EXPLORING INTERACTION DESIGN
PERSPECTIVES ON HEAVY VEHICLES

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Abstract
Interaction design is more crucial than ever as an ingredient in product development and digitalization. Its need is driven by a trend where software based functionality is becoming increasingly important in all types of product features, simultaneously as new technology moves the frontier where interaction between human and computer takes place. There is also a market demanding renewed experiences, more efficient, stimulating and fashionable, which enterprises seek to deliver to attract customers. Also, as systems, for example vehicle systems, get increasingly information intense, the information exchange with the user becomes a factor for safe and successful operation, thus increasing the need for a proficient interaction design.

This research investigates how interaction technologies, interaction design principles, and machine information systems can be used to provide user experiences and efficient interaction between the operator and industrial mobile machines; for example, agricultural machines and construction machines. The research combines software engineering and interaction design together with an industrial perspective. It does so by studies, both in literature and through field studies of operators, by design exploration and prototype realization.

The thesis describes the design space for heavy vehicles through different perspectives. It outlines the principal dimensions of interaction design and the benefits of including design in product and services realization. It presents perspectives on the challenges for the different stakeholders involved, covering the operator of the machines, the software engineer and the designer. It depicts a method for gaining detailed insights into operator’s daily behavior, with minimal interference with their work. Furthermore, it introduces a tool for practitioners to explore interaction design using mixed reality and free head movements, and it investigates possible interfaces using augmented reality.
Swedish summary / Sammanfattning
Interaktionsdesign är mer avgörande i produktutveckling och digitalisering än någonsin. Utvecklingen här drivas av en trend där mjukvarubaserad funktionalitet blir allt viktigare i alla typer av produkter samtidigt som ny teknik ökar designrymden för var sampelet mellan människa och dator kan äga rum. Användare efterfrågar förnyade upplevelser, mer effektiva, stimulerande och moderiktiga. Företag söker möta denna efterfrågan för att locka kunder och genera affärer. Dessutom, genom att system, exempelvis fordonssystem, blir allt mer informationsintensiva, blir sättet som informationsutbytet sker med användaren en allt viktigare faktor för säkerhet och funktionalitet. Sammantaget ökar behovet av en skickligt utförd interaktionsdesign.

Den här avhandlingen undersöker hur interaktionstekniker, interaktionsdesignsprinciper och informationssystem kan användas för att leverera användarupplevelser och effektiv interaktion för operatörer av industriella mobila maskiner, exempelvis jordbruksmaskiner och anläggningsmaskiner. Forskningen kombinerar interaktionsdesign och mjukvaruutveckling i ett industriellt kontext. Forskningen har bedrivits genom studier, i litteratur och etnografiska studier av användare i fält, genom utforskande design och genom prototyprealisering.

Avhandlingen beskriver designrymden för industrifordon från flera perspektiv. Dels från perspektiven av de grundläggande elementen inom interaktionsdesign, processerna för att skapa och förska inom interaktionsdesign samt fördelarna med designdriven produkt- och tjänste-förverkligande. Vidare tar den upp perspektiv utifrån situationen och utmaningarna för inblandade aktörer, såsom operatören av maskinen, mjukvaruutvecklaren och designern. Avhandlingen bidrar också med praktiska perspektiv, dels en metod för att få detaljerad inblick i operatörens dagliga beteende med minimal störning i sitt arbete, och dels ett verktyg för interaktionsdesigners att undersöker möjliga designs med virtuell förstärkt verklighet med hjälp av blandad virtuell verklighet och fria huvudrörelser.
Dedicated to Pauline, Vera and Wilford
Acknowledgements
Throughout the studies leading up to this thesis, I have had the opportunity to meet with many people that have enriched not only the research as such but also my life. There are too many to mention, but if you read this I would like to express my appreciation and say thank you.

I would like to take a moment and express my sincere gratitude to the people being closely related making this thesis a reality.

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My deepest gratitude I owe family, especially my beloved wife Pauline, my fantastic children Vera and Wilford, and my dear parents Gösta and Isa. Without your love, support and patience this wouldn’t have worked.

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Markus Wallmyr
Sundsveden, December 2016
List of Papers
Papers included in the thesis

This thesis is based on the following papers, which are referred to in the text by their letter or by title. The included articles have been reformatted to comply with the defined licentiate thesis layout.

A. Interactions and Applications for See-Through Interfaces: Industrial Application Examples
Wallmyr, M., 8th Nordic Conference on Human-Computer Interaction Fun, Fast, Foundational - NordiCHI workshops, Helsinki, Finland, 2014

B. Current Challenges in Compositing Heterogeneous User-Interfaces for Automotive Purposes
Holstein, T., Wallmyr, M., Wietzke, J. and Land, R., 17th International Conference on Human-Computer Interaction, Los Angeles, California, USA, 2015

C. Understanding the user in self-managing systems
Wallmyr, M., European Conference on Software Architecture Workshops - ECSAW 2015, Dubrovnik, Croatia, 2015

D. Seeing through the eyes of heavy vehicle operators
Wallmyr, M., Submitted to 16th IFIP TC.13 International Conference on Human-Computer Interaction - INTERACT 2017, Mumbai, India, 2017

E. Low-cost Mixed Reality Simulator for Industrial Vehicle Environments
Kade, D., Wallmyr, M., Holstein, T. Lindell, R., Ürey, H. and Özcan, O., 18th International Conference on Human-Computer Interaction, Toronto, Canada, 2016
Authors contribution in included publications

A. I was the sole contributor to this paper.

B. The work was shared equally between the first two authors, with the third and fourth authors being supervisor, where my main contribution was related to the application and UI layers and manuscript.

C. I was the sole contributor to this paper.

D. I was the sole contributor to this paper.

E. The work was shared equally between the first three authors. I contributed to the idea, implementation of the simulated environment, user evaluation and manuscript.

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Preface

“You’ve got to start with the customer experience and work back toward the technology – not the other way around.” (Steve Jobs) [37]
New interaction technology, mobile and customer market trends, and an ever increasing amount of information produced in modern mobile machine systems create new possibilities for user interaction. A competitive market also makes it important for Original Equipment Manufacturers (OEMs) to produce machines and services that increase efficiency and attract the customer. This research investigates how interaction technologies, interaction design principles and machine information systems can be used to provide a better user experience and an efficient interaction between the operator and the industrial mobile machine, for example, agricultural machines, construction machines, trains, cranes and boats. Inspired by the Swedish child TV program “stora maskiner” [95] that makes video reports of mobile machines that “rolls, digs, lifts, shovels, drags, extinguishes and empties” I will herein use the term “heavy vehicles” (my own modified translation).

Interaction design is more crucial as an ingredient in product development and digitalization than ever before. Not only is there a market demand for renewed, more efficient and stimulating, experiences. The borders where an interaction between human and computer take place, are rapidly expanding as computation and digitalization extend in areas that previously weren’t related to the digital world. For example through sensors that measure the ground conditions in order to adjust soil treatment, or active vehicle control systems that step in to prevent accidents or to autonomously control the vehicle.

Interaction designers are faced with two opposing forces: interaction is becoming more complex, while it simultaneously has to become more ubiquitous and natural to use in our daily behavior. This trend has been ongoing in the frontier research and commercial domains, for example through the results presented in tangible interaction and the mobile devices development.

The development of vehicles, industrial machinery and embedded systems has in recent time started to follow. One example of this trend is when Doug Oberhelman, Chairman and CEO of Caterpillar Inc., one of the biggest industrial equipment manufacturers, in 2016 introduced the term “the Age of Smart Iron – Digital Technology Designed to Transform Productivity, Efficiency and Safety on Job Sites”. As these systems are becoming increasingly digitalized, autonomous and complex, they require more understanding and design in terms of human-machine interaction.

This licentiate thesis concludes the research, courses, and other activities of the Ph.D. studies at its current mid-term state. It describes the results and work done towards providing different perspectives on interaction design in heavy vehicles, in theory, practice, and research. It presents the challenges for the different stakeholders involved, with emphasis on the operator of the machines. It depicts the results and methods used for gaining insights into an operator’s daily behavior, with minimal interference in their work. It, fur-
thermore, outlines the principles of research through design, interaction design realization and the benefits of including design when realizing products or services. It introduces a tool for practitioners to do exploration in free head movement mixed reality interaction, and it explores possible uses of augmented reality interaction in an industrial context.

With this thesis I will try, perhaps somewhat unconventional for a licentiate thesis, to provide a guide into the field even for someone less informed in interaction design. This has expanded the introduction but I hope that the contributions and the industrial perspective can give some bits of pieces of information to add to the web of interaction design knowledge, as well as some food for thought.
Introduction

What is design? It’s where you stand with a foot in two worlds - the world of technology and the world of people and humans purposes - and you try to bring the two together. (Mitchell Kapor) [47]

This chapter presents the motivation for the research, why there is a need for interaction design in heavy vehicles and the need to understand the user.

First, we turn to the past.
A short background on heavy vehicle interaction

Mechanization, in form of vehicles, aids us with many working tasks and stands for one the most efficient inventions in improving industries. One example is the combine harvester. It is considered one of the most economically important labor saving inventions [96] and part of changing the proportion of farmers in the US workforce from 38 % to 3 % during a century [97]. The same trend can be seen in other industrial segments, such as forestry, where a harvester and a forwarder replaced a whole team of workers doing manual cutting and transportation using horses.

![Early mechanized agriculture harvester.](image)

These machines have since from being only mechanical to use hydraulics control and electrical control systems (figure 1 versus figure 2). Powered by high performance embedded computers, using digital sensors and networked signals, the amount of information within the system has increased dramatically. More information offers new possibilities to make even more advanced machine operations; coming back to the combine harvester, where the operator can set the level of harvesting waste that is allowed and the machine automatically adapts the production to fulfill the required level. The system will adjust production and movement speed to supply the requested quality using sensor technology, cameras, and image analysis [99]. Setting the prior example aside, there are many systems that need an active control and decision making by the operator. In, for example, forestry harvesting, it has been observed that operators make 4000 control inputs during a working hour, putting a high mental load on the operator [72].
The automotive sector is researching different alternatives for interaction with all the functionality in a modern vehicle, as several hundred functions cannot be directly presented, and controlled, by the user [100]. The basic principle of having a primary, secondary and tertiary section of interaction in a car [48] is enhanced and re-imagined by adding more and larger screens, as well as, head-up displays, gesture control and voice interaction, etc.

The information age is also taking a stand in heavy vehicle applications [101]. Machines get connected and incorporated in information exchange with back office systems, receiving work material and reporting production. Vehicular Ad Hoc Networks (VANETs) [41] technologies are recently becoming applied in industrial heavy applications to increase safety and improve production efficiency [81].

In industry, many solutions are still realized with add-on systems, each with their own interaction and with different level of integration with the rest of the machine. This results in an inconsistent interaction, as well as information produced that is less beneficial for the stakeholders [19]. The move from directly mechanical or hydraulic control into electronic control has also affected the feedback perceived by an operator when operating the machine. With mechanically controlled machines a skilled operator “feels” how the machine is operating. With electronic controls operators, who I have observed [90], report that this is more difficult.

The limited haptic feedback, in combination with the increased administrative information being presented on displays, makes the way the information
is presented to the user increasingly important. This includes presenting the correct information from the system at the right time and in an appealing and usable way. It also includes to utilize other means of interaction than graphical user interfaces, by taking into account the increased amount of information that can be processed by the brain when using several sensing methods [87]. Something that is important not only for the reasons of efficiency and user experience but also for safety [65].

**Designing interactive products, user experience and user centered design**

Human-computer interaction has evolved through a succession of phases, as illustrated in figure 3. In the first phase, interaction was needed to perform a certain task. It was rarely adapted to humans, instead, it was based on the needs of the system. The human-computer interaction research came and created understanding, principles and relevant methods, to be used by developers of user interfaces and systems, to increase usability. In the third phase, the state of the art has traversed to the experience qualities. Extending the usefulness and efficiency to include some kind of experience, to motivate the user to acquire and use the product or service.

![Figure 3. The three stages of human-machine interaction. My own version based on material from [79].](image)

The industrial machinery is the essence of a utilitarian artefact [102], a product to create more wellbeing, in terms of what it helps us create and with less suffering during the creation process. Helping us, for example, in the creation of roads that provides a more convenient travel compared to plowing
through the bare nature, or to assist us in harvesting the crop from a field more effortless than with manual labor. When interacting with these machines, the experiences gained can be referred to as the product experiences.

Hekkert and Schifferstein define product experience as “user experience to physical objects or non-physical designs that have a utilitarian function, thereby excluding works of art and other non-utilitarian artifacts.” [43]. With their definition of product experience as “the awareness of the psychological effects elicited by the interaction with a product, including the degree to which all our senses are stimulated, the meanings and values we attach to the product, and the feelings and emotions that are elicited” [43], they argue that the research on subjective product experience is multidisciplinary, as illustrated in figure 4.

![Figure 4. Disciplines contributing to the field of product experience.](image)

The interaction with a product is, as per the definition above, highly related to the human and psychological factors, in other words, the interpretation by the user. This is also affirmed by standards and definition, for example, ISO 9241-210 that defines user experience as “a person's perceptions and responses that result from the use or anticipated use of a product, system or service” [106]. The user experience implies that it is not only the interaction with the system that should be useful and usable, it should also include factors such as emotion, prior beliefs and aesthetic factors [25].

The user experience for a product, in today’s connected world, is more than the use of the artifact itself. According to Norman it, “encompasses all aspects of the end user's interaction with the company, its services, and its products.” [70], including what the user perceives as indirect experiences. For example, that not only should the visual interface on a phone be effective and appealing. The phone should also provide a good experience of communication with clear sound, and good reception and the services around the product should provide an appealing user experience, including factors
like purchasing, packaging, and support. Furthermore, it should provide content services, such as app and media content availability. Where it is not only about servers for download and a visually appealing store. It is also about quick download speeds, informative descriptions, charts, recommendations and customer reviews, etc., that support the user in finding qualitative and interesting apps. Thus increasing the overall user experience.

Functionality is increasingly realized in the digital domain [13], up to 70 percent of new automotive innovation is reportedly being realized through software [9]. Subsequently, this means that the user experience is affected by how the digital interaction is designed. This is where the term interaction design comes in. While there is no commonly agreed definition of interaction design, Fällman defines its core orientation “towards shaping digital artifacts - products, services, and spaces - with particular attention paid to the qualities of the user experience” [28].

Designing interactive systems is about the creation of interaction between users and the artifacts they use. It could be an interaction using completely physical assets and senses, for example, the mechanical steering of a car. It could also be using elements of nature, for example how water can be used to tell the temperature, conveying the feeling of cold through ice, or heat by steam [45]. But more typically, it is about creating a meaningful interaction between digital systems and humans. Benyon describes it as:

“Interactive systems are things that deal with the transmission, display, storage or transformation of information that people can perceive. They are devices and systems that respond dynamically to peoples actions” (David Benyon) [6]

Here, the software and the information becomes an important material used to craft the design [58,59]. It may still involve interaction with physical objects, for example, a force feedback steering wheel in a car racing game, which provides the user with resistance in steering and vibrations when going on rough terrain. But is often about how information is exchanged through an audiovisual user interface.

Interaction design as a concept is relatively new. The term was reportedly coined by Bill Moggridge and Bill Verplank in the mid-80's and made its wider breakthrough a decade later [20]. However, the roots of interaction design go further back in time as interaction design partly stems from the Human-Computer Interaction field, where great emphasis is placed on quali-
ty of use, mainly connoting task efficiency and absence of usability problems [53]. Secondly, interaction design has, as the name suggests, origins from the design field. This adds aesthetics and function, as well as the working methods of design practice to tackle the area of interest. If relating it to other design professions, it is closer to architects and clothing designers, than art and visual designers [111].

One method to create product experiences in interaction design is through user-centered design and design thinking, two related concepts. Tim Brown describes design thinking as:

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“Design thinking - a methodology that imbues the full spectrum of innovation activities with a human-centered design ethos.” (Tim Brown) [12]
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User Centered Design originates from Apple, also in the mid-eighties, as a response to products and services being complex and unnatural to use [69]. Its basic idea is to “take the user into account every step of the way as you develop your product” [38]. User Centered Design emphasizes working practices that create an understanding of, and collaboration with, users of the system to gain insights into their perception of good experiences. It includes a deep understanding of the activity to be performed. Moreover, it addresses the surrounding eco-system that may be needed when technical solutions are not produced for its own purposes but as a part of a system.

Brown describes it further: “It is a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.” [12]. One classical example, from the just named Apple, is the iPhone. Touch-based smartphones existed already before the iPhone, but were a product more similar in interaction style to a mobile PC and used by those who had the willingness to learn and explore. Installing new software was, for example, a multi-stage process where one often needed a connection to a PC to obtain and install the application. Apple realized that the device must not only be easy to use, they also understood that the distribution and availability of content were important. The result was not only the iPhone with all its technology, it was also the AppStore as a service, with the backend that is required for its operation. This also gave additional sources of revenue, since Apple and its content providers, is not making revenue solely on the phones but also in the form of commission on sold merchandise through the App Store. We will later see what this did for the Apple business value.
Research motivation

The research goal is to gain knowledge on user interaction with a heavy vehicle information system, providing technologies and an improved body of knowledge to designers and developers when creating user experiences and information visualization. The human machine interface is the means to tell the machine what to do and also for the machine to tell the operator what it is doing. Potential efficiency and wellbeing might be negatively affected without deep knowledge of factors that affect the user interface and understanding of how to apply different technologies. Furthermore, there is even a risk that new functionality is added that decreases efficiency and increases mental load, thus potentially increasing the risks of failure as well as compromises human safety. One example of such is the Llanbadarn Automatic Barrier incident report where a train passed a crossing with the bars raised. One reason why this happened was because the operator was occupied with the driver machine interface and therefore missed the crossing indicator [24].

Although mediums with capabilities to interact with a richness of information are becoming more and more common in industrial vehicles, for example, touch displays instead of small dot matrix displays and separated buttons, there are still open research topics within the field. Even for the current state of industrial practice. For example, there are still problems of making usable interaction with touch displays in the context of a vehicle [82]. Attention is also gained on how to support user interacting with the vehicle systems, while not taking unnecessary focus away from the primary task, being, for example, the area of operation or the road [55].

Another example is the integration of additional services in the systems. Although new information based systems lead to production benefits [81], many solutions are realized with add-on systems and additional displays, as exemplified in figure 5. In some cases, this might not even be allowed for.

![Figure 5. Perhaps extreme, but an example of a machine cabin with a multitude of add-on systems [61]](image)
use in traffic situations [109]. These systems, developed by diverse suppliers, use their interaction idioms and different level of integration with the rest of the machine. The result is a non-homogenous interaction and information that is difficult to benefit from for the stakeholders [19].

Additionally, as modern interaction has expanded from the classic Human Computer Interaction to include the user experience. Providing the user with a better experience should, hopefully, lead to higher return on investment [34] and to products that are useful, usable, and engaging [6]. But there is a need to understand and how to apply the processes and techniques when designing user experiences in the heavy vehicle domain. The time aspect is also to be considered. As these machines take considerable time to develop, get into the market and have a lifetime for many years, they outlast the experience trend at fashion during their development. Thus they need to seek experiences outside the domain of trends, as well as offer experiences that last for a prolonged period [75].

Although the basic purpose for many heavy vehicles is still the same, the complexity of the vehicles is much higher with many more functions. Different technologies for interaction with the system are one part in making a better user experience. But one central concept is understanding of, and collaboration with, users of the system. As well as understanding what they perceive as a good experience.
Different perspectives on design

“Design is messy: designers try to understand this mess. They observe how their products will be used; design is about users and use. They visualize which is the act of deciding what it is.”
(David Kelley) [93]

As a background and extension to the included publications, this section briefly discusses the fundamental perspectives of interaction design and interaction design research: its concepts, practices and elements. It is addressed in the perspective of industrial machinery interaction and includes the industrial motivation to invest in this discipline.
Perspectives on the idea of design

“The designer designs a user-centered design”

This chapter will use a linguistic perspective to look at design. Based on the above sentence the term design can be observed as an object, a subject and a predicate according to the following linguistic rule: If the predicate is what is happening and the subject the one doing it, the object is what is being exposed for the subjects predicate action [103].

Design as object

The user interface can be seen as a machine's face towards the user, its eyes, its tactile senses and its voice [28]. Information can be presented from the digital embedded system through the visual user interface, or from analog and mechanical parts for that matter. Information can be communicated to the system via various levers, keyboard knobs, touchpads and buttons. Systems can also communicate verbally with the user, through audio signals, synthetic voices and speech recognition [54].

The way to communicate has to be adapted to the user, taking into account factors such their level of knowledge, their way of communication, age and prior experience [73]. Between humans, the communication style and its content are not the same with a child who is learning something new, compared with the communication that takes place during a surgical operation. The same difference in communication is also adequate for communication between a user and a machine, be it a computer or a different type of machine.

The form and the content should also be adapted to the task performed. In some situations focusing on a simple and clear interaction, so that anyone can do the job, in other situations focusing on control and productivity, preferably in an interaction that supports different types of usage levels [78]. In vehicle situations, it can also be critical that the user has undivided attention in order not to risk human safety. An example, when this was not the case, was when a train passed through a crossing with the bars up. This happened because the wrong interface in the locomotive was occupying the driver's attention [64]. Another, less extreme example, is when it is appropriate to use a touch screen or a rotary knob to navigate a vehicle interface [42], considering factors such as speed of operation, vibrations and possibility to perform the interaction without looking at the control.

Design is also about form and aesthetics, applying to both physical and graphical interfaces. As humans, we find pleasure and attraction towards the
things we perceive beautiful or interesting. Attractiveness and emotion should not be belittled in the interaction because it is an item of utility [32]. Even Sullivan [88], the originator of the term “form follow function”, adhered the art in the design.

Design as predicate

To design a product, a system or a function, in terms of interaction design is to design the interaction taking place between the user and the technology through different practices. The designer creates an understanding of user needs and the task being performed by, for example, surveys, studies and data collection. The designer then creates a concept for the system use through illustrations, descriptions and user scenarios, etc. With this knowledge as a base, the design goes further into the details in the form of information architecture, layout, materials, etc. Throughout this process, it is important to keep the focus on the user, which, for example, can be done by reoccurring user tests during the process [23].

The work of an interaction designer can include many disciplines, for example, psychology, craft, analytics, computer science, etc. But in its essence, the designer is a creator, a storyteller and a producer, trying to tell a story of what could be, shaping behavior and appearance of interactive artefacts in a way that appeals the receiver, see figure 6.

![Figure 6](image.png)

*Figure 6. Visual design of a showcase interface as part of company work, telling a story about the possibility to use the software and the computer to realize diagnostic functionality.*
Creating an interaction makes, like most disciplines, use of a set of processes, methods and tools. Interaction design processes basically include understanding, idea creation, realization and evaluation in a multi-cycle loop [6]. The designer’s toolbox contains many tools, but pen and paper take the designer a long way since the major part of the design is about creating ideas and form [71]. For early prototypes tools and materials from the hobby shop come in handy [40]. When it is about the visual design, some kind of drawing, design- and CAD-tools. In order to realize the interactivity, the development environment becomes the toolset and the code the material [58]. But it is not just about "creative" tools, it is also about tools like a word processor or spreadsheets, used to list, prioritize and analyze functions and requirements, as well as transform the designs into definitions for the development engineers. See figure 7 for two examples.

![Figure 7. Two examples of work performed. Left: use of simple paper models to evaluate unit designs with and compare with existing units. Right: a spreadsheet listing UX improvement for planning and prioritization. (text not supposed to be readable)](image)

**Design as subject**

A designer is a person who understands the user and the task and identifies the problem(s) that need solving. The designer has one foot in technology and can transfer the technology into solutions. The designer sees the market and the vision of what can be accomplished. The designer has the ability to, not only address the fine detail, but also the design of the service provided at the complete system level. The designer understands the aesthetics and what can appeal to people.

Design is often about facing “wicked problems” [14] with unclear definition and many possible outcomes. Nigel Gross concludes his book “Design Thinking” [22], where he investigates how different designers work, that designers are solution focused rather than problem focused and deal with ill-defined problems. Though, being solution focused they are not neglecting the problem, they are good at being “proactive in problem framing, actively
imposing their view of the problem and directing the search for solution conjectures” [22].

When looking at groundbreaking interactions or groundbreaking products where the interaction is a vital part [62], the designer is often pushing to break through barriers, to create something that is smaller, use technology in a new way, give users new ways to interact and assimilate information. But at the same time, it is about breaking barriers in terms of simplifying and refining, so that the interaction is natural, simple and instinctive.

To make a complex system simple and attractive is not just about an attractive visual layout and the right materials. It is also about design of the function and its content, in the bigger system perspective. The designer is the one who sees the whole picture, how all the pieces of the puzzle can sit together to make an attractive solution that solves the problem and increases the user value. We see this not only in digital interaction design, for example, Google's way of providing a well-targeted search functionality through efficiently combining a plethora of information sources. We also see it through historical examples, one being Thomas Edison and the light bulb [92]. Edison was not the first one to create a light bulb. In fact, he even bought the lamp patent from two Canadian inventors who hadn’t succeeded to commercialize their product. Edison, however, managed to provide the whole service of lighting, including electrical power distribution.

In working with the problem and solution, trying to create and envision a future, the designer must possess some level of creativeness with the possibility to envision. It seems popular that this envision is recorded, communicated, iterated and recorded via methods of art, for example using drawings and sketches. Being historical examples, like da Vinci and Edison, or more modern ones, such as Brown.

**Perspectives on the design space and its elements**

Design can be created in different ways depending on its objectives, in other words, it is designed from different perspectives. Examples of objectives are physical design, design for production, design for ergonomics, design following guidelines, design focused on aesthetics or art, design for specific focus groups, etc. The attention given to each objective yields a different result. If the focus is to make cheap products, elements such as ergonomics and aesthetic may play a lesser role while the design for efficient production is of higher importance. One can assume that there, to some extent, is a different body of knowledge needed for the various disciplines. Taking the same example as above: working with ergonomics requires knowledge of
anatomy, while the design of more efficient production is based on knowledge about assembly methods.

Still, the basic elements of input into the design are fairly the same. As outlined in figure 8 they are activities and purpose, context and environment, users and other stakeholders as well as technology and material [6].

![Design space diagram](image)

Figure 8. The basic elements of input for the designer to build the design

Context and environment

Context and environment concerns where the activity is performed, in other words, where the work and the interaction take place. Examples are the physical environment with weather, noise, etc., the organization and the processes that the user is working in, the support for the user in the form of manuals or someone to ask, the security and privacy requirements, as well as the social context, norms and customs.

Designing for industrial machines is to a high extent affected by the context and the environment. These types of machines operate in tough environments, with exposure to the elements of nature and rough operating conditions in terms of shock and vibration, see figure 9. This is also reflected in the testing requirements that electronic equipment needs to pass, being general environmental tests in terms of CE conformance, but also specific tests such EMC immunity [108] and industry-specific standards, for example, EN 50155 [105], that covers electronic equipment in railway applications. Some industrial machines are also affected by safety standards [107,112], that shall ensure that the product is designed to avoid harm on human beings. In certain cases, these types of standards also affect the HMI of the system, for
example, when reliability and validity of data presentation must be ensured [104]. This, in turn, affects the possible solutions achievable in terms of visual design and availability of technology.

Figure 9. A forestry harvester working in snowy and dark conditions.

The environment does not only affect the interaction with heavy vehicles through standards, it also affects the interaction more directly. Sunlight, for example, affects displays readability, making it necessary to select high brightness display elements and select colors schemes with high contrast for daytime use and darker schemes for nighttime use. In order to make the display readable at day time and not dazzling during night time.

Ergonomics is another area, the operator sits still for long periods, causing stress on the body. It is also reported that excessive movements are made, for example, to look out of the machine in certain angles with covered sight [29]. A good design of the interaction, including placement of the interaction devices can increase operator wellbeing. It can also improve information detection and intake, for example, when the information is within the visual attention area and less time is required to refocus on a display placed at the side in the cabin and then back into the surroundings [91].

Activities and purpose

The next element, activities and purpose, concerns the task performed by the user, of which the designer needs to have a deep understanding. It covers the activities and information need, when and how in time it is performed, its relation to other activities or users, etc. In order to design for the activity there needs to be an understanding of its purpose, in other words, what the
activity will lead to. Is it about process of information? Control or management of an artefact? Efficiency in time and/or resources, accuracy and/or satisfaction, and so on.

For heavy vehicles, the activities and purposes are, at a basic level, quite well defined and static. For example, the purpose of the excavator is to dig, move soil, demolish etc. And the purpose of a forestry harvester is to grab a tree, fell it, cut it into the lengths that produce the highest revenues, move to next tree etc., see figure 10.

The activities and purposes related to digitalization in this domain are however in transformation. One example of this is how one of the bigger precision and communication suppliers for industry applications started over 10 collaboration and integration projects with the big OEM during 2016 [113]. Many machines are now connected to precision GPS, giving not only geospatial data but also driver support, for example, prevention to dig at a certain depth, or ability to autonomously follow a path on a field.

![Agri Harvester Job Map](image)

*Figure 10. An example of a job map from an operator observation.*

Also, as machines get connected more information will be communicated from and between machines, opening up for more changes in purposes and activities related to digitalization. The communication, for example in agriculture, ranges from basic things such as reporting of covered field area to communication of soil condition treatment based on sensor data from the machine and sensors placed in the soil.

As higher levels of autonomy will be introduced, the activities and purpose of the operator will likely also transform into more managerial than operational, affecting the interaction with the machine, which I discuss in the paper “Understanding the user in self-managing systems” [90].
Technology and material

The third element is the technology and materials available for the designer. The designer has to select the appropriate technology to use and perhaps adapt it to realize the interaction, taking into account its limitations and possibilities. In its essence, it is about the input and output permitted between user and machine. But technology is also much more, through the things happening behind the user interaction, communication with other systems, suitable computing power, information storage, databases and more.

Materials can be physical materials that mediate the interaction and experience, but it can also be about material factors, for example having enough rigidness, weight and cost efficiency to realize the product.

Technology and material affect the interaction design with different constraints and possibilities. For industrial machinery, the environmental factors mentioned above affect the technology and material available, this because electronics must be selected that fulfill the standard requirements. The material must also cope with the wear and tear of sand, high-pressure cleaning, gloves etc. Additionally, the life span of the systems affects the technology, as these machines take a long time to engineer, will be produced for long times and have extensive operational and serviceable lifetime. Both software and hardware exist where suppliers commit to extended life cycles, being 10-15 years. But a machine system lifetime may sometimes exceed 30 years. This does not only affect the technology selected, it also affects licensing models. As well as integration with other services, as the system might have to be updated during its lifetime, in a time when communication standards and software will evolve.

Another factor affecting the technology choices are the production volumes. The possibility for custom components, for example, custom display elements, are limited. This because the production volumes are too small in comparison to the mobile and computer industry in general, or even to industries like cars. Interaction with these vehicles thus has to rely on standard components to a higher degree. Combining this with the high environmental requirements often make these components follow tail rather being the first in the technology forefront.

Users and stakeholders

Finally, but most essentially, the element of the user. Human-centered design, or User-centered design, are based on the idea that the system or artefact will be used by humans. Their needs and their prerequisites should be primary when designing interaction with the system.
All humans are more or less different, thus it would be difficult to create an interaction taking into account everyone. The designer’s requirements might not even have to include all possible users, but there are basic attributes that should be taken into account for the intended user group.

The user's physical factors, for example, physical size and clothing worn, affects the ergonomics, distance to artefacts, how small icons can be to support touch, etc. Other physical factors include how good sight and hearing a user may have, and how quickly reactions or movements can be carried out.

Different users also have different psychological characteristics. Naively, one would say that different people have different intelligence, which of course is far from the truth. However, through experience and education, users can have different ability to create the mental model of a system to effectively use it. For example, if the user has used similar systems before, it is easier to gain a mental picture of the new system, due to the past experience. But if a new design is introduced that violates the previous experience, it may instead require a relearning.

Individual differences also affect how we perceive different things and our instinctive reactions. Some persons are based on logical thinking, some see a problem as a challenge, others are more emotionally driven and some just want it to work, not interested in how.

User perception is also affected by social and cultural differences. For example based on the upbringing, social context, education, language skills and prior experiences. This can result in different interpretations of the interaction. For example, how colors and symbols are interpreted, as warnings or not. Different cultures are also more or less inclined to question the interaction, maintain customs and traditions, or consider things insulting and unacceptable.

As with other user groups, heavy vehicle users are a diverse group in terms of prior technology and interaction experience. Some having familiarity to digital interaction while some avoid to use it [90] and although the purpose and intended use of the machines are well known, studies report usage far outside the original intention [15].

A focus on the user interaction will be beneficial when the system is being deployed, however, there are more stakeholders that must be considered [18]. The operators are often not the persons making the decision to select a
specific machine or system. Other stakeholders, for example, purchasing or management, service engineers and economists, have their need and input in the selection process.

Also, as these systems are put together by different modules and components, provided by sub-suppliers as a more or less integrated platform, the designers and engineers of these systems affect the result. Additionally, the possibilities provided by the platform and its usability for the engineers will affect the interaction possible to create.

**Perspectives on design craft – the process and its activities**

There is a need for structured methods in order to systematically create useful interactive systems with a good user experience. Benyon describes it as: "Design is a creative process concerned with bringing about something new. It’s a social activity with social consequences. It’s about conscious change and communication between designers and the people who will use the system. Different design disciplines have different methods and techniques for helping with this process” [6].

In other words, there is a need for a process, a process that supports the creativity and sometimes fuzziness related to design. In a general perspective, for example in a commercial context in which a product is designed, produced, sold and maintained, the design process become part of the chain of processes, that combined, make up the product life cycle.

There are a few basic activities in interaction design and user-centered design, these are: understanding, envisioning, evaluation and design. Describing a process like this is, of course, an oversimplification but it helps us to define and discuss the work included. There exists a number of variations on these activities, for example, the founder of the design firm IDEO, David Kelley, sums it up in three stages: "Design has three activities: understand, observing and visualize" [93]. Benyon describes the activities of designing interactive systems as Understanding, Designing, Conceptual design, physical design, Envisioning, Evaluation and Implementation [6]. When examining the activities of the design process in a more general design perspective than interaction design, it is, for example, described by Lawson as “analysis, synthesis and evaluation” [56].

It is advised that these activities shall be iterated, in other words, to make a design based on the insights you have, test the design to create new insights, after which the design is refined and so on. The activities can be performed in different order and start anywhere. For example, it might be viable to de-
design a concept in order to get a better understanding on the necessary insights and observations needed. Or to start the ideation with a clean slate, giving room for new approaches in interaction. A personal observation, rather than supported by evidence, is that the work often starts in the technology. When a new technology has become available or popular in another industry, companies ask themselves how they could apply the technology, by doing a conceptual design and perhaps a prototype that provides understanding, market feedback and so on.

Figure 11 visualizes my interpretation of the process activities as Insight and observation, Concept envisioning, Design and Technology, Realization and Evaluation. This is also the process related to as part of the research method described later. The rest of this chapter will further describe the different activities.

![Figure 11. The basic activities within interaction design.](image)

**Insight and observation**

The purpose of this activity is to understand the environment where the work is performed, what the system should do, what requirements there are, the limitations as well as opportunities for improvement. Having knowledge on the task performed, and the user performing it, is essential to create an interaction that is more than just a shiny surface, thus there is an emphasis on the people who use the system and how they operate.

There are several approaches when establishing an understanding of the users and how they use the product or system. Some based on observing users and how they interact with the system, for example, ethnographic studies,
interviews and artifact collection. Other based more on the study of existing knowledge and models that can be used to understand and analyze a system's usability, for example, standards, literature, models and guidelines for the current domain.

In this research both “in the wild” observations and literature studies have been utilized, as visible in the attached papers. Reflecting on the approaches it is clear that different methods have different benefits. Interviews and conversations tapped into the experience of the operator while the recorded sessions provided details in operation and attention. Combining them gave additional insights. For example, when talking to the operators they expressed the need to make sure that no humans are too close to the machine. But when analyzing eye-tracking recording they did not always have the corresponding attendance around the machine.

Transferring the distilled learnings, from observations and insights to the other activity phases can be done by different artefacts, for example requirements that the design must fulfill, personas describing the user characteristics, job maps outlining the tasks performed (as exemplified in figure 10 on page 23) and scenarios that describe the workflow and the interaction performed (as exemplified in figure 12).

Concept envisioning

The purpose of the concept envisioning phase is to envision the future and how the interaction can take place. This is often done by creating concepts that show how the interaction will work. These concepts can then be communicated, discussed and evaluated with users and other stakeholders. Concept envisioning can, for example, be carried out through sketches, scenarios, rich pictures and prototypes. Their level and fidelity are adjusted depending on the needs and where in the realization phase the project is situated. An example of concept envisioning artefacts can be seen in figure 13 and figure 12.

Figure 12. A cut out from a presentation describing the function and driver task of a potato harvester. A result from one of the studies performed.
29, showing a see-through interface concept and samples from a demo application for a display computer.

Theory advocates that concept phase should be as lightweight as possible for the given occasion [40]. I fully agree with that, still, my experience is that the level of fidelity to use in the concepts is an act of balance. In the particular project exemplified in figure 25, concepts sketches were definitely a good way to work with the basic structure of the application and get started. However, as the developer's prior use of concept envisioning was quite limited, there was almost immediately a lack of detailed designs. Mainly for the developers to be confident what to realize because they couldn’t fill in the gaps between the sketch and what they had to realize.

The concept activities phase has a strong connection to the evaluation activities. Via evaluations, performed as user evaluations, heuristic evaluation or critique [5], it is possible to evaluate if a design is worth taking further or
not. By quickly making a number of diverse concepts and evaluate these, the probability increases that the energy is focused on relevant concepts when doing the more detailed design of the solution, see figure 14. Thus also countering the risk of refining only one take on the interaction and missing the potential offered by alternative solutions, known as "hill climbing" [114]. Performing this “plentifulness” in concept creation also increases the chances for new ideas, as participants are challenged to come up with several solutions to the interaction design [16].

![Figure 14. Illustration of expansion and reduction of plentiful concepts](image)

**Design & technology**

The design and engineering activity phase details the design, which information that should be included in the system and how it should be presented to the user. It includes both the more abstract design of information and interaction, but also the specific design of physical things and their behavior. Figure 15 shows one example of this, from the design of the interaction for the simulated excavator, used in the paper “Low-cost Mixed Reality Simulator for Industrial Vehicle Environments”. Covering both the physical devices to use and the information they mediate to the system. To succeed in the design, the technical aspects are included already here (in relation to the realization activity phase described next) because they essentially affect the alternatives and possibilities in the design.

Simultaneously it is often not possible to evaluate whether the technical choices will successfully realize the interaction sought, as technical possibilities and limitations might be discovered during implementation, for example, due to new and unfamiliar technology. It is therefore valuable if design and development go hand in hand during the product realization. Especially when it comes to designing functionality and user experience.
Realization

The realization activity stage is about creating the system or product of concern. Doing something with real functionality that users can operate, based on selected technologies and designs.

The observant might have seen that realization was not mentioned by more than one of the quotes regarding design process. Why was it then included and is there a relevance for its existence? The design process has its specific purposes and is in the complete product realization overlapping with other processes. In a classical waterfall model, with sequentially subsequent steps, the design process occurs relatively early. See figure 16.

Figure 15. Designing the interaction with the simulated excavator used to evaluate the simulator described in paper E.

Figure 16. Waterfall life cycle for a product life.
One threat to the design discipline is that the design phase gets too distanced from the realization project, thus it might even be reduced into a sub-activity that engineers have to handle while creating the product. For example for mechanical engineers to handle, while solving all the other challenges related to environmental requirements. Or for software developers to create, while simultaneously having to handle areas like optimization and communication architecture needed to fill the system with information. An engineer, under pressure to meet tight deadlines, might focus more on getting the system and its functionality to run at all, rather than focus on providing a good experience for the end-user.

There are of course developers and engineers who can do this, in the same way as there are artists and craftsmen who make both functional and beautiful creations [85]. In the same way as the craftsmanship of the knife maker, in figure 17, so can an interaction designer use the code as a material to craft the interaction [57]. But in large projects, it is not possible for one person to handle all the roles and disciplines, just as there are architects, carpenters, painters, HVAC engineers etc. involved in a construction building. In a project with both technically and timely challenges it can also be beneficial to have a distinctive separation of disciplines between design and engineering, this meaning separate roles, not separated teams, to ensure a strive against good interaction and avoid to get caught up in the simplest solution that takes the project further.

Figure 17. “Before you get to a place where you can make art... you have to master the basics [skills]”. Screenshots from a movie showing a knife maker who designs shape his knives with passion and skilled craftsmanship, keeping in mind both aesthetics and function for the chefs to interact with the food. Having spent months searching for the desired outcome. [31]

Buxton [16], Lindell [58] and others argue that the interaction design needs to be involved in several of the steps mentioned in the relation to the waterfall model. This to achieve a better user experience in the product, instead of an initial design that will not be evaluated and improved during the project. It might instead get watered out and limited, as the practical decisions of simplifying implementation alters the design. Integration of the design process as a part in the product development may then look like the process in figure 18. Here the design has an initial emphasis, to shape and define the
product. It does however not end there, instead, it follows along through the project. Addressing cases that require re-design or fine tuning to suit the current conditions. For example when technical solutions, opportunities and constraints affect the design.

![Diagram of Buxtons product development process](image)

*Figure 18. Modified version of Buxtons product development process [16].*

This way of integrating processes also fit better with agile development methods, where initial research, personas and high-level design can be carried out in pre-development. Then, during the sprints, the designer assists the current sprint while detailing the design to be used in the next sprint [1]. In this perspective the realization fits very well in the design process cycle, ensuring that the product being realized is continuously evaluated and refined, with a user focus.

Vehicle equipment has traditionally been developed in a waterfall fashion. But with computer-based vehicle systems, the agile methods are of interest and continuous software deployment is starting to become practiced. Such examples are the Tesla vehicles, or the recent Volvo XC90 platform, where software is deployed every two days [10].

**Evaluation**

When working with concept environment and ideation there is also a need to filter out the valid ideas. No idea is bad, but at the same time, all ideas are to be evaluated so that good solutions are filtered out and improved. To succeed, these evaluations shouldn’t wait until there exists detailed prototypes or real systems. Evaluations can start with simple sketches [71]. Use cases, for example, can be tested using wizard-of-Oz scenarios to evaluate the interaction with the user without having to develop the underlying functionality.

In user-centered design, the active involvement of the user is essential in the evaluation. Popular methods range from observation of user behavior, think aloud methods, cognitive walkthroughs and questionnaires [2]. The evaluations can be performed by direct user observation or supported by measure-
ments and tools like cameras or eye-tracking equipment [76]. Methods can also be combined, something that was applied when doing the evaluation of the industrial vehicle, presented in the included paper “Low-cost Mixed Reality Simulator for Industrial Vehicle Environments” (see also figure 19) where user observation and questionnaires were used. Other methods, that doesn’t directly involve the user is heuristic evaluations, consistency inspection and standard inspections [66].

![Figure 19. Preparing a user for an evaluation using the simulator prototype.](image)

The approach selected should match the maturity and complexity of the project, as well as the purpose of the evaluation. Evaluating the user experience in a vehicle infotainment system will, for example, use different methods than the break reaction time [49]. Additionally, the rigor of the evaluation must be considered both in type and in number of participants. In critical and academicals context, validity and quantitative results are needed, but for early and industrial evaluations a lightweight qualitative process is often preferred [80].

The evaluation itself provides direct insights and results. But the method to collect the results and convert it to product changes is at least as important as the design of the evaluation. For example, video recordings give lasting material from the evaluation but are time-consuming to analyze. However, without video there might be a need for additional assessors, taking notes.
during the evaluation so that the facilitator does not need to recreate findings from memory and mix focus on the test with documentation of findings.

Details regarding how results are analyzed, interpreted, presented can also have an effect, great findings may fall into oblivion before they have even been incorporated into activity planning because it is difficult for managers to capture the problem/solution.

Perspectives on the value of interaction design

Looking from an industrial perspective there is a natural interest to explore the commercial benefits of interaction design, user-centered design and user experience. Creating a product with a well thought out design will hopefully increase the commercial competitiveness. It is difficult to justify investments in activities that focuses on improving the usability or aesthetics, without a belief that this investment would give commercial contributions. In this section we will therefore look at the value of interaction design from a commercial perspective.

There are several factors why design thinking and interaction design should be of interest when a product is created, including also the aspects of HCI and usability as these are foundational for interaction design and user experience. But there are at the same time several circumstances why interfaces are being developed with too little attention to the user, some examples being, time pressure, focus on the function to be developed rather than its use, development based on technology rather than function, ignorance or lack of knowledge, a model of governance that do not realize the importance of usability, and so on. As interaction design is about creating something for the future it cannot be said that a design focus per se will lead to increased sales and revenues. However, there are several indications of benefits for those who put effort and focus on the interaction design.

When discussing the benefits, there can be both internal and external benefits [60]. Internal benefits lead to cost savings, better utilization of resources and increased employee satisfaction. Such examples are higher productivity, less user related errors, less time having to spend on employee training and employee support. External factors relate to increased revenues and improved customer relations. Such examples are increased sales, less customer support and training, increased perceived shareholder values as well as reduced product maintenance costs due to usage related errors. Following hereon we will look into a few examples from each area.

As mentioned earlier, vehicle systems features are increasingly realized through software, thus the way the interaction design is performed becomes an increasingly important differentiator in the competition for customers. We
can see this by observing other business areas that are highly software based, like websites, IT systems, and mobile devices. Jakob Nielsen mentions that "It is common for usability efforts to result in a hundred percent or more increase in traffic or sales" [68]. This reasoning is based on a world where the user can directly choose another alternative (another website) if frustration arises with the current site. Changing a complete vehicle is certainly not as swift as going to the next available website, but for apps and other third-party software in the vehicle, this is a fact to consider, especially as machine systems get increasingly opened up to cloud system providers.

Regarding a company's value, in other words, how it creates value for its shareholders, a study has shown that the design-driven companies have had a better stock market performance. According to an index created by the Design Management Institute, these companies have outperformed the S&P index by 228% [77], see figure 20.

As a case study, we will look at one of the companies that are utmost associated with design and technology, Apple. Apple went from being in trouble (1996) to be the most valued company in the world (2012). Bill Buxton argues that one of the factors that, at the end of the 1990th saved Apple and created the business value Apple possesses, was design as well as a holistic view of product experience and its ecosystem [40].

Buxton’s analysis ends in 2005. I have therefore expanded the analysis up until 2016, see figure 21, containing stock value and significant new product releases. This graph shows that the real expansion happens after Buxton’s analysis, when apple introduces the iPhone, together with its ecosystem of apps and services. It can be noted that during 2015 apple held 90% of the earnings in the mobile phone market, without having the highest sales numbers.

Figure 20. Stock index development for design-driven companies in relation to the S&P index. [77]

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It should also be noted that although not added to the graph, Apple has continuously released new models of their products as well as additional software improvements. However, one release does stand out, on June 10, 2013, in a period of significant decline in stock price and media discussion that competition is catching up, Apple releases a complete upgrade of its graphical user interface design and from there the stock recovers. It should, of course, be noted that other factors can also have contributed to the stock recovery.

The examples above indicate that a focus on design can increase the attraction at the product and the company. As such it is also a factor in facing the competition, in which one can compare the Apple example against Microsoft. Microsoft has been in the forefront of both market penetration and innovation in human-computer interaction (e.g. through various versions of Windows and Office packages), they are "one of the best-run businesses ever, but it has not been able to create highly desirable products. This provides an opening for competition." [20]. It should thought be noted that in recent years, Microsoft has expressed a higher focus on user experience and design [115] with one outcome being the Surface line of products [116]. This result has opened up for a new PC product category, the only PC product category currently showing growing numbers [74].

An early focus on the use of a product or service, its purpose, its users and its design as well as applying the processes and the palette of tools available through interaction design, increase the chances of the right product being
realized. Examples of information technology and digital products considered as failures are many. When the English magazine Business Insider, for example, lists 22 product failures, 13 were related to digital and information technology products [4]. Leading not only to missed sales but also at the cost of development. Another example is the Swedish Police IT system “PUST”, originally developed with the inclusion of user-centered design principles and considered a success. When the next version of the system was developed, usability tests and other user-centered practices was omitted. The system was instead specified to include the same functionality as the prior version. The result was a system, so frustrating to work with, that it was finally scrapped, with a development cost of 123 MSEK [89,110].

Moreover, adhering to Benjamin Franklin’s statement that "time is money", there are great benefits to invest in a well-designed user interaction. Even if a product is not a "failure" there are benefits of putting effort in finding the right product and designing it right, so that problems with the product or its use are discovered early in the project. The earlier a potential problem can be detected, for example by a lo-fidelity prototype, the less the cost to fix it. This leads to fewer retakes on functionality and subsequently less time and money spent in vain. “Once a system is in development, correcting a problem costs 10 times as much as fixing the same problem in design. If the system has been released, it costs 100 times as much relative to fixing in design” [39].

If an interaction refinement leads to increased efficiency in the work performed and the company has many users, there can be a quick return on investment. A company did, for example, spend “$20,700 on usability work to improve the sign-on procedure in a system used by several thousand people. The resulting productivity improvement saved the company $41,700 the first day the redesigned system was used” [27]

Effective interaction is not just that a function should be quick to perform. Another aspect is to do the right thing for the task at hand, with the right level of performance. A navigation system in a car might not need to show exactly the right position, but it is important that it, in a good way, communicates the junction in which to turn. In precision navigation, however, there may be much higher demands on the exact position and that it does not appear to wander based on varying GPS location fix. Having a well-designed and evaluated interaction helps in the early project stages to build up the system requirements. As well as it improves customers trust in the functionality offered by the product.
Research description

This chapter describes the research goal and the research questions.
Hypothesis

There is a wealth of information available in today's embedded systems and a variety of new technologies for communication with the user. With every new generation more features are realized, through software as well as through connectivity and integration between different systems. Many of these new features require interaction with the user, to do so they need to share the available interaction channels and do this in a way that is comprehensible, efficient and attractive. Thus, there is a need for a well-designed and insightful interaction for the user.

The hypothesis of this research is that application of interaction design principles can contribute to increased understanding and new perspectives on the design space of interaction design and user experience with software intensive embedded systems. Additionally, this will contribute to creation of innovative interaction designs that provide novel approaches to user interaction with heavy vehicles.

This first part of the Ph.D. research has investigated different design perspectives on heavy vehicle interaction. Since interaction design is user centered there is a natural interest to investigate the user perspective, to observe the user behavior and their current experiences using digital information sources, as this will form the base for further design elaboration. Additionally, the user is not the only stakeholder in developing, acquiring and maintaining the machine. Thus it is of interest to evaluate the design perspective of related stakeholders, their effect on and benefits for interaction design, including the economic benefits as well as the working processes and craft of interaction design.

Research questions

The main research question is how to describe the context and design space of heavy vehicles cabins, to enrich and support the operators’ user experience of the increasing information flow?

This question opens up for a broad research and includes elements of being a wicked problem. For example: while building quieter and more comfortable operator cabins, we limit the information to the operator. This while simultaneously adding more information load through instrumentations on a limited visual information channel. It is also a question without a clear ending criteria, neither in possible improvements for the operator nor in the amount of information exchange or type of interaction modalities available.

The focus is therefore narrowed towards visual user interfaces and a number of sub-questions are defined:
In order to enrich and support the user experience of the increasing information flow, we want to explore immersive visualization.

- **Design Exploration** – Can new technologies for immersive visualization of information enhance the user experience related to heavy vehicle interaction?

Additionally, in order to describe the design space we want to incorporate the perspective of the practitioner:

- **Design situation** - What are the current practices and challenges for practitioners when designing and developing interaction with software intensive heavy vehicles?

Furthermore, as argued in the section “Different perspectives on design”, it is crucial to understand and include the perspective of the users:

- **Interaction situation** - What are the current use and challenges for users and other industry stakeholders when interacting with heavy vehicles?
Design and research, method and approach

This chapter brings the perspectives on design together into a description of the research method, used to address the research questions.
Research method

According to Fällman [33], Zimmerman et. al. [94], Höök et al. [46], Schön [83] and others, interaction design research can be performed through design practice. Sennet [85] even argues that understanding is impaired when we separate practice from theory. The result of the practice can be expressed in many forms, for example sketches [16], through artefacts and systems [21], or through linguistic representation [52]. A strong concept is the exploration of possibilities as well as the reflection on design, its artefacts and possible future outcomes [5,83]. But in order to do so it must be based on understanding of the world and related fields, such as art [35], traditional HCI [53,94] and technology [17,30].

The approach in this work has been to address the research using practices of interaction design, in other words, the design process, as described in the chapter “Perspectives on design craft – the process and its activities” consisting of understanding, ideation, design, realization and evaluation.

The work has emphasized understanding of the elements which give insights to the design, the context, the activities, the technology, and the user. It can be noted that the user by this definition can also be other stakeholders. Sometimes it has not been the end user (in other words the operator) that has been the person if focus, instead it has been the designer creating the design, or the engineer building the system.

However, design practice in itself would not fully cover the research aspect and its aim to produce a knowledge contribution. Therefore Fällmans model of interaction design research has been incorporated [33], adding the elements of practice, exploration and study, see figure 22.

![Design Research Triangle as described by Fällman [33].](image-url)
What Fällman defines as Exploration has, in relation to the design process, similarities with the concept envisioning practice. There are however noticeable differences in their definitions, as exploration “often seeks to test ideas and to ask what if?” [33]. Furthermore, research exploration is typically not driven by a product or a market focus, nor based on the needs of a group of users. It instead, seeks new means of interaction and investigates additional solutions, technologies, and designs by provoking, leveraging and evolving on current interaction designs. A similar relationship exists for design practice, where it fully embrace that the researcher should be part in design creation, as any practitioner, with the addition that the work should be performed and reflected upon with a research question in mind.

Design studies is the activity “which most closely resembles traditional academic disciplines”, where the researcher analyses and reflects upon interaction design, its methods, its history and its artefacts. Design studies in this project include traditional academic activities such as courses, reading, discussing with others and attaining conferences.

Figure 23 illustrates how the process, elements and research fit together, where each of these elements or practices can be seen as different perspectives on design, including the resulting design, the design work and the designer.
Furthermore, as illustrated by the spiral that goes through the different perspectives, the process is iterative, where learnings from one iteration feed the next iteration etc. The Spiral model has existed in software engineering since the 80’s, at that time in a way to counter the limits of the waterfall model together with an emphasis on risk management [8]. However, in this case, the spiral reflects the design funnel and its characteristics of elaborating on different solutions followed by a reduction into the design result [16]. Spiraling to the center means that the work converges, focusing at the design artefact and reduces the possible alternatives. However, the spiral can also expand, search for more alternatives or seek general knowledge based on a specific design. These iterations can be quicker or slower, containing input from all perspectives or sub-set of them. Through this mix of expansion and reduction, together with the inclusion of different elements and activities, and the reflection on action and design, the designer can address the “wicked problems” [14], problems that are poorly defined, with contradictory requirements and a fuzzy end target.

Here are the design perspectives, referred to in the thesis title. The selection of different perspectives, to apply in use or to observe, within the interaction design work will result in different finding or outcomes. For example, only making realization with a focus on technology while neglecting elements of user and context, as well as neglecting practices of ideation and understanding, will draw the focus and outcome to into mere application of technology. Similarly, a work on user and understanding will provide new knowledge for future interaction design work, but it will not create any new designs or products.

Each of the two examples above present quite simple two-dimensional design spaces. Selecting to include more perspectives will result in a design space of higher complexity, but also a design space that is richer in terms of understanding and more rigid in its potential to find what Buxton expresses as the right design [16].
Approach

The research work has been carried out through a series of iterations through the research method, addressing the research questions from different perspectives. Figure 24 shows the work grouped in four logical iterations and how they applied were the research method.

Conceptual ideation

The work started with elaboration and expansion on the current understanding and use of information mediation in heavy vehicles, thereby addressing research question 1: design exploration. We asked ourselves how See-through technologies could be useful and have benefits in industrial applications.

This was done through practicing ideation and exploration as well as studying existing work. The work resulted in the article “Interactions and Applications for See-Through interfaces: Industrial application examples”. In figure 24 this iteration is named conceptual ideation. It covered all areas in elements and research, as well as ideation in the design process.

Figure 24. Research method application.
Analytical understanding

The next iteration aimed at understanding stakeholder’s situation. Addressing research question 2: Design situation with a focus on the challenges and needs designers and engineers face when creating integrated systems based on different technological platforms and services. As systems become more and more autonomous it was also of interest to get a perspective on forthcoming needs and benefits of performing user-centered interaction design, e.g. will interaction design and user-centered design still be of interest?

In figure 24 this section is named analytical understanding, as the work was mostly theoretical work of study and understanding, based on literature review as well as analytical reasoning through prior knowledge and dialogue with colleagues. The work reflected on the different practices as well as the artefacts involved in system creation, for example, stakeholder and activity understanding, software and hardware integration, input or output devices.

One field study was also performed, a study of an agriculture machine, where the operator of the machine and the farm manager was interviewed and I traveled with the machine, observing and recording the operation. The work resulted in two articles: “Current Challenges in Compositing Heterogeneous User-Interfaces for Automotive Purposes” and “Understanding the user in self-managing systems”. With additional material incorporated in the thesis chapter “Different perspectives on design”.

Empirical understanding

The conceptual ideation and the analytical understanding built the base for the third iteration aimed to gain knowledge from the real world and the perspective of the operator, thus addressing research question 3: Interaction situation. Special interest was aimed at the user’s attention and the level of perception in different visual areas, as this could provide perspectives on how to explore future interaction designs.

This was performed through seven qualitative ethnographic field studies. In these studies, eye-tracking glasses was used to record and analyze operator activities and their use of information systems while driving. Additional observations and interviews were also conducted. This work did not only practice methods of user study to generate knowledge, it also practiced and reflected on the methods of guerilla HCI for industrial use [67,71]. In figure 24 this work is marked as “empirical understanding” and resulted in the article “Seeing through the eyes of heavy vehicle operators”. Additionally, three laboratory studies were performed, two qualitative studies, observing devel-
opers challenges when building UI applications, as well as one quantitative study of simulated excavator use.

Conceptual prototyping

The final iteration turned the work back into more practical and exploratory aspects of interaction design. In order for designers and engineers to evaluate and iterate concepts for interaction designs, there must be some means of evaluation. In between very basic design elaborations, such as sketches, and end term evaluations, such as field tests, one can use simulators for evaluation. However, access to simulators is often limited to forward facing PC simulators which prohibit the operators natural head movement, to look around the vehicle to gain information. We wanted to explore the possibility to utilize a head worn mixed reality projector system in order to build a low-cost mixed reality simulator for industrial vehicles, that would allow evaluation of interaction design ideas in a rapid prototyping manner. The aim was to build a prototype for evaluation, thus the name conceptual prototype in figure 24.

This work started with ideation and followed through the whole design practice process to a quantitative evaluation. In terms of research, this work practiced design and further addressed research question 1: “Design exploration”. The work is presented in the article “Low-cost Mixed Reality Simulator for Industrial Vehicle Environments”.

As a summary of the approach, from all iterations, one can see that in terms of the design research the work started by practicing, exploring and studying. Thereafter going into more focus on study and in the end applying the knowledge to seek new ways of creating design. All work relates, to some extent, to the elements of design input. In terms of the design process, there is an emphasis on understanding, which may not come as a surprise given that this is a licentiate thesis, where understanding is needed to ground the future work, as well as to gain insights for future research in design practice and exploration.

In addition to the work described above there have been several additional activities carried out in research and employment. A few examples of these being: Design studies has been performed through courses and literature studies. Attending conferences and discussing colleagues etc. Design and management of graphical applications development as well as design workshop facilitation. Design reviews and mock-ups for both software and devices. A sample can be seen in figure 25.
Figure 25. A pinboard showing some of the artefacts from creating a demo application. Starting at the top it shows a page model and a basic page wireframe (supporting scrolling swipe screens), followed by some sketches and mood boards. In the middle the original and revised designs are shown, reflecting feedback from its initial use. The lower pictures show additional sketches and design concepts, as well as the application running on one of the devices.
A note on ethics

It may, at a first glance, seem self-evident that user-centered design and work with usability are ethically motivated. For example, human factors research achieved a 54% reduction of rear-end accidents via the centered high-mount brake light on cars [86]. Similarly, how designers visualized energy consumption [3] to encourage us to reduce our consumption of energy.

However, Friedman and Kahn et al. argue that usability shall not be conflated with ethics and human values as these might sometimes be in conflict [36,63]. One example of such conflict would be increased usability of lethal weapons. Another such example, that most of us would consider “evil”, is how designers used scents distributed in the air next to slot machines in an Las Vegas hotel and, as a result, increased the gambling by 45% [44].

This thesis does not have ambition to address the ethical aspects of interaction design. Still, as humans are involved in part of the research, we need to relate to the ethical aspect of this specific work. The part where human involvement occurred, was in the field studies and the simulator evaluations. We applied informed consent where the involved persons were informed about the purpose of the study and that they could withdraw at any time. Furthermore, the results where de-personified so that no specific individuals could be identified, thus protecting integrity of research subjects.
Contribution and introduction to papers

This licentiate thesis is written as a collection of papers, which presents the contribution to the research field, with supplementary material added in the thesis section.

The following section list the main contributions in relation to the respective paper.
The relation between each contribution and the research questions is presented in table 1.

<table>
<thead>
<tr>
<th>RQ</th>
<th>Paper</th>
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*Table 1. Relation between research questions and paper contributions*

The first paper, Paper A, Interactions and Applications for See-Through Interfaces: Industrial Application Examples, addresses RQ1 and contributes by exploring concepts of user interaction in heavy vehicles using see-through interfaces, together with a discussion on related risk and technical aspects. I was the sole contributor to this paper.

The subsequent paper, Paper B, Current Challenges in Compositing Heterogeneous User-Interfaces for Automotive Purposes, addresses RQ2 and contributes to the understanding of the challenges software engineers and designers face when building homogenous user experiences in the world of different service and component providers. It does so in a theoretical manner, presenting a separation of integration into different logical layers and their respective challenges. The work was shared equally between the first two authors, with the third and fourth authors being supervisors. Here my main contribution related to the application and UI layers and manuscript.

Paper C, Understanding the user in self-managing systems, addresses RQ3 and describes the need and benefits of understanding why the user is important in industrial machinery and that it is still of importance even though automation takes a larger portion of the machine operation process. It exemplifies this by examining an agriculture example covering current usage, challenges and benefits. I was the sole contributor to this paper.

Paper D, Seeing through the eyes of heavy vehicle operators, also addresses RQ3 and continues the work from paper C by studying user behavior in off-highway industrial machinery. This paper presents both an unobtrusive and practical method of gaining insights on operator’s use of machines in normal working conditions, especially their attention to different areas
outside the cabin and information systems in the cabin. I was the sole contributor to this paper.

Paper E, Low-cost Mixed Reality Simulator for Industrial Vehicle Environments, presents a cost-efficient simulator concept for mixed reality simulation. The simulator is based on technology from the gaming industry and off-the-shelf hardware. It enables free to look around visualization and mixed reality interaction. For the evaluation, a digital simulation of an excavator was made. It showed that the mixed reality simulator is perceived as more realistic, natural to use and immersive, compared to a PC-based forward looking only simulator, thus making it an effective tool for exploration of future design concepts around see-through interfaces. The work was shared between the first three authors, with the subsequent authors being supervisors. I contributed to the idea, implementation of the simulated environment, user evaluation and manuscript.
Conclusion and future work

Figure 26. Interaction design research towards user-centric design of heavy vehicles
Summary

As products become more and more software and information intense, interaction design becomes increasingly essential. The goal of this research was to gain knowledge in user interaction with heavy vehicle information systems, providing an improved body of knowledge and support to designers and developers, in the design of useful products with an appreciated user experience.

In sum, this research describes different perspectives on the design space of heavy vehicles, thereby addressing the main research question: “how to describe the context and design space of heavy vehicles cabins, to enrich and support the operators’ user experience of the increasing information flow?” It has done so by gaining an improved understanding of stakeholder situation, especially in the context of system engineers, designers, and vehicle operators. It has also provided an increased understanding of challenges regarding composing services from different information providers, into a homogenous system, from a system development perspective. Moreover, it contributes to the development and evaluation of user interaction design using simulators, to aid exploration of new concepts of user interaction in heavy vehicles.

Furthermore, the thesis describes how interaction design practices can be applied and beneficial in the development of software intensive embedded systems, not only because it results in good user experiences, but also because of its commercial benefits. The thesis also investigated the design space from the perspectives of its different elements, technology, the user, the activity performed and the context. As well as the perspective of the practices of understanding, ideation, exploration, design, realization and evaluation.

Future work

In the perspective of the full PhD research project, the work up to the Licentiate thesis has centered on gaining understanding and a foundation for the coming work, which will be to enhance interaction with heavy vehicles, focusing on selected stakeholders and methods for understanding, process and practice. It can be noted that the exploration contribution is still in its early stages as it is planned to be further researched during the coming work.

Different types of transparent interaction systems and augmented interfaces, that keep the user visual attention close operation, are currently an area of state-of-the-art interest [7]. The field itself is not new, head-up displays have been used for a long time in specific areas, aerospace being one early
adopter. But new commercial products have made the technology increasingly available and widespread. Heavy vehicles could use head-up displays to present key information within the field of view of the operator. Another alternative would be head-worn displays, that can be used to present information within the field of view of a user, regardless of the head rotation [50]. Smart devices such as mobile phones and tablets can also be used to display information about machine status, production, or settings. Within or at a distance from the machine. Mobile devices can also be used in augmented solutions, for example, in mobile see-through interfaces where information is overlaid on the display of the device [51,84].

Finally, there are many more areas to explore. How could speech interaction be used in the context of heavy vehicles? How haptic devices and traditional mechanic designs could be further used in interaction design, where the current emphasis directs to digital and visual systems? How could transdisciplinary approaches, using inspiration from art or understanding from cognitive science and psychology, enrich interaction?
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