gestalt-qualities and Gestalt laws as discussed in Gestalt theory should be considered in the development of mobile devices in order to meet work and user requirements. Design practitioners might argue that in design, and especially interaction design, principles were derived from Gestalt theory and developed over many years. This thesis, however, concludes that Gestalt principles in 3D design play a minor role. In Chapter 2, I refer to Chang, Nesbitt, and Wilkins (2007), who worked with multi-sensory displays and found that the principles of similarity and proximity are applicable for both the visual and haptic grouping of display elements. The result should give the motivation to extend Gestalt theory to a wider range of functions in 3D products.

This leads to the question of why tactile and kinaesthetic experiences are important in the interaction with mobile devices. Chapter 3 describes what is known about tactile and kinaesthetic senses and how the knowledge can be applied in the context of mobile technology. Various research works and projects have been cited, e.g. Poupyrev and Maruyama (2003), who have investigated actuator-based tactile feedback for a PDA touchscreen; Ryokai, Marti, and Ishii (2004), who presented the digital drawing tool I/O Brush; Harrison and Hudson (2009), who created dynamic physical buttons by pneumatic actuation in a visual display; and Hoff, Bjelland, and Bjørkli (2008), who developed a physical haptic interface for an in-vehicle audio system. In Section 3.2, I discuss the tactile perception of mobile devices and draw on the early work of Moore (1974), who investigated the tactile and kinaesthetic aspects of push buttons. Technology has evolved from mechanical devices to electronic digital devices, and in the past decades, from physically perceivable control elements to touch-based buttons. The present work, however, highlights the potential of physical gestalt-qualities, including geometric shapes and the textures of device components, to allocate functions to physical entities and is thus in line with research work, such as that done by Hoff, Bjelland, and Bjørkli (see Section 3.5).

The empirical results of the present thesis support the theoretical findings to the effect that the feature complexity in today's mobile technology challenges its users — in particular, if technology is applied in demanding work settings, where vision is often limited, mobility and flexibility are expected from operators, and efficient and safe task execution is critical. Based upon the knowledge about tangible design, this work therefore concludes that the complexity of currently used devices in the process industry should be reduced by providing intuitive tactile product cues.

One criticism of the present work may be that some facts about the human experience and understanding in everyday life, as introduced in Chapter 2, seem self-evident, and quite a few do not actually require a reference. However, these self-evident theoretical facts are often not reflected in the design of technical products. In recent years, in which the technology has undergone a rapid development, it has been shown that these facts have been forgotten by designers. The aim of this thesis is therefore to remind design of its responsibility and to rely more on theoretical and philosophical approaches — especially against the background of rapidly developing technology that seeks to replace people more and more. Philosophical considerations, however, should not be primarily technically oriented but must be based on people and their experiences. Joseph Weizenbaum (1978) already postulated the introduction of ethical thinking into scientific planning. This ethical thinking is all the more important in a working environment, such as the oil and gas industry, in which the application of technical handheld devices has an impact on their users (mentally and physically) and affects efficient and safe work performance. Lucius Burckhardt wrote in 1980: "Invisible Design. What this means today is: the conventional design that does not notice his social function itself. But that could also refer to: a design of tomorrow, which is able to consciously consider invisible overall systems consisting of objects and interpersonal relationships." (Burckhardt 1980: n.pag., translation of the author) Thirty-five years later, this statement has not lost its actuality. The results of the literature review of this thesis show that there is enough knowledge out there from both philosophical and technical sciences. However, philosophical and technical sciences should complement one another better (see Figure 8-1). In the design and software engineering areas, this seems to happen too little. The empirical results of the thesis show a lack of consideration of practical experience in technical developments.

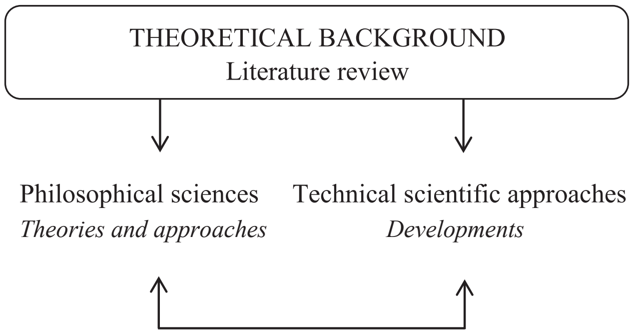


Figure 8-1: Philosophical and technical sciences should complement each other because theories and approaches of philosophy can inspire developments in technical, scientific fields.

Are the empirical findings consistent with previously published knowledge on the topic?
From a design perspective, the oil and gas workplace is not yet sufficiently described in the HCI literature. This is also found by Heyer (2009), who introduced the oil and gas workplace and its work practices by describing observations at an anonymised Norwegian gas refinery. Heyer's primary contribution is the discussion of this work setting from a computer supported cooperative work (CSCW) viewpoint and focusing on the perspective of the shift team that works in the industrial environment and the control room. However, whereas Heyer seeks to provide a descriptive presentation of the context serving as a resource for future design and research, this research aims to provide implications for design.

Previous published knowledge on the topic of ICT in the petroleum and nuclear fields are discussed in Chapter 4. The chapter has shown that others have also identified current work procedures in plant operation as being difficult in terms of plant status control and operational efficiency. For example, Farris and Medema (2012) explored portable handheld devices to improve human performance and reduce human error in routine fieldwork. Oxstrand, Le Blanc, and Bly (2013) aimed to replace paper-based procedures by providing portable computer-based technologies. Jokstad (2010) and Kaarstad, Strand, and Nihlwing (2012) tested handheld devices, such as the iPad and PDA, to achieve more efficient communication, a reduced workload for field operators and control room operators, and a better process overview. Moreover, Talevski, Carlsen, and Petersen (2009) report on challenges in applying wireless solutions in the oil and gas industry. There is consensus about the advantage of computer-based technology in the form of wireless systems over paper-based procedures, especially in terms of mobility and more efficient and safe plant operation. Nevertheless, our empirical findings presented in Chapter 6 also confirm the results of other researchers regarding the challenges of design and information engineering. For example, Talevski, Carlsen, and Petersen (2009) address user interfaces and the robustness of wireless devices in remote and hostile environments as well as options for seamlessly integrating devices with existing process control and operating systems. Farris and Medema (2012) received feedback from operators concerning the applicability of modern technology under the given environmental conditions and user demands, including the aspects of movement (e.g. when climbing ladders) and hands-free operation as well as the need for conductive gloves or corresponding touchscreen technology, which can be used with gloves.

On the social side of mobile technology, I agree with Kaarstad, Strand, and Nihlwing (2012), who report the concerns of operators who tested an iPad as a tool for monitoring process information. Their report notes that control room operators would feel monitored if management staff at all levels became a user group of the device. Our empirical findings support and document the concerns of operators about the handheld PDA solution used at Nyhamna to record process data. Also, in this case, some users of mobile technologies feel as though they are being controlled because the use of the PDA in the field allows for some control over inspections carried out and the opportunity to follow a logging tour precisely after the data have been transferred. These possible psychological impacts on users must be considered in the development (and implementation) of new systems.

However, the theoretical and empirical findings of this study do not support previously published results to the extent that handheld technologies could cause problems if the GUI is poorly designed. This work argues that the sole focus on well-designed GUIs can lead to the loss of interaction quality and claims for a broader view on user interfaces, emphasising the interdependence of graphic and product interfaces (see Figure 3-4 provided in Section 3.4). This includes material and physical product features (see the design examples presented in Chapter 7 and shown in Figures 7-3 to 7-5) and the inclusion of multiple sensory channels. To keep the operator focus on his or her task rather than on devices, the experience of the devices should be both visually and haptic. Moreover, the findings of the ethnographic fieldwork studies, which are presented in Chapter 6, lead to the conclusion that a functioning interaction between users and handheld technologies, depends on several factors including ergonomic aspects, GUI and functionality, technology complexity, system requirements, and effects on users and procedures, and it depends largely on environmental factors. The empirical research results confirm what Burckhardt stated in 1980: Workplaces and work situations consequently must also be treated in the design process; HCI does not just depend on the design of objects. It is also a question of how workplaces produce or prevent cooperation and interaction. This leads me to the validity of the research results against the background of Activity theory that was used as the inspiration for analysing the empirical data.

Was Activity theory suitable for responding to the research questions?

Chapter 5 highlights the relevance of Activity theory for the analysis of the empirical data presented in Chapter 6. What makes Activity theory interesting for responding to the research questions of the present thesis is that it considers human activity in the context of a unit of analysis. Similar to the approach of Distributed cognition, the core idea is that the human mind is intrinsically linked to the overall context of interaction between people and the world. In answering the research questions of the thesis, issues were identified in connection with efficient and safe plant operation, and opportunities for the design of handheld devices were emphasised. In line with Activity theory, the answers centre on the activity system of operators that is described by the interdependence among environment, rules, and artefacts. One of the main insights of this research work is that the lack of user acceptance of existing handheld devices used in industrial settings may be due to our little understanding of the complexity of HCI. To succeed with the design of handheld devices aimed at improving work performance at industrial facilities, the exploration of new technologies is not sufficient. Designing artefacts for end-users requires analysing collaborative activity as it unfolds in a specific environment, in given situations, and in a social fabric.

A shortcoming of this work is that the full potential of Activity theory for a detailed analysis of collaborative work that is mediated by mobile devices has been used in a limited way. For example, Badram and Doryab (2011) used the theoretical framework of Activity theory to analyse in detail how collaborative activity unfolds in a hospital ward and inside an operating room. The researchers were able to document how many activities a physician managed during a work shift, how frequently he shifted between activities, his patterns of mobility, and finally the temporal and collaborative patterns of these activities (Case A: Results section, para. 1). The present research work focused on the three-level concept of activity, which distinguishes activity from action and operation, and analysed the particular activity system of plant operators and illustrated the activity levels involved. However, recorded time sequences could have been used to generate quantifiable data. For example, timelines for individual operations such as data logging at the plant by aid of a handheld PDA could provide information on, e.g., target selection time, error rates, overall task completion time, or operator overload. Because the camera during the observations was not running continuously, this was not possible. In this sense, the validity of the research findings is limited by the few quantifiable facts. Activity theory is nevertheless regarded as being useful in this work because Activity theory provides a framework for describing human activity at various levels. However, the results of the analysis of this study are not merely based on Activity theory.

Are ethnographic methods and usability studies suitable for responding to the research questions?

Ethnographic research is often applied to investigate cultural phenomena, including behaviour and attitudes of a group or community. However, the same methodology can be applied to systems and processes to improve productivity within organisations or companies. I agree with previously published research that has found ethnographic methods to be useful in exploring work practices in the nuclear power and petroleum industry. For example, Oxstrand, Le Blanc, and Bly (2013) carried out structured interviews and “on-the-job observations” of fieldworkers at a nuclear power plant to gather information needed for developing a “model of procedures usage” (ibid.: 3). The model served as the basis for the design and evaluation of a computer-based procedure system. Heyer (2009) conducted ethnographic fieldwork at a Norwegian gas refinery that comprised observational studies and informal interviews. Being in the physical plant was seen as valuable for the development of an understanding of the process and work practices in the oil and gas workplace (ibid.: 363).

In the present case, ethnographic methods have been applied to gain an understanding of everyday work experiences and practices from the perspective of operators working at Norwegian gas processing plants. Qualitative interviews, participant observation, and video studies were used to explore the impacts of new introduced mobile technologies used in the control room and the outside facility on humans and human activity. In addition, usability studies were conducted to identify particular problems associated with the design of the devices. The methods were considered as being relevant for the purposes of this research study, as they helped to uncover discrepancies between the way in which mobile devices have been designed and the reality of how operators interact with them. Moreover, the ethnographic approach of the study ensures that all resulting insights are informed by the operators’ perspective.

However, a limitation of this work is that ethnographic research was conducted over a short period of a few days. The research activities included three fieldwork studies that have been carried out at Nyhamna over two days in 2010 and two days in 2011 and at Hammerfest LNG over four days in 2011 (see also Figure 5-2 in Chapter 5, which gives a chronological overview of the fieldwork studies). Spending more time in the field would have resulted in more valid and reliable outcomes.

Are the criteria for designing handheld devices to support task performance in the petroleum industry reliable?

In response to the third research question, design criteria for mobile devices were formulated. These criteria are based upon the theoretical and empirical findings of the research project, which were found to be valid. As described in Chapter 7, an important part of the research process was the observation of operators in everyday work situations where different tools and devices are used. The criteria support the analysed material of the ethnographic studies and the theoretical findings. The criteria are aimed at aspects of the design process and general industrial requirements for equipment intended for use in potentially explosive atmospheres, as well as product interfaces and the product design of mobile devices in terms of ergonomics, operating complexity, and wearable and tangible design and with regard to their practical application.

One question that has not been addressed is the issue of security and security updates for mobile devices, such as tablets, smartphones, and wearables. This is a main concern for companies, but it is beyond the scope of this thesis. Nevertheless, the unsolved security question concerning the data exchange of devices may critically affect the reliability of design criteria for future handheld devices for use in the petroleum industry. Lawrence Garvin (2014) warns against the completely untested area of communication between devices that should be considered unreliable, as the integrity of corresponding data exchanges processes are not yet guaranteed.

8.1.2 Unexpected findings

During fieldwork at the process facilities of Ormen Lange and Hammerfest LNG — and in particular, during interviews — it became obvious that operators would favour mobile devices such as smartphones and tablets to support daily work. In line with this trend, Shell has — in cooperation with Ormen Lange and developers such as Bartec Pixavi — started implementing today's mobile technology. Apart from the lack of current user evaluations and usability studies of the technology in practical use, it was surprising to realise that 1) a seemingly unrestricted user acceptance of today's mobile technologies exists and 2) screen-based devices that require users to navigate through a graphical interface in an environment where the visual recognition of information and the identification of buttons is critical due to the conditions of environment, may be suitable. An explanation of the first unexpected finding may be that a positive user experience with corresponding technologies from everyday life could be crucial for preferences in everyday work. According to the information centre medianorway (2015), 70 per cent of the Norwegian population (9-79 years) reported having access to tablet computers in 2014, compared with 37 per cent two years before. Moreover, access to smartphones increased, from 57 per cent in 2012 to 80 per cent in 2014. Mobile devices, such as iPhone and iPad, have obviously influenced the language, mentality, actions, and social and cultural understanding of many people. The everyday lives of many people are affected by these technologies. It should therefore not be surprising that people also wish to use smartphones and tablet computers for their everyday work.

Regarding the second unexpected finding, there are currently too little data that provide reliable information on the suitability of screen-based devices, such as computer tablets, for use in hazardous work environments. Further research is needed on this topic in order to determine whether or not the product designs of these devices positively affect efficiency and safety in process plants in the petroleum industry and how operators evaluate their usability in support of field operations. To return to Activity theory and its application to HCI research, this theoretical framework can be used to analyse verifiable indicators, such as work interruptions or target selection time, and makes it possible to estimate the degree of improvement by modern mobile technology with multi-touch screens.

8.2 Main contributions

The research contributions of the present thesis can be divided into theoretical and practical contributions. They are summarised as follows:

Theoretical contributions:

- knowledge about mobile equipment used in an industrial work setting that is not yet sufficiently documented in the HCI literature and a description of the effects that the design of mobile devices has on efficient and safe plant operation
- empirical research material on the activity system of field operators working in the oil and gas sector and end-user assessments of quality and usability of mobile devices
- a theoretical frame on cognitive processes in HCI and the sensory perception of objects for understanding the complexity of the design task for HCI

Practical contributions:

- design criteria and their values for designing mobile devices to help to increase their user acceptance and hence to help to improve efficient and safe plant operation in hazardous environments
- an evaluation of three different design approaches to identifying opportunities and challenges of modern mobile devices

The theoretical contributions provide a better understanding of the phenomena of human experience and understanding in everyday life as well as an understanding of the impact of design on the experience of technical equipment. The novelty here is that the knowledge is based on theories provided by both literature and hands-on insights. Even though the field observation was of short duration, the results from the field work provide answers to the questions of how the design of mobile devices really affects efficient plant operation and how, from a user's perspective, design and usability support work. One of the main insights of this research is that the user's focussed attention on work tasks can be distracted by operating their mobile equipment, since handling, navigation, text input, reading displayed information, and data transfers require the user to focus on the devices. In terms of human performance, and viewed at a certain distance, we might provocatively ask the follow questions: Does mobile technology really provide us with mobility? Should we not examine mobile technology much more closely in the context of movement and actual human action? Using activity theory, the present study attempts to contribute to an understanding of the activity system of operators, which is characterised by mutual relations among industrial environment, safety, and mobile technology. However, this is only the beginning. To create really good solutions, designers and software developers should immerse themselves deeper into the everyday work of plant operators and should study their daily work over a longer period. Ethnographic research should be extended in time and scope.

The aim of future mobile product development for industrial applications in critical environments must be to create ideas for better interaction with the products. This applies particularly to practical implementations in which the visual attention of the users may be affected by different factors. If operators of a gas processing plant follow their ordinary tasks, their attention is directed to multiple things. Human-computer interaction can be challenging in these circumstances. Future handheld devices should therefore support human activities and associated movements and should not draw the attention of the user primarily to the device. As described in Chapter 4, the interaction with devices should be reduced to a minimum to perform tasks successfully. Designers and software developers have the responsibility to consider the human aspects when developing future technologies.

The practical contributions of this thesis are linked to the design of new handheld devices for use in the oil and gas industry. The proposed design criteria result from a detailed analysis of the theoretical and empirical findings. Their value lies in looking at different parts of a larger picture. Even though handheld devices are comparatively small, they are becoming more complex, and the correct interaction with small devices in hazardous environments is critical and comprises much more than the devices alone. The design task, therefore, cannot be limited to merely designing interactive products. It needs to be extended to also consider the circumstances of human acts and the practical implementation of new products in existing environments. The design criteria are relevant to the design approaches that have been discussed in connection with the criteria and their value. The evaluation of the approaches, however, reveals opportunities and challenges that are still to be overcome.

Relevance for development and research

Some of the contributions may have relevance for different domains. For example, the proposed design criteria are believed to be valuable for the development of future applications for use in areas such as the military sector, fire and rescue service, or water treatment.

Other contributions that have been presented above may be relevant for software development and design, as they highlight the problems for the design of interactive products for use within integrated operations in the petroleum industry. A challenge for some companies involved in the development of mobile applications is that they can hardly acquire hands-on insight offshore. Access to first-hand information seems to be difficult to obtain. Companies are often limited to conversations with offshore workers and other activities. Together with the elaborated design criteria, the practical experiences from the ethnographic studies may therefore enable designers and engineers to improve the product usability of mobile devices used in industrial settings and to better meet the requirements of both users and work environments.

In addition, the results of this thesis may be of interest for the wider HCI community and for researchers within the fields of energy technology and human factors and ergonomics.

Relevance for oil companies

The contributions may also have relevance for oil companies such as Shell and Statoil, as the contributions provide not only new insights on how mobile devices affect operators mentally and physically but also how they affect efficient and safe task execution. The results also provide new insight on how situations and physical space may affect human activity. Moreover, the research results can guide companies in ordering technologies and require subcontractors to work according to ISO 9241-110 and ISO 9241-210, which provides requirements and recommendations for human-centred and ergonomic design principles for interactive systems.

9 CONCLUSION AND FURTHER WORK

This thesis has focused on operator-device interaction in the petroleum industry. It has presented theoretical and empirical findings on the interaction with the real world — in this case, in a demanding work setting — which includes sensory experience, and it has demonstrated how to apply ethnographic research methods to a contextual analysis of operator activities at two Norwegian natural gas processing plants. In the thesis, I explain:

- why theory is indispensable for the design task of HCI
- what distinguishes the concept of gestalt from "form"
- why it is necessary to design technology from a user's perspective.

Using the example of handheld devices for use within integrated operations in the petroleum industry, the thesis has demonstrated how fundamental these aspects are in order to achieve practical results. Its subject is the design of *small devices*, and the research has shown that there is a need for a comprehensive, in-depth design and context analysis to come to design criteria and their value, which can help to improve user satisfaction as well as efficient and safe plant operation. Building on that, knowledge has been developed about the activity system of field operators by drawing on key elements of Activity theory and based on field research where an ethnographic approach was used. The findings resulted in following design criteria for handheld devices to help to increase user acceptance of mobile technologies for use in hazardous environments and thus to help to improve plant operation:

General criteria

- Extend the design process beyond the product development.
- Take devices as well as physical space and procedures into account.
- Focus on task performance rather than design performance.
- Meet ATEX Zone 1 requirements for electrical devices.

Product design

- Make devices wearable and tangible.
- Focus on the practical use.
- Consider behavioural patterns and experiences of users.

Product interface

- Focus on product interfaces rather than merely graphical interfaces.

- Make devices accessible to users through ergonomic interfaces.
- Simplify operating complexity and logic.

In particular, the research has responded to the questions of:

- how the product design of mobile devices affects efficiency and safety in Norwegian plants in the petroleum industry (research question 1)
- how field and control room operators evaluate the design and usability of mobile devices in support of field operation (research question 2)
- and how mobile devices should be designed to meet efficiency and safety requirements (research question 3).

9.1 Main conclusions

Design as a technical and scientific discipline
The thesis has shown that a direct link between the elaborated theoretical framework provided in chapters 2, 3, and 4 and the empirical studies provided in chapters 5 and 6 is required in order to attain practical results.
Task performance as primary action
Those practical results should be aligned with the development of wearable and tangible technologies, as their use is no longer the primary action if the devices are meaningfully designed. In light of operator-device interaction, the primary action is linked to task performance within challenging work environments. Wearable and tangible technology may support the way in which operators act in the plant.
Design understanding
Interaction design should not only be considered in light of screen design but also involve graphic and physical aspects because interactive products must be able to be understood and used both two- and three-dimensionally. Moreover, the design of human-machine interactions includes the design of new products and systems; the design of environments where these products come into action; and the design of the "first introduction", "transitional learning phase", and the "final regular use phase".
Responsibility of the designer
Designers should understand the role of responsible design and should implement design accordingly. Responsibility may not be transferred to systems but must first and foremost be taken over by their developers and thus by humans.
Ethical thinking in design research
Design has a social function and must be able to consider not only visible but invisible systems that involve objects *and* interpersonal relationships. Especially in technical developments, philosophical and technical sciences should complement one another better in order to really meet the requirements of people who will use technologies.

Conclusively, I hope the present thesis will make those who develop future handheld devices sensitive to the ethical questions of user-centred design of technology. On the other hand, aspects of activity have become visible that concern the oil industry, as integrated operations and the resulting implementation of modern technologies have consequences for working situations and working space. To return to the starting point of the present work, I will draw once more on the concept of the lifeworld of phenomenology, which tells us that the world is already structured and meaningful, and this reminds us that new technologies must be embedded in these existing structures.

9.2 Further research work

Firstly, it is important that more research be conducted to investigate how operators use touchscreen-based devices under different mobility situations and to generate quantifiable data on target selection and overall task completion times, error rates, degree of attention, and measures of workload. Additional empirical studies are needed to understand the impact of environmental conditions on these parameters. Some research has been conducted, e.g. on the impact of different mobility situations (sitting, walking on a treadmill, and walking through an obstacle course) on stylus-based tapping performance on a handheld PDA (Lin et al. 2007); on the effects of changes in motion, lighting level, and task type on performance and the workload of mobile device users (Barnad et al. 2005); and on the relationship between walking speed and text input performance (Mizobuchi et al. 2005). However, these studies have been reduced to pen- or stylus-based mobile computing and were carried out in simulated environments, such as corridors and observation rooms, where the stress factor is low and distances short. There is a need for more empirical research in time-constrained, data-driven environments where process operators are required to perceive process data rapidly in fast-paced situations.

Secondly, the author hopes that the design criteria that have been proposed in this work will be considered when developing future portable devices for use in demanding industrial environments. In doing so, I suggest extending the research to the variety of technologies available in the form of wearable and tangible products.

Thirdly, Norway, and in particular the region around Stavanger, is known for its offshore activity, where there is great focus on improving efficiency, saving time, and reducing cost. Companies such as Bartec Pixavi and Apps wish to contribute with their competencies to streamline offshore operations through mobile solutions. Given our rapidly evolving technological world, there seems to be a wealth of opportunities to build even smarter solutions and more efficient offshore services. However, we must ask ourselves the following questions: Where does the human remain? Is the focus still on people? Should technology be the sole criterion for measuring efficiency? As we have shown in this work, the importance of people in the literature is emphasised repeatedly. But are the right conclusions for the latest technological developments also drawn?

Computers, mobile computers in particular, are increasingly likely to make decisions that have been made by people to this point. Digital assistants are no longer restricted to only handheld computers and Smartphone applications. They act as driver assistants, autonomous robots, unmanned aerial vehicles, or RFID labels. We can expect that in the future, these technologies will also be used in factories and plants. Drones, for example, could be used to analyse and monitor processes. By means of data glasses, operators could be warned of danger zones or could be guided through the plant. Moreover, a RFID-based information infrastructure could identify objects by electromagnetic waves and coordinate production lines.

Technology is no longer just passive; it now acts. Some people in the software industry and the scientific community are already worried about it. For example, Bill Gates and physicist Stephen Hawking, persons of influence, are warning against the risks of artificial intelligence, which is not least about ethical issues and the control of people over technology. Other enterprisers, like Tesla CEO Elon Musk, are calling for national and international regulation in the field of artificial-intelligence research to ensure that the research in this area is conducted with caution (Bager 2015). Further research should therefore address questions as follows:

- What possible applications should be examined?
- What ethical frameworks must be established?
- What are the social, political and environmental consequences?
- How do people change over time, and how will the relationship between man and technology change?

In order to answer these questions, research and technology should be extended into the political and social dimensions because despite all the advantages that digital assistants bring for humans — thanks to their 'comprehensive knowledge' — digital assistants have no general knowledge. Individual experience combined with social knowledge is unique to human beings. Only human beings can make ethical decisions.

Finally, the author believes that in addition to the technological aspects, environmental aspects must play a role in future research in the field of oil and gas production. The present work has not given more attention to this important problem because it would go beyond the subject of the work. Given climate changes and the enormous future challenges for humans and the environment, the question of how long we want to continue to use fossil-fuel reserves and optimise oil and gas production and processing using increasingly intelligent technical solutions should definitely be asked. Despite the efforts to return and store carbon dioxide in the seabed (as for example at the Melkøya gas processing plant near Hammerfest), the CO_2 emissions by the burning of fossil fuels is too high worldwide.

Research institutions such as IFE and SINTEF as well as several engineering education programs already carry out research and development in renewable energy technologies. Given the broader context of this work — technology development to support human task performance — the presented research results may also show opportunities for the area of renewable-energy sources.

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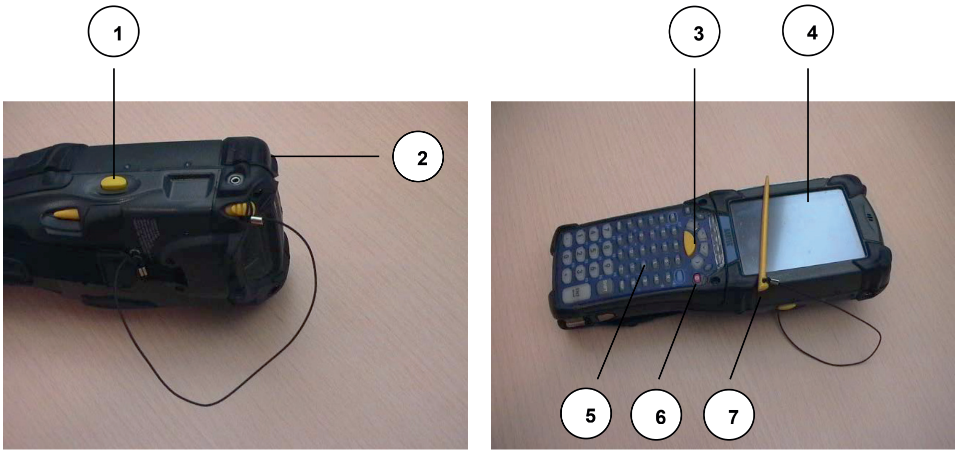
APPENDIX A

Product interface of the MTP850 Ex TETRA terminal

1	Emergency button
2	Antenna with in-built GPS
3	LED status indicator
4	Top microphone
5	Display
6	Accessory connector
7	Function key
8	On-Off, End, Home key
9	Loudspeaker
10	Speaker phone control key
11	Bottom microphone
12	Navigation key
13	Send key
14	Menu key
15	Rotary knob
16	Programmable side buttons
17	Push-to-talk button (PTT)

APPENDIX B

Product interface of the mobile computer MC 9090ex-K



1 Scan button
2 Exit window
3 Scan button
4 Touch screen
5 Keypad
6 Power button
7 Stylus

Operating system: Windows Mobile 2005
Display: 3.8", 1/4 VGA colour display with touch screen, 240 x 320 pixel
Dimensions: 231 mm x 91 mm x 105 mm
Weight: approx. 1320 g

APPENDIX C

Interview guide – MTP850 Ex TETRA terminal

- (1) I hvilken del av Norge bor du?
- In which part of Norway do you live?
- (2) Hvor lenge har du jobbet her på Nyhamna?
- How long have you worked at Nyhamna?
- (3) Kan du beskrive oppgaven din som operatør her på anlegget?
- What are your tasks as an operator?

- (4) Hva bruker du MTP850 Ex terminalen til?
- What do you use MTP850 Ex for?
  - *(4a) Hvor ofte bruker du TETRA terminalen om arbeidsdagen?*
  - *How often do you use the TETRA radio during the day?*

- (5) Når og hvordan ble MTP850 Ex terminalen introdusert på din anlegg?
- When and how was the MTP850 Ex radio introduced at Nyhamna?
  - *(5a) Hvordan gjorde du deg fortrolig med terminalen?*
  - *How did you familiarize yourself with the terminal?*
  - *(5b) Har du fått kurs i tillegg?*
  - *Did you get a course in addition?*

- (6) Hvordan liker du terminalen?
- How do you like the radio?
- (7) Har du brukt andre terminaler før?
- Have you used other radios before?

- (8) Har du lyst til å fortelle om første gangen du brukte terminalen?
- Can you tell me about the first time you used the radio?
- (9) Hvilken funksjon hhv. funksjoner bruker du mest?
- Which functions do you use most frequently?
- (10) Finnes det funksjon som du ikke har brukt så langt?
- Are there features that you have not used so far?
- (11) Kan du fortelle om en situasjon der du ikke fikk brukt terminalen som ønsket?
- Do you remember a situation where you could not use the radio how you would like?

- (12) Hvordan sender du meldinger?
- How do you send messages?
  - *(12a) Hvordan redigerer du forhåndsbestemte tekstmeldinger?*
  - *How do you edit predetermined text messages?*
  - *(12b) Hvordan velger du telefonnummer?*
  - *How do you select telephone numbers?*

- (13) Hva mener du om tastaturet?
- What do you think about the keypad?
    - (13a) Kan du bruke tastaturet med hansker?
    - Can you use the keypad with gloves?
- (14) Hvordan liker du skjermdesignen?
- How do you like the screen design?
    - *(14a) Hvordan takler du menyen og navigasjon?*
    - How do you cope with the menu and the navigation?
- (15) Kan skrift og tegn på skjermen alltid leses lett?
- Are fonts and signs of the displays always easy to read?

- (16) Har du allerede opplevd en nødssituasjon der Emergency-knappen måtte brukes?
  Have you ever experienced a situation, in which the emergency button has been operated?
    - *(16a) Hva syns du om tilgjengeligheten av knappen?*
    - *What do you think about the availability of the button?*
- (17) Har du allerede opplevd en situasjon der "Man Down" alarmen ble aktivert?
- Have you ever experienced a situation, where the"Man down" alarm has been activated?

- (18) Hvordan liker du dobbel funksjonen av dreieknappen?
- How do you like the dual function of the rotary knob?
    - *(18a) Kan du bruke dreieknappen mens du går med hansker?*
    - *Can you use the rotary knob with gloves?*

- (19) Hva syns du om størrelsen og vekten (400g) av enheten?
- What do you think about the radio's dimension and weight?
- (20) Hvordan vurderer du håndteringen av terminalen med hansker generelt?
  How do you rate device operation with gloves overall?

- (21) Hvordan vurderer du batterilevetiden?
- How do you rate the battery life?
    - *(21a) Hvordan fungerer batteriet om vinteren?*
    - *How is the battery in winter?*
- (22) Hvordan og når blir batteriet ladet opp?
- How and when is the battery charged?
- (23) Syns du at radiodekningen er tilstrekkelig?
- Do you think that radio coverage is sufficient?
    - *(23a) Finnes det ømfintlige område i arbeidsomgivelsen din i forhold til radiodekning?*
    - *Are there sensitive areas within your work environment regarding the radio range?*
- (24) Hvordan liker du lydkvaliteten?
- How do you like the sound quality?

- (25) Bruker du accessoirer som headset, mikrofon, or leather case?
- Do you use accessories like headset, microphone, or leather case?
- (26) Bruker du annet utstyr i forbindelse med din jobb enn TETRA terminalen?
- Do you use other equipment in connection with your job than the TETRA terminal?

- *(26a) Bruker du bærbart utstyr i tillegg til TETRA terminalen?*
- *Do you use portable equipment in addition to the TETRA terminal?*

- (27) Jobber du tett sammen med andre operatører på anlegget?
- Do you work closely with other operators at the plant?
    - *(27a) Hvor mange kollegaer jobber du sammen med?*
    - *How many colleagues do you work with?*
    - *(27b) Jobber du tett sammen med bemanningen i kontrollrom?*
    - *Do you work closely with staff in the control room?*
    - *(27c) Bruker du hovedsakelig TETRA terminalen for å kommunisere?*
    - *Do you use mainly TETRA terminal to communicate?*

- (28) Hvordan vurderer du produktets brukervennlighet?
- How do you rate the product usability?
- (29) Hvor solid er terminalen etter din oppfatning?
- How solid is the terminal in your opinion?
- (30) Savner du noen funksjoner?
- Are you missing any features?

APPENDIX D

Coded transcription

Ormen Lange 2011-09-22
Mobile computer MC 9090ex
Samtale Terje (IT), Hans Jørgen (IT), Kjell (Operatør)

Samtale med Terje
• **[Mål** er at operatører går runder til å sjekke en del punkter og samle en del data på målinger. **P 4.2]**
• **[**Regneark som bruket tidligere, list opp alt de skulle sjekket. **P 4.2.1]**
• **[**Det som har vært tilfelle tidligere er at dem har gått runder, men det var ingen som har kikket og analysert data. Data bare havnet i en perm. Det som kanskje har skjedd av og til er hvis det noe har havarert, har man kanskje i ettertid gått inn og så kikket, dvs. man har brukt data reaktivt. **P 4.2.1]**
[Ønsket nå er å være mer proaktivt, dvs. å samle inn data og kan bruke data til å gå inn i PI (Process Information, Shell`s standard system/database for lagring av prosessdata) for å ta ut historikken der. **P 4.2]**
• **[**Hovedmålet som ble satt opp første gangen var å samle data på utstyr, manuelle måler, som brukes ute i anlegget til å måle for eksempel temperatur, trykk, en del manuelle målinger. **P 4.2]**
• **[**En sideeffekt er at man har litte grann kontroll på at operatørene går runder (selv om det ikke er hovedhensikten). Papirarket kan fylles ut ved å sette seg ned på en plass, med en håndholdt enhet er man fysisk ut på plassen og gjør seg kjent i anlegget. **P 4.1]**
• **[**Hovedønsket er å samle data, få inn den verdien og kan bruke den proaktivt, følge med trender. **P 4.2]**
• **[**Noen plasser er barkodene satt opp å sjekke om ting er ok eller ikke ok. Det er veldig mange. Og andre plasser så er det å legge inn verdier, temperaturer, trykk og forskjellige. Det kan vi kombinere. **P 3.4]**
• **[**Det vi skal utvikle litt videre nå det er for eksempel å ha kontroll på filter. **P 4.2.2]**
• **[**Målet er å kanskje fase ut fordi vi driver å måle litte grann på noe på grunn av at vi bruker det regnearket som basis (det regnearket som vi brukte før) for å få startet opp noe og lå inn alle punkter. Så runden vi har i dag er egentlig en kopi av det regnearket. Men det vi ønsker er det å fase ut for eksempel avskrivning av en transmitter som måle verdi fordi den har vi i SAS systemet likevel. Så den blir litt for dumt at den må sjekkes andre temperaturer og trykk som vi har i SAS systemet. Og da ønsker vi altså å fase ut dem og så får inn en del andre kontroll som kjøle og litt sånne ting. **P 3.5, 4.2.2] [**Og kanskje noen flere manuelle målinger for å ha verdier. **P 3.5, 4.2.2] [**Og så kikker vi litt på intervaller, hvor ofte vi trenger å sjekke forskjellige punkter. Det er ikke alt vi trenger å sjekke hver dag, noe tar vi en gang i uka.
P 4.2.2]

• **Teknikk**: [Barkode teknologi **P 3.4]**
• [Vi har barkoder ute på alle punkter. **P 3.1]**
• [Vil tippe 300-400 tagger er plassert ut nå. Det skal ikke utvides. **P 3.3]**

• **Usability**: (Utskrift av enheten på bordet.) [Det som er også kommet litt det er jo at teksten som kommer opp er ikke helt klar (teksten på skjermen). Vi må jobbe litte grann mer med det som er viktig når du får opp et spørsmål. Teksten som kommer opp kan være litte grann sånn misvisende. Det ønsker vi å forbedre. **P 2.1]**
• [Det vi også jobber litt med, det er å få ... vi tenkt oss en del sånne ferdig definerte verdier inn i en slags meny her. **P 1.12]** [Det absolutt beste er hvis vi har fått systemet der, og så har vi vært ute og funnet mye feil, og så vi har fått ferdig definerte verdier her, og så har vi dokket den når vi kommer inn, så har den lagret notifikasjon her automatisk i SAP. Det må da være den ideelle verden. Nå er den en egen selvstendig PC som må startes, det går ikke an til å integrere inn i Shell sitt IT nettverk. **P 5.1]** [Så vi har en egen. Da samhandler jo ikke det med SAP og alle andre systemer vi bruker. **P 5.1]** [Hvis du har vært ut i anlegget og funnet noe feil som ikke er på sjekkpunktene dine så skulle det gått an å bare trykk den tagg nummeret og hatt faste feilkoder sånn som du egentlig har i SAPet, bare lagt inn, og så skulle det kommet opp. **P 1.12, 5.1]** [Nå er ikke jeg sånn tilhenger av at: plukk inn og så går det automatisk, ikke sant. Men det kunne kommet opp en liste som du har akkurat: den skal inn, den skal inn, den skal inn ... Og så går det automatisk. Det er å være effektivt. **P 1.12, 5.1]**
• *DB:* [Bruk av tastaturet, brukes alle funksjoner? *(Hans Jørgen kommer) Terje:* Bruker vi mye på den her? *HJ:* Nei. **P 1.5]**
• (HJ har med seg enheten.) [Enheten brukes uten utløser (trigger), i stedet den gule Scan button. Utløseren ble egentlig ikke vurdert å ha. *HJ:* Vi har vel egentlig ikke vært klar over det. **P 1.5]**
• *DB* snakker om tyngden. *Terje:* [Egentlig utrolig at den skal være så store og klumpet, når en tenker på mobiltelefon teknologi. *DB* nevner EX klassifikasjon, batteri. *Terje:* Men jeg tenker i forhold til hvordan batterier er i en moderne mobiltelefon. **P 1.6]**
• *DB:* [Er dere fornøyde med batteri levetiden? *HJ:* Det har vi ikke fått noe tilbakemelding på. Eller noe negativ tilbakemelding på. *Terje:* Hva er varigheten på den hvis de tar den med seg ut? Hans Jørgen: Det var sånn par tre timer, tror jeg. **P 1.4]** [Det som har vært et problem det er sollys. Den er ikke lyssterkt nok. Vi har vært ut på noen dager hvor det har vært kraftig sol og da ser vi nesten ikke ... Og da har vi også fått tilbakemelding på fra operatørene. **P 1.1]**
• **Bruk**: (HJ begynner å vise meg hvordan systemet brukes.) *HJ:* [Vi har to sånne loggere per område. For å ha en i reserve. Men vanligvis så går dem jo bare med en om gangen. **P 4.1]** [Så den her er da område 3. Og så har vi da et varierende antall turer per område. Det kan vi se her. **P 4.2]** [Så har vi da område 1, ganske mange turer, de forskjellige skiftene (for eksempel ettermiddag, to og tre). Og så har vi da de forskjellige systemene. **P 4.2]** [Så har vi område 2. Da er det litt færre turer. **P 4.2]** [Og så har vi område 3 hvor det er fire turer. Så vi skal ... område 3 i dag. Sannsynligvis renseanlegg eller en av de ... eller ... selve område. Så det er de forskjellige turene. **P 4.2]** [Hvis du ser på hvordan turer er bygd opp ... så har vi taggerne her. De bygd opp taggen sånn at den starter med OL for Ormen Lange, det gjør alle tagger i Ormen Lange, og så ender dem på ML, Manual Logger, sånn at vi kan kjenne igjen enkelt ... ut av alle taggerne som er sånne ML tagger. **P 3.4]** [Det er to typer tagger, for å si det sånn. I hovedsak, det er de som vi kaller for digitale tagger som enten ... hvor du bare gjør en forhåpentligvis objektiv vurdering og sier at utstyr er enten ok eller ikke ok. Og så er det den typen hvor du da taster inn et tall, en verdi. **P 3.4]** [Du leser jo et instrument (HJ viser et eksempel) ... hvor du da legger inn en overlast verdi. Og den tastes inn. **P 4.1]** [Og en runde kan bestå fra 10 opp til over

80 tagger. **P 3.3]** **[**Nå begynner vi å få litt erfaring og det vil skje at vi skal for det første redusere antall forskjellige turer og vi skal også prøve å få ned antall tagger innenfor hver tur. Det er alt for mange. Det er for mange både turer og tagger. *DB:* Det klarer man nesten ikke på en tur, eller? *HJ:* Jo, det gjør man, men det kan fort bli litt uoversiktlig. **P 3.5]**

• (*Kjell kommer.* DB gir litt bakgrunnsinformasjon angående forskningsprosjektet sitt. HJ informer at vi holder på med å gå gjennom litt sånn bakgrunn slik at jeg får sett hvordan det skal fungere i teorien, og så får vi se hvordan det fungerer i praksis når vi kommer ut på anlegget.) *DB* forteller om erfaringer på Snøhvit og i denne forbindelse om håndteringen av papir, ATer, tegninger osv., og beskriver målet av prosjektet i forhold til enklere smarte løsninger som erstatter papir. Gesture based interaction nevnes.

HJ: **[**Det er ganske interessant at det er faktisk underholdningsindustrien som leder an i utviklingen, spill industrien, dataspill. **P 6]**

• *Kjell:* **[**Papir er noe å drite i. Det er lite egnet til å ta med seg ute i felt. **P 6.1]** *HJ:* **[**Samtidig må teknologien fungere. Det må være sånn at den oppfattes om en avlastning og fremskritt og ikke som en belastning. *Kjell:* Helt klart. **P 6]**

• **[***DB* snakker om prosedyren rundt ATer, om aktivering og deaktivering av ATer. *HJ:* Da bruker vi radioen. *Kjell:* Vi bruker da radiokommunikasjon. **P 6.2]** **[**Og det er jo en vist belastning på operatøren som skal melde ... ute her og samt at det ... som må håndtere det har ... det er en kilde for feil da for å si det sånn. **P 6.2.1]** *HJ:* **[**Det har jo faktisk skjedd. **P 6.2.1]** *Kjell:* **[**Det er masse feil. ATer som skal midlertidig avslutte blir completed og det medfører da en frustrasjon for den som skal ha AT i mange dager ... Den er useless. **P 6.2.1]** **[***DB* forteller om feil oppgavebeskrivelser på ATer, om mye kommunikasjon mellom operatør og kontrollrom og mye tidsbruk i denne forbindelse. **P 6.2]** *Kjell:* **[**Og så i tillegg til det er det også for oss som skal drive om melding til her da, så må vi bytte kanal, på AT kanal, og jeg kan jo bare snakke for min egen del, det er jo mange ganger i ettertid ... at jeg glemmer å gå tilbake til ... kanalen, og så er det folk som driver å rope og blir mer og mer irritert for at jeg ikke svarer. (alminnelig latter) Og det forstår jeg godt. Men det må jo vises forståelse fordi at ting kan gå glippe av seg. Når det er masse ting som skjer omkring der, så det er ikke alt at du greier å huske på å gå tilbake.

P 6.2, 6.2.1] *Terje:* **[**Sånn "Default" - når du har vært ut på en annen kanal som AT kanal eller sånt så når du er ferdig så skulle han automatisk komme tilbake til ... **P 6.2.2]** *Kjell:* **[**Ja, enten det eller så kunne det være lytting. Når du er på en av de to kanaler så lytter du bare den andre. **P 6.2.2]** *HJ:* **[**Det burde gå an og sett opp det. (HJ informerer om aktuelle utprøven av radioene ifbm en ny lydprofil. **P 6.2.2]** **[**Kjell forteller om vanskeligheter med å høre hva slags meldinger gikk. De hørte at det var en melding, men ikke hva det var. **P 6.3]** **[**HJ informerer om en workshop i oktober hvor de skal starte arbeidet med å se på bruk av enten håndholdt eller radio i forbindelse med håndteringen av AT. **P 6.2.2]**)

• *HJ:* Men skal vi ta en gjennomgang av hvordan det fungerer nå? Og så går vi ut.

• **[**Kjell, HJ og Terje snakker litt om turene og deres oppbygg. Det framheves at område 1 har vesentlig flere tagg. **P 3.3]** *Kjell:* **[**Som turene er oppdelt nå så blir det urimelig mye arbeid. På samme plassen, på samme nivå da, så har du to tagger. Den ene ligger på den turen og den ligger på den turen. Skal du gå dit til først så må du helt ned på bakke nivå for å bli ferdig med denne turen, og så for å starte neste turen igjen, så må du opp igjen dit. *HJ:* Ja, det er unødvendig. **P 3.1]**

• (HJ viser turen) *HJ:* **[**Så her er turen som er faktisk lagt inn i PI. Her ligger da de verdiene som er lagt inn selv. Og da kan jeg gå på den for eksempel, og så her har du da verdien som har målt tidligere. Det gir en veldig god oversikt. **P 5.1]** **[**Men nå vet jeg ikke, taggene ble også lest av SAS? Så spørsmålet er hvorfor vi legger den inn i ... logger inn manuell. **P 5.2]** *Terje:* [Der da må jeg bytt ut. *HJ:* Så her er det en tagg som også leses automatisk av kontrollsystemet og legges inn i PI. *Kjell:* Vi har jo et automatisk system som samler mye av det samme som vi gjør da også. Så vi trenger ikke dobbel ... **P 5.2]**

• *Terje:* **[**Det er veldig lett å se egentlig ... den som har "T", den er i hvert fall inn i SAS systemet. "T" sier at signalet ble transmittert. "T" for transmitting. Så når den mangler den T-en, så er det feil tagger egentlig, i henhold til kode manualen og slik. **P 5.1]** **[**"PDI" er indikator. "PI" det er en trykk indikator. Den skulle egentlig har "PDIT" i henhold til kode manualen. Når jeg sitter og ser i systemet så ser jeg med en gang, alle som har den T-en, dem vet at de finnes i systemet. **P 5.1]** (Kjell forteller om Draugen der de har faktisk to forskjellige betegnelser av tagger, det du leste i kontrollrommet på skjerm og det som ... de taggerne ute ... det kunne mangler en bokstave. Da ble det sånn ... hvis du stod ute så ropte du: Kan du sjekke den og den taggen for meg? Nei, jeg finner den ikke.)

• *HJ:* **[**Skal vi se hvordan det brukes? (HJ viser enheten) *HJ:* Starter. Og så skal det stå PI. Så starter det programmet. Og så får du de turene som vi har på område 3 da. Og da skal vi ha rensanlegg, natt. Da markerer jeg den og så trykker på den. Og det her må operatøren gjør da. Og så får man opp et time stamp og da kan du enten velger den der eller si set current. Så ok. Så går den rett i skanne bildet for barkoden, og da bare ... få opp taggen og så velge ok eller ikke ok. Og så kan du enten trykk der eller der (Enter). Og så går du til neste barkode. Skal vi se om vi finner en som har en verdi på. Der har vi en. Sånn, da velger du inn tall, 5.6 for eksempel, Enter. Og videre til neste. Sånn holder du på. **P 1.5]**

• **[***DB* spør om først alle tagger tas før data overføres i PI eller om data overføres imellom. *Terje:* Ja, vi tar alle. *HJ:* Vi har ikke overføring. For å få overført så må du sette inn alle enhetene i en dokking stasjon og så gjør du overføring. Dokking stasjonen står ved siden av kontrollrommet. **P 5.1]**

• **Usability:** **[***DB* spør Kjell om erfaringen sin med enheten i forhold til håndteringen, ergonomi osv. *Kjell:* Det går per erfaring. Så det blir bedre og bedre. **P 1.7]** **[**Men hvis du ser enheten her, så ... det blir litt skråvinklet. Så mine erfaringer er hvis du holder den omtrent som her, så går det bedre. Men hvis du holder den sånn her, så treffer du sannsynligvis under ... **P 1.6, 1.7]** **[**Mens skanningen går det greit. Bortsett fra den skarp sollys. Da sliter du litte grann. Du sliter med skanninger fordi du ser ikke hva du peker på. **P 1.3]** **[**Og så i tillegg til det, skjermen er for lyssvak sånn at du ser heller ikke har du pekt nok eller ... **P 1.1]** **[**Og enheten er heller ikke følsom nok, kan du si. Du sliter litt med trykking på skjermen.

P 1.3] (Terje forteller om samme erfaringer med iPhone 4 sin som var i begynnelse helt jævlig. Han nevner tykkelsen på glasset.) *Kjell:* **[**Jeg tror det går jo å justere sensitivity på ... *Terje:* Det vil jeg også tro. *HJ:* Men backlight er satt opp til maks. *Kjell:* Det er klart, jo bedre backlight du har, jo mer batteri spiser den. **P 1.2]** **[***DB* spør om bruk av fingertrykk. *HJ:* Det er noen som bruker finger. *Kjell:* Ute i felt sånn er du pålagt å bruke hansker, ikke sant. Og for min del i hvert fall, så blir det mye krøll. **P 1.6, 1.7]** *Terje:* **[**Jeg tenker sånn i forhold til ... så hadde et stort tastatur som du kunne styrt med. **P 1.12]** *Kjell:* **[**Ja, men da må det være alfanumerisk, så du slipper å ... Nei, det må være alfabetisk, ellers ... *Terje:* Ja, jeg tenker litte grann sånn piltaste sånn at du kunne bare ... omtrent som å flytte nesten en mus. Jeg bare så for meg at det kunne være enklere enn å begynne å ta med blyanten. **P 1.12]** *Kjell:* **[**Jeg syns for min del, den blyanten den er greit nok. *HJ:* Det er erfaring. Erfaring at du vet akkurat hvor du skal trykke. **P 1.7]** ([Kjell bruker blyanten med hansker på. **P 1.7]** DB forteller om Agloves hansker som har sølvfiber og som understøtter bruket av kapasitive berøringsskjermer. Kjell tror at den type hansker er veldig kalt om vinteren.)

• *DB:* **[**Finnes det sted på anlegget der dere har flere barkoder, tett sammen, med kort avstand, slik at dere må holde enheten meget eksakt for å kunne skanne? *Kjell:* Det er litt variabelt. **P 3.1]** *HJ:* Det vil du se når vi kommer ut i anlegget.
• *HJ:* Skal vi bryte oss ut på det? *Kjell:* Hvis ikke vi skal spise lunsj først.
• *DB:* **[**Da er det bare ett spørsmål før jeg glemmer det: Har kontrollrom operatørene samme informasjonen dere har på enheten (skjermen), på samme tid? *Kjell:* O ja, ja. Mye av det. Eller ... det er punkter som er lik eller det er samme tagger som legger der som også kontrollrommet har og det er real time, kan du si. I tillegg til det så har vi i kontrollrommet et sånt system, PIMS (Project Information Management System) og alt blir jo logget, alt som skjer i kontrollrommet det blir notert, for å si det sånn. **P 5.1, 5.2, 3.1, 3.3]**
• *DB:* **[**Og barkodene må utveksles etter en stund, eller? Pga slitasje? *Terje:* Det blir slitasje. *Kjell:* Og det har skjedd. Og så måtte vi da skrive ut nye. **P 3.4]** **[**Vi har plast tagger som vi limer strekkoder på. Så har vi på en film, sånn UV-beskyttelse for at ikke solen skal ... selv om det er ikke så mye sol så ... *HK:* Spesielt plagsomt i sommer i hvert fall. **P 3.4]** *Terje:* **[**Spesiell beskyttelse for regn også kanskje? Det er mer viktig. *Kjell:* En lite sånn tak over ... **P 3.5]**

Ormen Lange 2011-09-22
Mobile computer MC 9090ex i bruk
Presentasjonsrunde med Terje (IT) og Kjell (Operatør)

Pumperom
• *Kjell:* **[**Æhm, nivå på diesel og temperatur, olje ... det som foregår på natterstid, kan du si. **P 3.4]**
• *Kjell:* En gang forige uka da, så skjekket de olje på ... maskinen. Eller så ... hvis du veit maskinen har gått, sjekk olje. Terje: Ja. Kjell: Fordi, den bruker ganske mye olje. Terje: Den gjør det? Kjell: Ja. Kjører tre timer, femti liter vil jeg tror.

Målestasjon
• *Kjell:* [På ettermiddag da er det sånn visuell sjekk. **P 3.4]** **[**Nå skanner jeg tagg som ikke er på den turen her. Da fikk jeg jo feilmelding. Avslutte det. Og så bare trykke OK. **P 1.10]**
• *Terje:* **[**Sjekk B-pumpe på ettermiddagen og A-pumpe på natt? *Kjell:* Nei. *Terje:* Det står N der. *Kjell:* Okay. Det må være feil. **P 3.4]** **[**Du skjønner, nå fikk jeg feil verdier. **P 1.9]** **[**Skal vi se. *Terje:* Det burde i hvert fall være det samme ... på turen her ... samtidig. *Kjell:* Ja, det er jo det. (Kjell skanner.) Sånn. Dette her er jo ... Natt, det er feil. **P 3.4]**
• *Kjell:* **[**Hvis du ser her nå, du ... at her den skanningen ... den lysmangel (manko?) som vi har ... du ser ikke hva som stå ... om du har truffet eller ... **P 1.1, 1.3]**
• *Terje:* **[**Og gjør det, her er Ettermiddag, har det noen forskjell? Når vi laster båt en gang i uka. *Kjell:* Nei, det har vel ingenting ... *Terje:* Nei, fordi ingenting forandrer seg helt fra i dag til i morgen hvis ikke det kommer en båt her. *Kjell:* Nei, sånn hvis maskinen ikke har gått, så er det ingenting som forandrer seg. *Terje:* Sånn, egentlig å gå inn her hver dag det er ... *Kjell:* Nei, men vi kan gjøre det ... en tagg da ... *Terje:* Ja, ja, også bare inn å sjekke at det ikke var noe ... og trøbbel. Men du trenger ikke å gå sjekke olje nivå hver dag ... av ting som står. *Kjell:* Nei, på ting som er ikke i drift så er det ikke nødvendig. *Terje:* Nei. **P 3.3, 3.5]**

Lastekai
[På lastekaien er det visuell sjekk, dvs. å skanne barkoder og trykke ok. **P 3.4]**

Ettermiddagsrunde med Silje (Operatør) og Margrethe (Lærling)

MEG Renseanlegg
• *Silje:* ... Tagg og Tagg group ... tar du den ... trykker ok, Enter, og så kan du gå til neste.
• *Silje:* Så, her må du skrive ...
• *Silje:* Her skanner vi en.
• *Silje:* Den er ok.
• *Silje:* Så må vi gå bort på andre pumpe som ...
• *Silje:* 10,64.
• *Silje:* 6,5.
• *Silje:* Trykk ok.
• *Silje:* Det er ... måler. Den er da ganske viktig. (...) Men den her funker ikke. Så vi bruker ... eller prøver. Da er det sånn. Og så skriver ok.

APPENDIX E

Data analysis – categorization scheme

1. PDA usability problems
1.1 Dissatisfaction about an aspect of the GUI
1.2 Uncertainty about an aspect of the GUI
1.3 Dissatisfaction about an aspect of functionality
1.4 Uncertainty about an aspect of functionality
1.5 Use of functions
1.6 Dissatisfaction about an aspect of ergonomics/physical comfort
1.7 Satisfaction about an aspect of ergonomics/physical comfort
1.8 The user cannot achieve the task goal
1.9 The user has made an error
1.10 The user is able to correct an error
1.11 The participants make a suggestion for improvement of the GUI
1.12 The participants make a suggestion for improvement of functionality/physical comfort/ergonomics

2. Content problems
2.1 Uncertainty about an aspect of the electronic text
2.2 Suggestion for improvement

3. Logging procedure problems
3.1 Dissatisfaction/uncertainty about the positioning of tags
3.2 Problem of finding tags
3.3 Dissatisfaction/uncertainty about the number of tags
3.4 Different types of tags
3.5 The participants make a suggestion for improvement of aspects of tags

4. Effects of use of the PDA
4.1 Effects on users
4.2 Effects on procedures
4.2.1 Earlier procedures
4.2.2 The participants make a suggestion for improvement of procedures

5. System problems
5.1 Problems with the transfer of data
5.2 Double check of data

6. Other aspects/comments

6.1 Dissatisfaction about paper-based equipment

6.2 AT-procedures

6.2.1 Dissatisfaction about an aspect of AT-procedures

6.2.2 The participants make a suggestion for improvement of the AT-procedure

6.3 Dissatisfaction about an aspect of the radio device

6.4 The participants make a suggestion for improvement of the radio device