Usability Requirements and Deduced General Design Concepts for Mobile Solutions in Production Contexts at ZF

Simon Harhues
Abstract

Usability Requirements and Deduced General Design Concepts for Mobile Solutions in Production Contexts at ZF
Simon Harhues

The thesis project collected usability requirements and formulated design principles for mobile solutions in an industrial production context. A second aim of the present thesis was to evaluate the applicability of the contextual design (CD) methodology in such a context.

Methods from the CD process were employed and a design workshop was held to gather data for the usability requirements and the design principles. The case study methodology was used to evaluate the CD process.

Important aspects of the work practice found could be clustered according to the categories: information technology (IT) hardware and system, communication, documentation, and work organization. The five design concepts: easy learning and expert performance, user control and guidance, peripheral attention and unobtrusiveness, robustness and resilience, and holistic solution and background information were formulated and enriched by examples to ensure a high usability of future mobile solutions.

The CD methodology proved to be useful for investigating a production context. Further research is needed first to develop a mobile solution following the outlined design principles and second to evaluate the principles by usability testing of the mobile solution.

Handledare: Michael Eitenbichler
Ämnesgranskare: Mats Lind
Examinator: Lars Oestreicher
IT 14 041
Sponsor: ZF Friedrichshafen AG
I would like to thank my reviewer Prof. Dr. Mats Lind from Uppsala University for his discerning and valuable supervision.

Thanks are also due to my supervisor Michael Eitenbichler from ZF and all other colleagues from within the IT Innovation Management (ITIM) who supported me generously in my thesis work. In addition I would like to thank all the co-workers who took part in the contextual design (CD) process and agreed to be observed and interviewed by me for the present thesis.
# Contents

1 **Introduction** 9
  1.1 About ZF Friedrichshafen AG . . . . . . . . . . . . . . . . . . . 9
  1.2 Definition and Trends of Smart Devices . . . . . . . . . . . . . 10
  1.3 Thesis Goals and Motivation . . . . . . . . . . . . . . . . . . . 12

2 **Previous Work** 15
  2.1 Existing Literature . . . . . . . . . . . . . . . . . . . . . . . . 15
    2.1.1 Mobile Solutions in Non-Office Environments . . . . . . . 15
    2.1.2 The Contextual Design Process in Non-Office Environments 19
  2.2 Existing Solutions at ZF . . . . . . . . . . . . . . . . . . . . . 21
    2.2.1 Friedrichshafen . . . . . . . . . . . . . . . . . . . . . . . 21
    2.2.2 Passau and Staňkov . . . . . . . . . . . . . . . . . . . . . 21
    2.2.3 Saarbrücken . . . . . . . . . . . . . . . . . . . . . . . . . 22

3 **Methods** 23
  3.1 Contextual Design . . . . . . . . . . . . . . . . . . . . . . . . . 23
    3.1.1 Contextual Inquiry . . . . . . . . . . . . . . . . . . . . . . 23
    3.1.2 Affinity Diagram . . . . . . . . . . . . . . . . . . . . . . . 25
    3.1.3 Artifact Models . . . . . . . . . . . . . . . . . . . . . . . . 26
    3.1.4 Physical Models . . . . . . . . . . . . . . . . . . . . . . . . 26
    3.1.5 Personas . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27
  3.2 Usability Requirements . . . . . . . . . . . . . . . . . . . . . . 27
  3.3 Design Concepts . . . . . . . . . . . . . . . . . . . . . . . . . . 29
  3.4 Case Study . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 30

4 **Results** 35
  4.1 Contextual Design . . . . . . . . . . . . . . . . . . . . . . . . . 35
    4.1.1 Affinity Diagram . . . . . . . . . . . . . . . . . . . . . . . . 35
    4.1.2 Artifact Models . . . . . . . . . . . . . . . . . . . . . . . . 36
    4.1.3 Physical Models . . . . . . . . . . . . . . . . . . . . . . . . 51
    4.1.4 Personas . . . . . . . . . . . . . . . . . . . . . . . . . . . . 54
  4.2 Usability Requirements . . . . . . . . . . . . . . . . . . . . . . 59
    4.2.1 Importance of Usability Factors . . . . . . . . . . . . . . . 59
    4.2.2 Performance Style . . . . . . . . . . . . . . . . . . . . . . . 63
    4.2.3 Defect Style . . . . . . . . . . . . . . . . . . . . . . . . . . 64
    4.2.4 Process Style . . . . . . . . . . . . . . . . . . . . . . . . . . 65
    4.2.5 Subjective Style . . . . . . . . . . . . . . . . . . . . . . . . 66
    4.2.6 Design Style . . . . . . . . . . . . . . . . . . . . . . . . . . 67
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATM</td>
<td>automatic teller machine</td>
</tr>
<tr>
<td>CD</td>
<td>contextual design</td>
</tr>
<tr>
<td>CI</td>
<td>contextual inquiry</td>
</tr>
<tr>
<td>CITM</td>
<td>Corporate IT Management</td>
</tr>
<tr>
<td>ERP</td>
<td>enterprise resource planning</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAQ</td>
<td>frequently asked questions</td>
</tr>
<tr>
<td>GUI</td>
<td>graphical user interface</td>
</tr>
<tr>
<td>HCI</td>
<td>human-computer interaction</td>
</tr>
<tr>
<td>HMI</td>
<td>human-machine interaction</td>
</tr>
<tr>
<td>ICT</td>
<td>information and communications technology</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IT</td>
<td>information technology</td>
</tr>
<tr>
<td>ITIM</td>
<td>IT Innovation Management</td>
</tr>
<tr>
<td>KVP</td>
<td>continual improvement process</td>
</tr>
<tr>
<td>LCV</td>
<td>light commercial vehicle</td>
</tr>
<tr>
<td>MEMS</td>
<td>micro-electro-mechanical system</td>
</tr>
<tr>
<td>NFC</td>
<td>near field communication</td>
</tr>
<tr>
<td>OS</td>
<td>operating system</td>
</tr>
<tr>
<td>PACT</td>
<td>people, activities, contexts, and technologies</td>
</tr>
<tr>
<td>PC</td>
<td>personal computer</td>
</tr>
<tr>
<td>PDA</td>
<td>personal digital assistant</td>
</tr>
<tr>
<td>PS</td>
<td>production system</td>
</tr>
</tbody>
</table>
QR quick response
RFID radio frequency identification
ROI return on investment
SUS system usability scale
UCD user-centered design
UX user experience
WIP work in progress
WLAN wireless local area network
ZF PS ZF Production System
Chapter 1

Introduction

1.1 About ZF Friedrichshafen AG

The ZF Group is a global leader in driveline and chassis technology and has 122 production companies in 26 countries. ZF is one of the ten largest automotive suppliers worldwide. ZF employs more than 72,000 people worldwide with sales currently of about €17 billion in the year 2013. (ZF Friedrichshafen AG 2014a)

As part of the Corporate IT Management (CITM) the IT Innovation Management (ITIM) follows new information technology (IT) trends – technologies, products, and methods – and examines them in close cooperation with other expert and IT departments regarding their reasonable application at ZF.

The ZF Group develops and produces transmissions, steering systems, axles, and chassis components as well as complete systems for the applications cars, truck/light commercial vehicles (LCVs), bus & coaches, off-road equipment, rail vehicles, helicopters, motorcycles, lift trucks, machine and system construction, test systems, civil mobile cranes and special vehicles, marine, military vehicles, agricultural machines, and wind power. (ZF Friedrichshafen AG 2014b)

All business units of ZF are assigned to the four divisions:

- Car Powertrain Technology
- Car Chassis Technology
- Commercial Vehicle Technology
- Industrial Technology

The production in all business units follows to the ZF Production System (ZF PS). The ZF PS is the consolidated production system (PS) of the seven historical PSs, Global Production System or the Saarbrücken Performance System for example, from the different former subsidiary companies (Broecheler 2010, ZF Friedrichshafen AG 2011). The ZF PS is used to ensure a lean and smooth production process across the whole ZF Group. It is based on the following six guiding principles: (ZF Friedrichshafen AG 2011)

- Employee and team orientation
- Process orientation in client and supplier relations
- Standardization and flexibility
- Just in time
- Zero mistakes
- Innovation and continual improvement process (KVP)

1.2 Definition and Trends of Smart Devices

Smart devices are defined by Fraunhofer-Gesellschaft (2014) as all “electric devices, which are wireless, mobile, networked, and equipment with different sensors (like geosensors, gyroscopes, temperature, and as well cameras)”. Smart phones, tablets, and data glasses are named by Fraunhofer-Gesellschaft (2014) as examples of smart devices.

Poslad (2011) points out that smart devices are information and communications technology (ICT) resources consisting of both system hardware and software which can be static or fixed at design time. Poslad adds that beside smart devices are able to execute services themselves, they are also support additional hardware plug-in resources to extend their usage. Defining smart mobile devices, Poslad (2011) states that these devices act as single interfaces to different local and remote application services. It is emphasized that while these mobile multi-purpose devices ease access and interoperability of services they are less open to upgrade hardware components. According to Poslad (2011), mobile smart devices are usually personalized devices for an individual user.

For these ubiquitous devices, Weiser (1991) suggested following three form factors – all having visual output displays:

**Boards:** Meter sized display devices for collaboration, like tabletop surface computers or smart boards.

**Pads:** Decimeter sized devices which are hand-held, like laptops or tablets.

**Tabs:** Centimeter sized devices which can be accompanied or worn, like smart phones or smart watches.

Due to the ongoing development of technical devices Poslad (2011) suggested the following additional three form factors:

**Dust:** From nanometers to millimeter sized micro-electro-mechanical system (MEMS) devices, which are cheaply manufactured and do not have any visual output displays, like sensors or actuators.

**Skin:** Organic computer devices which are fabric based, for example for clothing.

**Clay:** Devices based on smart dust and smart skins, which can be formed into arbitrary three dimensional shapes.

The market of mobile smart devices is still growing. In 2010 more smart phones than personal computers were shipped (Menn 2011). In 2013 smart phones sales also overtook the number of feature phones sold (Svensson 2013, van der Meulen & Rivera 2013).
A concentration of operating systems (OSs) for smart phones can be seen. According to press releases of Canalys (2013) and IDC (2013), the market share for smart phone OSs will concentrate in the future on Android, iOS, and Windows phone, cf. table 1.1.

Table 1.1: Market share of smart phone operating systems. Source: Canalys (2013), IDC (2013)

<table>
<thead>
<tr>
<th>OS vendor</th>
<th>2012</th>
<th>2013</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Android</td>
<td>67.7%</td>
<td>75.3%</td>
<td>67.1%</td>
</tr>
<tr>
<td>iOS</td>
<td>19.5%</td>
<td>16.9%</td>
<td>14.1%</td>
</tr>
<tr>
<td>Windows Phone</td>
<td>2.4%</td>
<td>3.9%</td>
<td>12.7%</td>
</tr>
<tr>
<td>BlackBerry OS</td>
<td>4.8%</td>
<td>2.7%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Others</td>
<td>5.6%</td>
<td>1.2%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

Source: Canalys, IDC

In 2012 employees of 48% of the companies in the European Union (EU) were provided with portable devices – either portable computers like laptops, notebooks and tablets or other portable devices like smart phones personal digital assistant (PDA) phones – that allowed mobile Internet connection for business use. The devices were most dominantly used to access the enterprise’s e-mail (88%) followed by accessing public available information (86%). Less often used were the devices to access company’s documents (56%) and dedicated business applications (45%). (Giannakouris & Smihily 2012)

Forrester Research Inc. predicts following six trends for the topics mobility and computing in 2014: (Gownder, Voce & Williamson 2014)

- Mobility
- Wearables
- Gestural computing
- Channel innovation
- Intelligent assistants
- Fragmentation

It is thus pointed out to “actively shape mobile deployments” and they suggest to companies “to make some decisive strategic choices about their mobile strategy, and their own role in shaping that strategy” (Dransfeld 2014, p. 2) The strategy to follow a user centered approach by splitting the user base is recommended in addition by Dransfeld (2014, p 3).

According to an American survey from 2013 published in Gownder, Voce, Frechette & Williamson (2014, p. 4), adult consumers preferred wearable device locations. The most accepted will be a sensor device clipped onto clothing (29%), followed by wrist bands (28%). Devices embedded into clothing will be accepted according this study more (15%), then glasses, earbuds/headphones, and embedded in jewelry (all 12%).
Although smart glasses by Google still only exist as developer previews, SAP published last year together with Vuzix a proof of concept showing hands free working with an augmented reality solution for smart glasses by Vuzix in the work field of logistical processes (Springer 2013). Smart watches are already more present, and Google announced in March 2014 an OS for wearable devices, especially for smart watches, called “Android Wear” (Pichai 2014).

1.3 Thesis Goals and Motivation

This thesis has two main goals:

The first goal is to define requirements and to deduce design concepts for mobile solutions to be usable in a production context at ZF.

The second goal is to evaluate the contextual design (CD) process in a manufacturing plant environment and suggest changes to the process to make it more applicable to a production context.

The different production departments at ZF regularly have tasks or usage contexts where the use of traditional means for work like binders, pen, and paper is not very handy. Nevertheless these are the working materials which are in many areas still most commonly used although many processes are already supported by or depending on computer systems like enterprise resource planning (ERP) programs.

The use of off-the-shelf digital solutions like laptops, tablets or smart phones as an alternative to traditional means for work is perceived as to be often not possible or at least to be not very usable. The use of a laptop might not be possible in a waste water tube, using touch input on a smart phone with protection gloves or oily fingers could not work or holding and touch controlling tablets in a high environment to maintain cranes might be too dangerous. Frequently a direct connection to software systems like directories, ERP, software or data warehouse management systems is needed to improve the work practice. The increasing possibilities of mobile solutions raises hope to overcome media gaps, improve quality, reduce errors and in general increase effectiveness, efficiency and satisfaction.

The motivation for the present thesis arises from the fact that ITIM sees the need to create mobile solutions especially tailored to the production context at ZF to achieve a high usability (cf. ISO 9241-11:1998 1998). As outlined above, the requirements found in the production contexts are significantly different to a traditional office environment.

The first tasks of this thesis after collecting knowledge from prior conducted research are to analyze the workers which potentially will use the smart devices in future, their work tasks they conduct and especially the context in which they work. In addition existing mobile solutions get analyzed as well. After a comprehensive understanding of the contexts and key aspects of the work tasks is achieved the next steps are to formulate requirements and design guidelines that a mobile solution must fulfill to be usable in a production context at ZF.

This thesis project focuses on the first two phases of the user centered design process – to understand and specify the context of use, users and organizational requirements – to generate a generic as possible set of requirements and derived
design concepts. The next two phases of the user centered design process are not part of the present thesis. It is also not part of the thesis project to create a complete design solution for a specific work task or process, nor to evaluate such design solution. (cf. ISO 9241-210:2010 2010)

The user centered design process is not conducted exceptionally deep and detailed as the focus is on a broad analysis of different related contexts.

The secondary academic aim is to use the current project as a case study to evaluate the strengths and weaknesses of the CD process in an industrial setting. Traditionally, as it can be seen by the case studies presented by Beyer & Holtzblatt (1998, pp. 26), by Holtzblatt et al. (2004, pp. 28), as well as in available literature, most projects using the CD approach took place in an office environment or comparable contexts like a laboratory. Not much could be found about using CD at a shop floor in an industrial production company. Additionally this project is not focused on improving or newly designing one system but looks at different tasks using different systems. The common ground at this point is that all work shall be supported by the same hardware category and does take place in the same work environment.
Chapter 2

Previous Work

2.1 Existing Literature

2.1.1 Mobile Solutions in Non-Office Environments

Researchers have published numerous different papers concerning the usage of mobile solutions in different contexts, such as assembly lines, construction sites, processing plants, maintenance departments, industrial training settings, and many other different non-office environments. In the vast majority of cases aspects of the investigated work are similar to the work happening in the production context at ZF.

*Bridge the physical and digital world* has been a common goal which should be fulfilled by mobile solutions. Nilsson et al. talk about creating a system “that supports the process of physical inspection and attempts to make the transition between physical interaction with the plant and interaction with digital representations of the plant smooth.” (Nilsson et al. 2000, p. 2) as “operators need the ability to bridge the gap from symbolic representations on computer screens to a detailed understanding of the machinery on a physical level coupled with tacit knowledge of process dynamics.” (Nilsson et al. 2000, p. 2). One idea named is to create smart objects by attaching wireless devices to manufacturing objects (Huang et al. 2008, p. 704). A key process to support this is structured data collection (Bowden 2005, p. 60) as manual processes do not reflect the operational dynamics (Qu et al. 2012, p. 2345).

Another key goal found was to bring digital objects or information into their physical location of context. Dahlstedt et al. (2013, p. 51) talk about augmenting information. Maartua et al. (2007, p 3) and Emmanouilidis et al. (2009, pp. 94) highlight showing contextual information at distinctive locations. At construction sites the documents perceived most useful were drawings, data collection forms, correspondence, progress information, and specifications (Bowden 2005, p. 60). It was pointed out that it was crucial at a waste water plant “to make it possible for the operator to create and modify his own points of interaction on the locations and at the times of his own choosing.” (Nilsson et al. 2000, p. 5) to enable them to stay in their physical context but still have access to digital information needed. Entering information, such as for example quality issues, into the central databases (Stiefmeier et al. 2008, p. 46) and using smart devices to communicate with central databases (Kondratova 2004, p. 346) were
referred to as well as exchanging data between operations and maintenance, and higher management (Emmanouilidis et al. 2009, p. 93). In general, it has been pointed out that standards are needed to link systems and provide greatest benefit, instead of creating island solutions (Bowden et al. 2006, pp. 673).

A third goal often found, was to create location awareness. The question to be answered is where material is (Huang et al. 2008). Especially tracking of work in progress (WIP) material is implemented using mobile solutions (Qu et al. 2012, p. 2354). Indoor and outdoor navigation is used for logistics tracking (Emmanouilidis et al. 2009, p. 96). Davis (2002, p. 67) stated that “[w]ith pervasive computing, tracking of physical work and movement of goods is continuous and available on demand.”.

Different strategies were mentioned in research to reduce and prevent errors in daily work by using mobile solutions. Improving traceability and information accuracy (Huang et al. 2008, p. 1) was one way, another approach found was to point out errors (Maurtua et al. 2007, pp. 4) or to provide the workers with warnings when a step in the work process was missed (Stiefmeier et al. 2008, p. 46). Not only when handling WIP items, was it repeatedly mentioned that mobile solutions were used to overcome the problem that “manual identification sheets are frequently damaged, lost, or misplaced” (Huang et al. 2007, p. 6) and that manual documentation is in general error-prone (Qu et al. 2012, p. 2345).

Another aspect of improving the work was to use mobile solutions to create a common understanding of the current situation, which until recently usually happened via informal talk. Nilsson et al. stated that an important aspect of the operators’ work was the daily round trip, which in addition to matching the actual state of the plant to the digital representation was used to create a common understanding of the situation among the operators. This was achieved by informal communication when they met each other by chance and by analyzing traces left by their colleagues, such as abandoned equipment or dismounted parts (Nilsson et al. 2000, p. 3). Davis (2002, p. 69) talked about improving the communication, and it was stated elsewhere that often different departments did not know what the current situation in other departments looked like (Qu et al. 2012, p. 2345).

Although the operators normally took a fixed path, their attention constantly shifted to different places (Nilsson et al. 2000, p. 3), creating the need for a very flexible mobile solution. Flexibility was an important aspect for Qu et al. (2012, p. 2354) as well as allowing the workers to react to changes in real-time.

Another frequently mentioned aim of using mobile solutions was to improve health and safety of workers (Efstratiou et al. 2007). After all, in a capitalistic system, an important and common goal was to become more efficient, to save costs, to finally increase profit. Aspects named by Huang et al. (2008, p. 701) contain operation efficiency, reduced labor costs, and increased speed. Emmanouilidis et al. (2009, p. 93) named reducing operating costs and improving production efficiency as well. In the case studies presented by Stanford (2002, p. 14), the delivery of information could be cut down from two or three hours to about 20 minutes, by eliminating running back and forth to central terminals. Bowden (2005, p. 60) stated that the return on investment (ROI) for a mobile solution in the construction industry is reached in less than twelve months, improving efficiency of data capture, access to data, and data integrity. Huang et al. (2007, p. 6) add that “data entry operations are non-
value adding activities” anyway and Qu et al. (2012, p. 2345) pointed out that manual paper work is wasteful and could be eliminated by mobile solutions. Time and money could be saved by shorter training periods as presented by Maurtua et al. (2007, p. 4) as well.

Mobile solutions, especially for non-office environments, need to overcome certain obstacles to be usable. Peripheral interaction is noted as an important topic, as Emmanouilidis et al. (2009, p. 98) noted that users are occupied with attention-sensitive tasks, or with manual work while using mobile devices. And Siewiorek (2002, p. 80) added that distractions are a problem in mobile environments as users are occupied with walking, driving, or other real-world interactions. The design must thus make it possible to “minimize workers’ cognitive load and avoid distracting them from their primary tasks” (Stiefmeier et al. 2008, p. 42). Their idea was to use a “proactive context-aware system that uses unobtrusive sensors to track each step of the performed task and presents the worker with the information needed at any given moment” (Stiefmeier et al. 2008, p. 42) instead of a traditional graphical user interface (GUI) based system.

A sensitive topic is the complex of permissions, identity management, user tracking, and privacy. Authentication is seen by Zuehlke (2010, p. 135) as very important, to make sure that not every user can access every device in a plant. Zuehlke (2010, p. 135) pointed out that this will lead to new privacy issues, as device tracking enables the monitoring of workers.

Once mobile solutions are introduced, workers rely on a robust and stable system. Stiefmeier et al. (2008, p. 42) stated system reliability and robustness as essential factors in an industrial setting. It is said that “[s]mooth functioning of wireless connectivity in industrial environments can strongly affect the acceptance of wearables” (Stanford 2002, p. 16) as well, which is not easy to achieve in a context where much iron and steel is present. Where possible a combination of sensor modalities was used to increase robustness, whereupon the sensors on a car body recognized the task and wearable sensors were used to improve robustness (Stiefmeier et al. 2008, pp. 43). According to Stiefmeier et al. (2008, p. 49) “merging information from motion, muscle activity, and location” was used as a “multimodal segmentation method” to overcome the issue of synchronizing the data stream as “a single sensor domain isn’t sufficient” (Stiefmeier et al. 2008, p. 49).

Especially when voice input needs to be used, special techniques must be employed in a noisy environment to keep the system stable. Often mobile devices equipped with a noise cancellation microphone are needed, as explained by Stanford (2002, p. 19) and Goose et al. (2003, p. 70). Another solution is to enable speech input only on a specific phrase (Goose et al. 2003, p. 68) or to restrict voice input to a limited set of simple commands (Emmanouilidis et al. 2009, p. 100). It might be the case that the noise in a specific context is too loud for voice input or phoning in general (Emmanouilidis et al. 2009, p. 98).

The hardware used for mobile solutions needs to fulfill different requirements as well. Physical robustness is a topic which seems obvious in a non-office environment. The devices must withstand dust and dirt, temperature variations, humidity, and different light conditions (Dahlstedt et al. 2013, p. 48). But besides being resistant to impacts with hard surfaces, and extreme temperature ranges, Stanford (2002, p. 19) and Efstratiou et al. (2007, p. 129) pointed out that the mobile devices still need to be comfortable, reasonable and lightweight as well.
With respect to the size of mobile devices, a screen size of six to eight inches for tablets is suggested, to be easy to transport, but still large enough to see all necessary information at a glance (Stanford 2002, p. 14). And investigating the context of use on construction sites, Bowden (2005, p. 61) concluded that further research is needed as “alternative ways of delivering drawing information is required, or devices/drawings need to be adapted”, because currently drawings are A3 or A2. The generic statement “size and weight should be limited” by Emmanouilidis et al. (2009, p. 98) was further developed with the idea that mobile devices need to fit into a pocket, so as not to stay at the desk (Dahlstedt et al. 2013, p. 49). Ashok & Agrawal (2003, p. 31) added that such devices “must be small and light enough to fit inside clothing, attach to a belt or other accessory, or worn directly like a watch or glasses” In general human anatomy introduces minimal and maximal dimensions for possible mobile devices (Siewiorek 2002, p. 82).

Covering the topic of ergonomics, Efstration et al. (2007, p. 129) said that mobile solutions must be easy to set up, use, and master. It is pointed out that they must be flexible, allow different postures of the user, and must not hinder them in their work (Maurtua et al. 2007, p. 4). According to Emmanouilidis et al. (2009, p. 99) text typing should be limited as on-screen keyboards are not convenient, and the designer and developer need to keep in mind that stylus input is poorer than mouse input. Dahlstedt et al. (2013, p. 49) suggested considering the installation of extra devices with big screens and keyboards if a mobile solution is not sufficient on its own. Touching the field of electromagnetic rays, Ashok & Agrawal (2003, p. 34) stated that “it is desirable to contain radiation to the surface of clothing and away from the body, especially as the number of wearable electronic devices and usage increase.”.

With respect to using mobile solutions, in an industrial context, Zuehlke (2010, p. 135) stated “one problem here is the variety of different devices, which are also designed with significantly shorter life cycles as the rest of the plant.” Dahlstedt et al. (2013, pp. 50) named the shorter mobile life cycle as well. Stanford (2002, p. 15) in addition stated that the usage of a common OS is preferred, to have a range of systems and applications available.

Network coverage is another topic frequently found in literature. Emmanouilidis et al. (2009, p. 93) called “24/7 connectivity for active data management” a key characteristic of mobile solutions. Sepulcre et al. (2011, p. 1) explained that the wireless local area network (WLAN) setup depends on the environment, as there might be highly reflective materials such as metal, and especially as antenna height is low and nodes tend to move in a production context. Dahlstedt et al. (2013, p. 47) added the problem of the complete absence of network capabilities, for example in contexts like mines. To keep bandwidth requirements low, Stanford (2002, p. 15) suggested using devices with internal disk space. And Ashok & Agrawal (2003, p. 33) added “networks must not have line-of-sight (LoS) requirements”. The environment affects radio frequency identification (RFID) reading accuracy (Qu et al. 2012, p. 2355) as operation can be hampered by the presence of metal surfaces or liquids (Emmanouilidis et al. 2009, p. 103).

Besides research covering single fields of applications, more generic work is available as well. Summarizing human-computer interaction (HCI) issues of mobile solutions for a variable work environment, York & Pendharkar (2004, p. 772) describe the objective of their paper as “to provide a survey of litera-
ture regarding computing in a mobile environment.” And Häkkilä & Mäntyjärvi (2006) present in their paper design guidelines for context-aware mobile applications.

Bowden (2005, p. 60) pointed out that in opposition to common stereotypes, site-based staff in construction are ready and willing to use mobile technologies. Discussing the introduction of mobile solutions, Stanford favored involving users at an early stage (Stanford 2002, p. 16). In addition to the early involvement of users, Bowden (2005, p. 60) argued in favor of developing a solution with a short learning curve. A user-centered design (UCD) approach is favored by Maurtua et al. (2007, p. 11) and Emmanouilidis et al. (2009, p. 93) as well. Efstratiou et al. (2007, p. 129) emphasized the huge amount of different stakeholders in an industrial setting.

2.1.2 The Contextual Design Process in Non-Office Environments

One common implementation of UCD is the CD methodology introduced by Wixon, Holtzblatt & Knox nearly 25 years ago (Wixon et al. 1990), and later presented in more detail by Beyer & Holtzblatt (1998). The CD process has its root in the contextual inquiry (CI) method for data gathering as described for example also by Raven & Flanders (1996).

The CD process has been applied in many different contexts. For example it was used to design online and hardcopy documentation (Raven & Flanders 1996), to gather user requirements for mobile exhibition systems (Fouskas et al. 2002), to identify potential innovations for problem-orientated learning software (Blechner et al. 2003), introduction of automatic teller machines (ATMs) (De Angeli et al. 2004), to study digital music library systems (Notess 2005), to design a pizza ordering system, a calling system for medical checkups, a food recipe grouping web, a computer game, a personal athletic trainer, task and time registration (all as practical parts of a university course) (Lárusdóttir 2006), to evaluate a course administration system (McDonald et al. 2006), to implement an ERP system Vilpola et al. (2006), and to design automotive human-machine interaction (HMI) designs (Gellatly et al. 2010).

Raven & Flanders (1996, p. 12) point out that “gathering direct user information” is a strength of CD, which is especially useful for implementing solutions to problems found. Notess (2005, p. 2) adds that CD gives answers to intents and motivations of users as well and McDonald et al. (2006, p. 439) concludes, that in their case study about 2/3 of the problems found did not lie within the evaluated system, but within the context of use as well.

Early literature criticizes the fact that no ad-hoc tools and guidelines are available (Fouskas et al. 2002, p. 20). As mentioned later by Notess (2005, p. 2) and Lárusdóttir (2006, pp. 4), this is solved by Holtzblatt et al. (2004), although according to Notess (2005, p. 3) operational definitions are still needed in order to make CD a proper research method. Blechner et al. (2003, p. 95) stress that CD is labor and time intensive and Lárusdóttir (2006, p. 2) found that for people inexperienced in CD, preparation of interview took longer than the interviews themselves.

In addition Fouskas et al. (2002, p. 20) points out the need for researchers with diverse backgrounds to conduct the CD process. Gellatly et al. (2010, p. 157) used web-conferencing tools to enlarge the design team for interpretation.
tasks by remote persons. Another solution to extend the CD team by including other stakeholders, such as external consultants was used by Vilpola et al. (2006, p. 152). Especially for walking the data to find new design ideas, Lárusdóttir (2006, p. 3) believes it is key to involve people not being part of the project team.

While some case study projects worked extensively on work models (cf. for example McDonald et al. 2006, p. 438), others in contrast did not do much work modeling, but instead concentrated more on the CI phase (Raven & Flanders 1996, Fouskas et al. 2002).

For McDonald et al. (2006, p. 440) it was no problem to define the focus of the CI, but still the importance of different information types gained in the CI was unclear beforehand. For Vilpola et al. choosing a focus for the CI in the case study to implement an ERP system was not self-evident. Vilpola et al. (2006, p. 150) suggest using the work of “long-term, multi-skilled, expert-type professional users” or a central process. Gellatly et al. (2010, p. 157) experienced that early interpretation helped to refine focus of later interviews. And Gellatly et al. (2010, p. 159) state that user’s intents are more stable than their tasks, thus focusing on them makes it easier to generalize the findings.

Raven & Flanders (1996, p. 4) mention the three different implementations: work-based interview, post-observation inquiry, and artifact walkthrough as CI methods. These different strategies are described by Holtzblatt et al. (2004, pp. 69) as well, intended for cases where the work practice does not permit classical CI interviews.

Video taping of non-interruptible work to provide context in CIs afterwards is described as working well (Blechner et al. 2003, pp. 92, 95). Raven & Flanders (1996, p. 8) and Blechner et al. (2003, p. 92) taped audio and video as well. While Raven & Flanders (1996, p. 6) and Gellatly et al. (2010, p. 157) conducted the CIs as pairs, Fouskas et al. (2002, p. 13) used a combination of interviews and observations in separated phases and locations, as the observer tried to stay unobtrusive so as to not affect the observed persons. Fouskas et al. (2002, p. 19) stated in addition that the people did not want to be watched during their work. De Angeli et al. (2004, p. 34) used structured interviews for the CI phase. Depending on how much work was available, McDonald et al. (2006, p. 438) reports that the length of the interviews was between 30 minutes and 1.5 hours.

It is suggested by Raven & Flanders (1996, p. 5) and Fouskas et al. (2002, p. 21) that at least three interviews be conducted at different sites and per site to see overlap in the results. Blechner et al. (2003, pp. 91) state that ideally 10-20 interviews should be conducted with people having different work roles. Fouskas et al. (2002, p. 12) interviewed no single actor group, but a variety of actors. And Lárusdóttir (2006, p. 3) experienced that the affinity diagram had low quality because of lack of data as not enough people got interviewed. McDonald et al. (2006, p. 438) used a follow-up interview of 20 minutes to answer open questions after the interpretation of the initial CI.

McDonald et al. (2006, pp. 337) used structured problem reports instead of affinity diagrams to better support problem extraction. Blechner et al. (2003, p. 93) described how flow, sequence, and cultural models were developed in parallel. Artifact models were developed thereafter, and because of time constraints no physical models were developed. Vilpola et al. (2006, p. 150) used consolidated work models to model the complete company. One consolidated
artefact model was designed by Gellatly et al. (2010, p. 160), but became too large and cumbersome to use.

2.2 Existing Solutions at ZF

As part of the present thesis, different examples of existing mobile solutions at the ZF Group were looked at. At all but one ranges of operation contextual interviews were conducted to find out how workers currently use the existing solutions and what problems occur. The knowledge gained is intended to be used to improve future systems. At plants in the following cities mobile solutions were investigated.

2.2.1 Friedrichshafen

At the plants in Friedrichshafen two different existing mobile solutions at the special vehicles transmission department and the mobile maintenance department were observed.

An off-the-shelf Fujitsu Lifebook E Series office laptop and two different cable-based bar code scanners are used to create digital assembly documentation at the special vehicles transmission department for the train gear box assembly. At the power train assembly for trains a comprehensive documentation is needed, including ten different codes containing serial numbers to be scanned and several serial numbers, tool identification numbers and measurement results to be entered manually. The work happens assembly-line based, consisting of four assembly stations. The assembly time is around eight hours. Initially laptops were used to enter the data directly into a Microsoft Word form enriched with macros along the assembly. As data was repetitively lost due to system crashes, the form now gets printed after initial values are entered and the additional values are added by hand during the assembly process. On the back of the paper form, temporary calculations are noted down. The laptop is mounted next to the first assembly station. In the end of the assembly the additional values are transferred to the digital form, which is saved on a network share. The assembly documentation is bilingual as the customer gets a copy of it as well.

The mobile maintenance department uses the movilizer application on smartphones to document inspection work. The yearly inspection of fire protection flaps was observed. In the beginning the list of fire protection flaps to be inspected is downloaded to the smartphone, in this case an Android based Samsung device. During the inspection, first the barcode of the fire protection flap is scanned. The inspection protocol, consisting of some checkboxes and radio buttons is then completed. If an error is detected at the fire protection flap, a textual description can be added. In the end the inspection result is saved to the device and after a bunch of inspections has taken place the results are all transferred together via a cloud service to the SAP backend system.

2.2.2 Passau and Staňkov

Both in Passau and in Staňkov mobile hand held computers with integrated bar code readers are used. The devices found there are mostly ruggedized Motorola
MC55A0 and MC9190 devices using the Windows Mobile OS. They are connected via WLAN to the company network. The ruggedized charging jack makes it easy to handle the charging process. The area of application is especially concerned with the warehouse management. Other fields of application include the cost center cast iron and the test systems department. The latter switch back to personal computers (PCs) to enter numbers if no bar code exists. The touch screen is perceived by many other workers to be too cumbersome to use. Most interaction thus happens by scanning bar codes, touch input is normally limited to pressing some buttons. Authentication often happens by scanning bar codes for user names and passwords as well. A stylus input can be used in addition to a finger.

Regularly problems occur as the result of lost WLAN connection. At the request of the business departments using the mobile solutions, increased effort has been spent in recent month by the IT department to improve consistency in the visual design, enlarge buttons, and to support the whole process instead of offering island solutions. In the future it is planned to introduce data matrix codes in addition to traditional bar codes.

2.2.3 Saarbrücken

Different processes at the plant in Saarbrücken are supported by mobile solutions. These processes use not only bar codes, quick response (QR) codes, and data matrix codes, but also RFID tags. A closer look was taken at the disassembly process for gear boxes which show quality problems at a quality check during or after the assembly.

In this process, ruggedized Motorola devices were used in addition to panel computers. Most of the digital process happens on the touch-enabled panel computer and only specific tasks like reading bar codes and reading and writing RFID tags are done with the mobile device. Although it is a device made for industrial usage, the loudspeaker did not work after the device has been dropped at the observed work place. While reading bar codes and RFID tags normally works fine, writing RFID tags does not work regularly. Often several tries are needed until writing succeeds.
Chapter 3

Methods

3.1 Contextual Design

A UCD approach, as defined in ISO 9241-210:2010 (2010), was employed to gather understanding of the requirements for mobile solutions in a production context at ZF. As the work practice shapes the usability requirements, a UCD process seemed sensible to use. This perspective is confirmed in literature by, for example, Maurtua et al. (2007, p. 11) and Emmanouilidis et al. (2009, p. 93). The methods used in the present thesis have evolved from the contextual design (CD) process as described by Beyer & Holtzblatt (1998) and Holtzblatt et al. (2004), which is an instance of a UCD procedure. Beside the previous knowledge in applying CD, its focus on “finding out how people work” (Beyer & Holtzblatt 1998, p. 21), and the ability “to share the thinking process and results with others.” (Beyer & Holtzblatt 1998, p. 22) were reasons to choose the CD methodology. Because a broad insight in different contexts was intended, not all methods of a CD process were used, but different departments were chosen for examination. The following subsections describe the methods used for this thesis project. The results gathered are presented in chapter 4 on pages 35–76.

3.1.1 Contextual Inquiry

A CD process starts with the contextual inquiry (CI) phase. CI is the process of observing, collecting artifacts, and interviewing potential users of a computer system in their work to get to know them, their work practice, and their work environment (Benyon 2010, pp. 274). Beyer & Holtzblatt (1998, p. 22) talk about “understanding the customers: their needs, their desires, their approach to the work.” The person being observed and interviewed is seen as the expert in their work, whereas the interviewing person acts like an intern who wants to learn about the work (cf. Beyer & Holtzblatt 1998, pp. 42). The interviewing person is thus a participant observer (Graziano & Raulin 2010, p. 120). Beyer & Holtzblatt introduce the following four principles for CI:

Context: The contextual interviews have to take place in the work environment of the worker as much work happens subconsciously and only concrete data is relevant. (Beyer & Holtzblatt 1998, pp. 47)
Partnership: The interviewee and the interviewer should be equal partners. From time to time the interviewer needs to step back and just observe the work being conducted, while at other times it is important to ask questions why something is done to understand the intention behind it. (Beyer & Holtzblatt 1998, pp. 51)

Interpretation: The pure data needs to be interpreted to be useful. In the end a shared understanding of the work is needed. While this is done in a first step already during the contextual interview with the user, it is later done by an interdisciplinary team when interpreting all data again. Keeping the right relationship to the user is crucial to ensure a correct interpretation. (Beyer & Holtzblatt 1998, pp. 56)

Focus: While interviewing, the interviewer is taking a point of view on the work. While this happens partly deliberately, for example to focus during the work on problems with current systems to improve them, much focusing happens unconsciously. Triggers are for instance the former education of the interviewer or assumptions they have. It is important to be aware of this aspects and fight against them. (Beyer & Holtzblatt 1998, pp. 61)

Ten different contextual interviews at the plants in Saarbrücken and Friedrichshafen, plus one phone interview with a colleague at a plant in Passau were conducted for the present thesis. The work contexts looked into cover disassembling, assembling, production resources and tools supply, and mobile maintenance at different departments.

The goal was to capture a broad image of the production context at ZF by observing work which was as diverse as possible (Beyer & Holtzblatt 1998, p. 76). The interviewee were thus chosen in a way to be able to investigate a diverse set of work practices.

Because of the focus of the project, time limits, and business issues, in some cases only one or two workers per work process were interviewed (cf. Benyon 2010, p. 276). As six interviews took place at different work processes at the same department, an introductory group talk for all involved employees was given (cf. Holtzblatt et al. 2004, p. 82). The workers council was informed as well and in general employees were eager to get to know why work of their colleagues was observed and for what kind of project about mobile devices the data was intended for.

Pen and notebook were used to take down notes during the contextual interviews, unfortunately permission was not given to record the audio as a backup. Where allowed, a smart phone was used to take pictures of the work space and artifacts. In addition printouts and digital copies of forms and instructions were collected wherever possible. Conducting the contextual interviews within the employees work place was always possible. (Cf. Deal with the unexpected issues Holtzblatt et al. 2004, pp. 84)

In cases where mobile solutions were already used for daily work at the investigated work areas, the focus was set on their usage, and especially on present problems and breakdowns with the current IT systems.

Whereas the idea was to follow the workers for about two hours along their work as suggested by Holtzblatt et al. (2004, p. 83), in some cases the contextual interviews took significantly more or less time. The reasons for this lay in inherent aspects of the different work tasks – although most could be defined
as “normal” following the classification by Beyer & Holtzblatt (1998, pp. 73) – and the progress of the CI process as well:

• Production resources and tools supply happened at different stations which were approached by a small electric truck. There was no other solution but to accompany the driver between the stations.

• Assembly times of observed gear boxes are between four and eight hours. For the first interviews it was important to follow the whole work process along to get an overview.

• For later interviews at gear box assembly tasks only key aspects were observed, that differed from already investigated work steps which reduced the observation time very significantly.

Interpretation was handled as an iterative process, starting while note-taking during the field interviews. As soon as possible after the interview – avoiding talking to anybody about the interview in the meantime – the notes were transcribed, using a word processing software, translated to English, and interpreted (Holtzblatt et al. 2004, p. 95). The interpretation can be seen as a way of coding (cf. Graziano & Raulin 2010, p. 123), focused on the intents and other important aspects of the work tasks. Unfortunately there was no possibility to get support from other people for interpreting at this stage although it would have increased the data quality (cf. Holtzblatt et al. 2004, pp. 101).

3.1.2  Affinity Diagram

All interview notes collected during the CI phase as described in subsection 3.1.1 on pages 23–25 were the basis for the affinity diagram. The roughly 250 affinity notes were printed on perforated place cards. As recommended by Holtzblatt et al. (2004, p. 160) about six square meters of office wall space were covered with paper to pin the notes on, and blue, pink, and green sticky notes were used to create a hierarchy.

All notes from all interviews were used to create one consolidated affinity diagram in one go. Being an inductive bottom-up process, the cards were grouped by whatever groups emerged out of the data (Benyon 2010, p. 300). The process can be seen as a style of data snooping (cf. Graziano & Raulin 2010, p. 325). Labeling for the first two hierarchies was done “using the voice of the customer—saying what they do and how they think.” (Holtzblatt et al. 2004, p. 159).

A second person from the ITIM was able to support me constructing the affinity diagram. This not only speeded up the process, but also introduced another layer of interpretation of the data through discussion of the notes and their meaning when putting them up.

Only few notes were not put up as they did not fit the affinity diagram, holding for example only demographical data that was considered to be irrelevant (Holtzblatt et al. 2004, pp. 167). In addition to the affinity diagram, some work models were created as well. The models used in the present thesis – artifact models and physical models – are described below. As the goal of the present thesis is not to redesign one concrete work process, but to gather important work aspects of different processes and tasks in a similar context, no sequence diagrams were created.
3.1.3 Artifact Models

“Artifacts are the tangible things people create or use to help them get their work done.” (Beyer & Holtzblatt 1998, p. 102). Artifacts were collected during the CI process by either taking copies or photos of relevant objects. In some cases representations of GUIs were collected as well (Benyon 2010, p. 286). It was not allowed to take photos or collect objects at all departments, thus hand drawn sketches were used as a substitute for some artifacts.

The collected artifacts were annotated to reveal the aspects of interest. Special attention was paid to the following components of an artifact model as enumerated by Beyer & Holtzblatt (1998, p. 105):

- the information presented itself
- the structure explicitly and implicitly given by its usage
- additional annotations to the object
- presentation and how it supports the usage
- usage of the artifact
- breakdowns when using the artifact

The overall goal of the artifact model is to reveal the intents fulfilled by the artifacts (Holtzblatt et al. 2004, p. 134).

3.1.4 Physical Models

The physical model shows where the work takes place, to answer the question why it is carried out in the way it is (Benyon 2010, p. 291). Holtzblatt et al. (2004, p. 136) explain that the model shows how the user is affected by their physical surrounding and how they use the physical environment, by either focusing on a site model or on a workplace model. Both types were used in this thesis, depending on which suited better.

Beyer & Holtzblatt (1998, p. 117) name following aspects of the surroundings that should be modeled in a physical model:

- The places itself in which the work happens
- The physical structure that limits and defines the place
- Usage and movement paths workers follow
- Hardware, software, and other tools used for communication to show who is communicating to whom
- Key artifacts and where they are placed
- The layout of the tools, artifacts, furniture, and the physical space and how it supports work
- Breakdowns, caused by the physical context
As the focus is on how workers respond to the physical location, shop floor plans and work place drawings are not physical models by themselves, but were used as a starting point, being altered to point out the important aspects (Beyer & Holtzblatt 1998, p. 119). Photographs and sketches, drawn during the contextual interviews, were used as a base for the physical model as well, as suggested by Holtzblatt et al. (2004, p. 139).

As different work processes at different departments and physical locations were observed, these different physical models were not consolidated, but instead kept separate. Each model can be used to exemplify show a specific occurrence of an important aspect of work in a production context.

3.1.5 Personas

The concept of personas was introduced by Cooper (1999). Baxter & Courage (2005, p. 42) define a persona as “[a] fictional individual created to describe the typical user based on the user profile”. Different sources such as classical user studies (cf. Baxter & Courage 2005, pp. 43) or applying the people, activities, contexts, and technologies (PACT) framework (cf. Benyon 2010, p. 56) can be used to generate data for personas, as well as conducting a CD process (cf. Holtzblatt et al. 2004, pp. 181) as done in the present thesis.

By creating personas, abstract user data becomes more concrete, brings it alive, team members and stakeholders who do not meet the real end-users can connect more easily to them, and personas create a shared understanding of who the users are (Baxter & Courage 2005, pp. 48). It was thus for such a big company as ZF perceived helpful to use personas.

A persona summarizes on one page a users name, photo, background, key goals, tasks, and roles (Holtzblatt et al. 2004, p. 182). Holtzblatt et al. suggest focusing on core roles for creating personas as “[t]oo many personas create their own distractions” (Holtzblatt et al. 2004, p. 184) and might be a sign for of a lack of a clear focus in the project.

For the present thesis five personas were written, covering the following four job roles, perceived to be the ones using mobile solutions in future most intensively:

- assembly operator
- warehouseman and supply driver
- holiday worker
- foreman

Two personas were written for assembly operators, as their demographics data, professional background, and skill set varies a lot.

3.2 Usability Requirements

Six (2009) suggests first deciding on usability factors and then establishing metrics. She also stresses finding out what aspects of user experience (UX) are critical.
The literature has mainly two perspectives on looking at usability factors, deriving from the two common definitions of usability. The first approach defines \textit{effectiveness}, \textit{efficiency}, and \textit{satisfaction} as the three usability factors for specific users, tasks, and context, following the International Organization for Standardization (ISO) definition of usability (cf. ISO 9241-11:1998 1998). A second perspective looks at the five usability factors \textit{learnability, efficiency, low error rate, memorability, and user satisfaction} defined by Shneiderman (1992) and Nielsen (1993) for specific users, tasks, and context.

The five usability factors by Shneiderman (1992) and Nielsen (1993) can be mapped to the three more generic factors mentioned in the ISO 9241-11:1998 (1998). It was thus decided to use the ISO definition of usability.

\textit{Safety} is strongly connected to HCI and for example mentioned by the ISO 9241-210:2010 (2010) as one effect of computer usage the UCD process should ensure. Rogers et al. (2011, p. 19) include safety as one of the usability goals as well, saying that it “involves protecting the user from dangerous conditions [...]”. The physical environment, being potentially dangerous in an industrial plant, is explicitly named in ISO 9241-11:1998 (1998) as part of the context of use. Although not being named as one of the three usability factors in the ISO definition directly, in the present context of industrial production, work safety is perceived as an equally important aspect of usability and was therefor added as a fourth usability factor to the definition of usability used in the present project. Thus following usability factors are the onces used in the present thesis:

- Effectiveness
- Efficiency
- Satisfaction
- Safety

According to Lauesen & Younessi (1998) usability requirements can be formulated in following six different styles:

\textbf{Performance style}: Performance objectives for specified users doing specified tasks are defined. Examples could be: Inexperienced users learn the system within one week; experienced users can do task A in under three minutes.

\textbf{Defect style}: A variant of the first style, limiting the number and severity of problems. Examples could be: Unlimited inconveniences, but only 0.1 task failures per user.

\textbf{Process style}: This specifies the usability aspects of the process, rather than of the final product. Examples could be: The usage and usability test of at least five prototypes during the system design is mandatory.

\textbf{Subjective style}: Criteria for the satisfaction of the user with the system are defined. Examples could be: Eight out of ten people have to like the system; at least six out of ten users must recommend it to colleagues if asked.
**Design style:** The layout of the system is defined in screen pictures and screen functions. Examples could be prototypes and mockups of the future system.

**Guideline style:** Guidelines and standards are named that need to be followed. Examples could be the iOS Human Interface Guidelines by Apple for mobile applications or the IP68 standard for smart phone cases.

Both, the affinity diagram as outcome of the CD process, as well as the ZF PS – presenting guiding production principles and the company culture – were matched against the usability factors derived from the ISO definition of usability plus safety. As often more than one usability factor is important, an attempt was made to focus on the most important one and additionally only specify the second most important factor. The outcome is obviously a rather generic overview about usability requirements, without the possibility to define metrics, as it covers various work tasks by different users in a common context – which is the common ground here.

The usability requirements were thus based on exemplary cases from the observed work. Examples for all six styles presented above were formulated, based on the instructions presented by Lauesen & Younessi (1998). All these fleshed-out usability requirements will help in understanding how to apply the generic usability requirements to a concrete situation.

### 3.3 Design Concepts

Design concepts are used to convey core values and general guiding principles derived from requirements (cf. Moser 2012, pp. 146). The notion is enriched by examples showing how to implement the definition. Many big brands use design concepts to show their design vision and explain the underlying design principles for their mobile applications (Android n.d., Apple 2014, Canonical n.d., Microsoft n.d.a, SAP 2014) and desktop applications as well (Apple 2013, Microsoft n.d.b).

The design concepts were derived by taking data from the affinity diagram and the usability requirements. A further elaboration and designing of examples was done in a meeting with colleagues from ITIM and some additional colleagues from the IT department responsible for IT systems at the shop floor. The appointment took place on May 15 from 1:00pm to 3:30pm with 10 people working in five pairs.

The meeting had following agenda:

**1:00pm – 1:45pm “Walk the wall”:** Getting into the domain knowledge by presenting the affinity diagram, artifacts, physical models, and personas. Breakdowns were shown and first design ideas popped up. Finally the initial design concepts were introduced briefly.

**1:50pm – 2:50pm “Sketch it”:** The goal of the main working phase was to sketch an exemplary aspect of a future mobile solution for each of the design principles.
1:51pm (5 minutes): Group forming, selection of design principle to support, choice of design source, user, task, and context.¹

1:57pm (2 minutes): Individual sketching of first idea. Afterwards the first sketch was thrown away as the first idea is always bad...

2:00pm (8 minutes): Deepening the understanding by looking again at the affinity diagram and the models.

2:09pm (7 minutes): Exploring potential mobile solutions by sketching as many different ideas as possible.

2:18pm (9 minutes): Selection of one solution sketch to focus on. Deciding which ZF PS principle the sketched solution could support. Digging deeper and fleshing out the sketch towards a prototype.

2:28pm (7 minutes): Changing of one group member and testing of the prototype by the new group member.

2:36pm (5 minutes): Refining the prototype by sketching out different ways to incorporate the feedback, exploring of new solutions.

2:42pm (8 minutes): Creation of the final prototype.

3:00pm – 3:30pm “Let’s talk”: Each group presented their solution and got feedback on their results from the other teams (six minutes per group).

As a root for the prototypes some ideas were given on what they could be based on:

- Digitizing an artifact
- Solving of a breakdown
- Exploring a design idea
- Increasing effectiveness, efficiency, or satisfaction for a work practice

The results of the meeting were added to the design concepts, serving as examples how the principles could be implemented.

### 3.4 Case Study

The research method of a case study was chosen to evaluate the CD process in a manufacturing plant environment to find out if and how CD methods would need to be changed to be applicable to such context – the second thesis project goal.

Yin presents the following definition of case studies (Yin 2009, p. 18):

1. A case study is an empirical inquiry that
   
   - investigates a contemporary phenomenon in depth and within its real-life context, especially when
   - the boundaries between phenomenon and context are not clearly evident.

¹ One extra minute between each method was reserved for giving explanations.
2. The case study inquiry

- copes with technically distinctive situations in which there will be many more variables of interest than data points, and as one result
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
- benefits from the prior development of theoretical propositions to guide data collection and analysis.

The second research goal covers the hows and whys, no control of behavioral events was needed, and the research focused on contemporary events. Conducting a case study thus fitted the present thesis project (cf. Yin 2009, p. 8). Runeson & Höst (2009, p. 3) additionally state that case studies provide deeper understanding of the unit of analysis than controlled experiments.

Darke et al. (1998, p. 280) stress that the unit of analysis must offer data collection broad and deep enough to answer the research question acceptably. In addition it is pointed out that other factors like the purpose of the project, the resources available, and the required deliverables influence the design and scope of a case study (Darke et al. 1998, p. 181). The CD process (despite consisting of different methods) conducted at the production context at ZF as a whole was chosen as the unit of analysis, leading to a single-case (holistic) research design (cf. Yin 2009, p. 46).

No discrete case study protocol was created during this thesis project, although its importance is highlighted by Yin (2009, pp. 79), as the present thesis report, together with the book about CD by Holtzblatt et al. (2004), covers all important aspect of a case study protocol.

No separate pilot case (cf. Yin 2009, pp. 92) was conducted. Instead the experience from former CD studies was used as an initial starting point, using the outcome of the first CI interviews to refine the later interviews.

Yin (2009, pp. 101) names documentation, archival records, interviews, direct observations, participant-observations, and physical artifacts as the six sources of evidence to use in conducting case studies. They were used as far as applicable as described in the following:

**Documentation:** All documents created for conducting the CD process and resulting from it were collected. Examples are introduction texts used for the CI, guidelines about how to create an affinity diagram, and all resulting models of the CD process as presented in section 4.1 on pages 35–59.

**Archival records:** Archival records were not present, no former CD projects are known for this unit of analysis.

**Interviews:** Interviews played only a secondary roll as first of all only I was familiar with the method of CD and only I had prior experience with it, in addition to the fact that most of the work conducting the CD process were done solely by me. Nevertheless where other colleagues were involved in the methods, they got asked about their impression and feedback on the methodology.

**Direct observations:** Observations are already an important aspect in conducting the CD process. But most observations happen in a way
describe as participant-observation. No outside observations could be done as I was running the CD process myself.

**Participant-observation:** This way of observing involves the observer being an active part in the process. This is exactly how the observer should behave during the CI phase, thus no problems with biases being produced were expected. During the CI a second focus of observing was added for the case study.

**Physical artifacts:** All physical artifacts being used during the CD project were evaluated as part of the case study. Examples are pens, a notebook, a smart phone, and a tablet.

According to (Yin 2009, pp. 114) a good case study must follow the following three principles of data collection: using multiple, not just single, sources of evidence; creating a case study database; maintaining a chain of evidence. As explained above, more than one source of evidence was used to collect data. No separate case study database was created, but all data items were kept within the CD database as an additional layer since the data was highly interlinked. It was thus ensured that no data would be lost and it would be possible to be able to have “ready access to the case data at any point during or after the study.” (Darke et al. 1998, p. 283). This thesis report together with all cited bibliography, especially with the more process step orientated text books by Yin (2009) and Holtzblatt et al. (2004) serve as a chain of evidence.

To analyze a case study, Yin (2009, pp. 130) presents four general analytic strategies:

1. Relying on theoretical propositions
2. Developing a case description
3. Using both qualitative and quantitative data
4. Examining rival explanations

As suggested by Yin (2009, p. 130) these strategies are not mutually exclusive and a mixture of these were used to analyze the collected data. Relying on the theoretical proposition that changes to the CD process might be needed to make it useful in an industrial production context guided the analysis of the data, thus being on guard for problems and breakdowns in the CD process. Following a descriptive strategy, the analysis could be structured according to the methods used and models created as part of the CD process. Not much quantitative data was collected during this case study project, thus only a limited set of numbers was available to be compared to other literature. For deviations from the original CD methodology, rival explanations were evaluated to see if it was the industrial context influencing the CD process.

These strategies mentioned above serve as a skeleton for the five analytic techniques for case studies explained by Yin (2009, p. 136):

1. Pattern matching
2. Explanation building
3. Time-series analysis
4. Logic models

5. Cross-case synthesis

In this thesis work pattern matching against the literature (Holtzblatt et al. 2004) was used to investigate if and how the context of use being an industrial shop floor influenced conducting the methods and altered the results of the CD process applied.

Darke et al. (1998, p. 287) mentions a potential overlapping of data collection and data analysis activities, and Runeson & Höst (2009, p. 10) even defines these two phases as iterative. In this case study the data collection and analysis phases were dependent on the structure of the CD process, as successfully completing the CD process was the main goal.
Chapter 4

Results

4.1 Contextual Design

In this section the direct results of the CD process are presented. The CI in the work contexts named in subsection 3.1.1 on pages 23–25 provided the data for the affinity diagram, the artifact models, the physical models, and the personas. It thus does not have any dedicated results.

4.1.1 Affinity Diagram

The affinity diagram revealed the five major topics

1. IT hardware and system
2. Communication
3. Time/Efficiency
4. Documentation
5. Work organization

as key aspects of the work happening in the production context (possibly) supported by mobile solutions. Much more important than this five abstract categories are the concrete aspects, covered by 54 blue labels and the corresponding affinity notes.

Figure 4.1: The consolidated affinity diagram.
4.1.2 Artifact Models

Figure 4.2 shows an excerpt of a daily updated so-called noise list. This list contains all defective gear boxes making noises. On each workday (Mondays – Fridays) a meeting is held to discuss how to solve a specific noise problem. The repair decision is entered in the last column. The list is not only used by the assembly operators to read their tasks, but also for them to find out by themselves what to do if they have to repair a gear box with noises on a Saturday, when the daily decision meeting is not held. In this case, the assembly operator looks for former gear boxes in the list with the same noise hierarchy.

Figure 4.2: A copy of a noise list, showing defective power trains and their repair decision.

To prevent errors, the inboxes and outboxes of kanban stations are normally color coded as shown in figure 4.3 on the next page. Green is used for inboxes, and red is used for outboxes. At some kanban stations the inbox and outbox are just labeled with a descriptive tag, without the use of colors.

Although the different material boxes do have mixed colors, these codings cannot be used to conclude the content as each different supplier uses a different color (cf. figure 4.4 on the facing page).

The drivers of the production tools and resources supply department strictly follow the rule of not picking up any undocumented material from a kanban station at a machine. What to do with the material at the warehouse could otherwise be ambiguous. Documentation is thus key. Nevertheless the kind
Figure 4.3: The inbox and outbox of kanban stations are color coded.

Figure 4.4: Different colored material boxes at a kanban station.
of documentation can vary and is not standardized. Individually printed word processing documents and hand-written comments on how to deal with a material as seen in figure 4.5 are common.

Figure 4.5: The documentation of a material that will be returned from the machine to the warehouse.

The truck driver attached the hall plan (seen in figure 4.6 on the facing page showing the positions of the kanban stations) to the truck. It contains contact persons for the kanban stations as well. As the positions of the kanban stations are subject to change, the plan is not up to date. While the driver normally knows the location of the kanban stations, the plan is an important aid for holiday workers.

Smaller, frequently used production tools and resources, such as cutting inserts, get packed into shelves at the kanban stations. While the space is enough for the normal lot size, in special circumstances – like a doubling of the lot size due to delivery limits by the supplier – the space is not enough. Boxes need to get stacked up on top of the shelves, increasing the possibility of taking wrong cutting inserts (cf. figure 4.7 on the next page)

Figure 4.8 on page 40 shows a list of contact persons and their responsibilities and phone numbers. The list is located next to the driver’s seat. The yellow box in the bottom right corner of the photo is used to put the collected kanban cards in.

At the warehouse the kanban cards get attached to the respectively commissioned tools with a rubber band as shown in figure 4.9 on page 40. The kanban card is the key element for controlling the process and thus must not be lost.

In figure 4.10 on page 41 a truck which is used to deliver the production tools and resources is displayed. The truck only has one driving seat and is battery powered to avoid exhaust fumes in the production halls. There can be a lot of traffic in the production halls, mostly fork lifters, but also for example trailer trains, pallet jacks, and bicycles.

Holistic documentation is needed especially for the assembly of power train parts for trains. An elaborated assembly journal is used for quality assurance reasons. Serial numbers of parts, identification numbers of tools, and calculation
Figure 4.6: Sketch of the hall layout with positions of kanaban stations pinned on the truck.

Figure 4.7: The kanban shelf shown is too small to fit the doubled lot size.
Figure 4.8: The list of contacts is located near the drivers seat.

Figure 4.9: How kanban cards and kanban materials get put on the truck.
values need to be documented. Figure 4.11 on the next page shows an axis check
list, which is used to document at different stages of the assembly process that
the axis was checked for errors. Each check point has to be signed by the
assembly operator with their personnel number.

Each project is accompanied by assembly documentation, which is filed away
in a binder. Part of the assembly documentation used by the assembly operators
is the bill of materials. It can get rather long; in one of the observed assembly
projects it contained in total 60 pages, 18 and 42 pages each for two parts to be
assembled. The first page of such a bill of materials is given in figure 4.12 on the
following page. If it changes, the respective position is updated with the new
material and the change number is increased, as well as the change date and
the validity dates are updated. The change is not documented or visualized in
any other way on the bill of materials. This means that if an assembly operator
notices in the quality assurance documentation a different change index, they
have to skim manually through the complete old and new bill of materials to
find the new position.

Drawings as displayed in figure 4.13 on page 43 of the power train parts being
assembled are included in the assembly documentation normally as printouts in
A4 or bigger. They are not used on a daily basis, but are sometimes needed for
new employees or infrequently built power trains.

The filled preassembly journal in figure 4.14 on page 44 consists of a front
and back side. Values are added by hand. Assembly operators use basically
three different techniques to keep the paper clean, firstly either removing the
gloves each time values are written down, secondly using a paper towel between
Figure 4.11: The empty axis check list which is part of the assembly journal.

Figure 4.12: The first page of a bill of materials of a power train which is part of the assembly documentation.
Figure 4.13: Two drawings that are part of the assembly documentation of a power train.
their gloved hand and the assembly journal, or thirdly writing down all values temporarily on a paper towel and then after the assembly is finished copying them over to the documentation. The preassembly journal has to be signed by the assembly operator. If two workers assemble it together, they trust each other and just one signs it.

Some parts have to be expanded to be able to assemble them, which is done by heating them up to either 70°C or 110°C using an induction heater as shown on the photo in figure 4.15 on the next page. The induction heater emits a magnetic field. The supplier thus recommends to persons with a pace maker to keep 5 meters away from it.

If the assembly workers spend time with other things than assembling power trains, they have to write down these times in the missing times report shown in figure 4.16 on the facing page. If different occasions of absence are for the same reason, they can be combined together.

The first two pages of a filled assembly journal are shown in figure 4.17 on page 46. This assembly journal is similar to the preassembly journal seen in figure 4.14, but includes hand-written annotations in addition. Here the assembly operator wrote down calculations concerning how much to grind off on some free space of the assembly journal. Other assembly operators were observed doing the calculations on a paper towel or with a felt pen on the work place table. On the upper part of the first page of the assembly journal, two adhesive labels with a QR code and a datamatrix code are attached to the paper. The labels were removed from the two parts being assembled and were scanned in to include them in the assembly journal. This assembly journal was intended to be operated digitally. But the software kept crashing, which caused data loss and thus expensive disassembly tasks to reread the serial numbers of
Figure 4.15: The induction heater shown is used to enlarge materials during the assembly process.

Figure 4.16: All times not spent on assembly tasks need to be documented in the missing times report.
already assembled parts. Thus currently only initial numbers are typed in and the assembly journal is then printed, filled in by hand, and in the end typed in again.

Figure 4.17: The used assembly journal includes hand-written annotations and two stickers.

Figure 4.18 on the next page is part of assembly guidance that is hanging at the relevant work place. However the observed assembly operators did not use it, as they have learned the assembly steps by heart. The assembly guidance is mainly important for untrained assembly operators. Each assembly task to be done at a work place is named and then visualized in it, divided into single work steps. Important aspects and possible causes for errors in the work steps are highlighted with red font color.

The cog wheel photographed in figure 4.19 on page 48 has an embossed datamatrix code. It was added to increase the documentation speed and reduce the error rate, as it can be scanned. Unfortunately it was observed, that the scan always failed, unless the cog wheel was cleaned with acetone just before scanning the roughly one centimeter square big datamatrix code. A couple of different other cog wheels had an embossed datamatrix code as the chosen artifact. Other parts either had an adhesive label which needed to be removed before the parts could be assembled, or did not have any scannable code at all, but just a number which needed to be typed in.

Two different cable-based scanners (cf. figure 4.20 on page 49) are used to scan the datamatrix codes and QR codes, thus including them into the assembly journal. As one of the scanners had problems scanning both code types, a second scanner was added. Due to the higher prices of cable-free scanners, cable-based scanners are used. The assembly operators complain about difficulty of handling, as the cable is always in their way, sometimes it is too short, and gets
Figure 4.18: Part of the assembly guidance of a power train which is posted at the work places.
Figure 4.19: The cog wheel shown has the serial number embossed numerically and as a datamatrix code.

entangled at the parts being scanned.

As being part of the quality assurance, a wear pattern is created which is documented in the assembly journal shown in figure 4.21 on the facing page. The wear pattern is marked on two sides of a cog by paint, then turning the cog wheel, and finally using tape to copy the mark to the paper document. Again the person taking the wear pattern has to sign the assembly journal.

An example of a wear pattern sticked on the assembly journal can be seen in figure 4.22 on page 50.

To prevent broken parts from being assembled, they are marked with a rejection tag, shown in figure 4.23 on page 50. The layout is dominated by a large red sign so that it is clear at the first glance that this part is defective. In addition to information about the part and its defect, contact details of the person adding the rejection note to the part are part of the tag. The rejection tag has a punched hole in the top left corner to fixate it to the rejected part.
Figure 4.20: Two scanners used to scan different codes for the digital assembly journal.

Figure 4.21: Part of an unused assembly journal used to document a wear pattern.
Figure 4.22: A wear pattern which was done for the assembly journal.

Figure 4.23: Rejection tag that is used to mark broken parts.
4.1.3 Physical Models

At the disassembling in the plant in Saarbrücken the workplaces are aligned in lines, separated by hall paths. Figure 4.24 shows a part of the hall. Two workplaces are always joined together. The layout of two such workplaces is described in more detail in figure 4.25 on the following page. There are central computers and printer, where for example the noise list is accessible. Depending on the workplace, using the central computer and printer may involve long walks through half of the hall.

Figure 4.24: A sketch of the hall layout in the disassembly department in Saarbrücken revealing long walking distances.

Figure 4.25 on the next page shows how two workplaces are composed. In the middle of two workbenches one central panel computer is mounted, used by two assembly operators at the same time. As the workers cannot keep all cost center numbers in mind, they have a printed list hanging next to it. Two wireless scanners for RFID tags and bar codes, and datamatrix codes respectively are located next to the panel computer.

A section of a typical production hall layout is shown in figure 4.26 on page 53. Machines, and also offices are located left and right to the hall paths. Kanban stations are often located closer to their respectively machines, than to the hall paths. It thus happens that kanban stations are positioned behind ma-
Figure 4.25: Two work benches and the structure of their key working tools.

chines or inside an office and can thus not easily be seen by the driver delivering production tools and resources while they drive along the hall paths.

It is common that two workplaces assembling gear boxes share one set of machines and tools when they assemble the same power trains. A typical layout of such a setting is shown in 4.27 on the next page. The deployment area is used by the logistic personnel to deliver parts and by the assembly operators to put the assembled power trains on. Nevertheless it is sometimes the case that the assembly operators have to search for their material in other places. While it is not too far to walk to the foremen, it regularly happens that they are not at their posts as they have to walk to the different assembly places to check the work and answer questions from other assembly operators. The whole hall has only one place in the corner where the grinding machines are located. It is quite far to walk there and often waiting time is spent there until a machine is free.

In figure 4.28 on page 54 a short assembly line for power trains can be seen. The assembly operators prefer to operate it as island assembly, they thus follow their power train along and assemble it completely. During the observation phase the digital assembly documentation was not used as intended, as the application kept crashing. Initial values were thus entered in the beginning, the journal was then printed, taken along the assembly process to be filled in by hand and in the end the assembly operator walked back to the laptop to type in the values. Alongside the assembly trolley (marked orange), a trolley for big parts is used. Smaller parts are taken from trolleys and shelves located at the four different work places. The induction heater and freezer are used to heat and cool down parts in order to be able to assemble them. Freezing of the parts takes several hours until the target temperature of $\sim -40^\circ$C is reached.
Figure 4.26: Part of a production hall layout with machines and their kanban stations to deliver production tools and resources.

Figure 4.27: Schematic drawing of two assembly islands and their relevant surrounding work equipment.
4.1.4 Personas

The following personas were created upon the material from the CI as described in subsection 3.1.5 on page 27.

**Assembly Operator Anton Jung**

Anton Jung is a rather new employee at ZF in his early twenties. He finished his vocational training just two years ago and has worked in the department for special vehicles transmission since then, mainly assembling group spur drivers for trains.

Unlike some of his colleagues, he was able to get a permanent contract, which gives him a lot more work security than his colleagues working on a temporary basis only at ZF. Anton likes his work, especially the work atmosphere and always wants to actively participate in improving his work environment. He points out the importance of being treated as a human being and not as a machine, he strongly prefers working on an assembly island at his own pace to working on the assembly line. Anton is eager to learn more and is thinking of future study in order to broaden his knowledge.

Like nearly everybody of his age, Anton owns a laptop and has a modern
smart phone that he uses intensively. He is also interested in having a wearable fitness tracker as well, since one of his hobbies is mountain biking and he likes swimming in Lake Constance after work in summer too.

Anton’s goals are to

• assemble different types of power trains;

• learn how to assemble additional types of power trains;

• improve the work process and environment, and actively participate in decisions touching his work place.

His main tasks to fulfill above stated goals are

• collecting his parts to be assembled;

• communicating changes in the assembly process to his colleagues;

• assembling power trains;

• grinding components;

• measuring different values of raw and finished parts;

• documenting assembled serial numbers, measured values, and used tools;

• confirming finished assembly to his foreman;

• getting training on the job in the above tasks;

• finding improvement potential in existing work processes;

• getting involved in designing work places and processes for new power train assembly.

The primary role of Anton is as assembly operator of different power trains in the department for special vehicles transmission.

Assembly Operator Peter Alt

Peter, now in his mid fifties, has worked for ZF all his life. He started as an assembly operator many years ago after his vocational training and has since then gained a lot of knowledge on the job. He has found the best ways to do his work for himself and wants to stick to his best practices.

Peter not only assembles different types of power trains, but also does individual work tasks like disassembling power trains which are defective in order to fix the error, for example by exchanging broken parts. He also gives training on the job to younger colleagues, showing them how to assemble different types of power trains. Peter in general only works from Monday to Friday in normal shift, but is willing to work on Saturdays as well if he is asked to.
Peter is rather conservative regarding changes in his work environment, as he has seen many trends coming and going, not all improving the work situation. He was recently given his own smartphone by his daughter, but uses it only rarely. He would like to explore the IT world more, but is sometimes scared off by the complexity. While Peter is in general open regarding the usage of mobile devices in his work context, he is sceptical regarding the monitoring capabilities of such devices and thus would prefer to work without them until he is convinced that smart devices do not track his work behavior and have a real benefit for him.

Peter’s two main goals are firstly to disassemble, repair and assemble different types of power trains, and secondly to teach others how to assemble additional types of power trains.

Following tasks belong to his goals:

- Collecting the parts needed for his work;
- communicating changes in the assembly process to his colleagues;
- assembling and disassembling power trains;
- grinding components;
- measuring different values of raw and finished parts;
- documenting assembled serial numbers, measured values, used tools, and errors he finds;
- confirming finished assembly and repaired power trains to his foreman;
- giving training on the job in above tasks.

Peter’s primary role is assembly operator of different power trains, in addition he gives training to new colleagues.

**Warehouse Man and Supply Driver Horst Maier**

Horst works in normal shift at the production resources and tools warehouse, and spends a significant number of his work hours delivering these production resources and tools to the several machines out in different factory halls.

He is over 40 years old and has two children he is proud of. His wife works part time as a cleaner. Horst believes it is important to do his work responsibly and identifies with his work strongly. Although he tries sometimes to improve his work environment, he is aware of how small his effective range is and he frequently depends for such improvements on the support by his colleagues, whose priorities are often set differently. He uses his computer at home to create support documents for himself.
Horst is hopeful that if he ever gets mobile devices for his work, these will improve his work. He believes in the competence of the designers and developers of such systems and is confident that someone will explain to him how to use them if he could not understand it by himself. Horst still uses an old and robust mobile phone for his private communication.

Horst has a diverse set of goals for his work:

- correctly transfer production resources and tools into and out of stock;
- commission the requested material error-free;
- deliver all requested production resources and tools on time.

The related tasks for above goals are

- transferring material into stock;
- releasing material from stock on the basis of an incoming order;
- checking stock when releasing material from stock;
- preparing a shelf with all production resources and tools to be delivered;
- loading the truck with all material;
- delivering all material to the machines;
- checking stock and kanban cards at the machines;
- returning used production resources and tools.

Horst’s two main roles are as warehouse man and as driver for production resources and tools.

**Holiday Worker Stefanie Hauser**

Stefanie studies math and sports with a view for becoming a teacher. She is 22 years old, living in a small city near to a ZF plant, where her father works as an engineer. She works at ZF as a holiday worker some weeks during her summer holidays to earn some money to finance her studies.
Stefanie does not know which area she will work in when she applies for a holiday job at ZF, but all possible work fields are in the production area. She has no problem with working on the assembly line and/or working in two or three shift models, as it is only for a limited time to earn some extra money. She does not expect to do any interesting work, but still would like her work to be not too boring. The work she does has to be easy to learn as she is only there for a very limited time.

While Stefanie does have a smart phone for her personal use, she normally always asks her boyfriend if she does not understand how to use it and she does not have any experience with applications in an enterprise context. She uses only a couple of applications on her phone on a regular basis.

Her goals are to do a good job, to be able to work at ZF next summer again and to earn a lot of money in little time. Most of the holiday workers like her work at ZF several years in a row, but they do not necessarily do the same work each year.

Depending on her chosen work context, her tasks are a subset of the tasks mentioned for the personas above. Especially the following tasks are potentially part of her work:

- collecting the parts to be assembled;
- doing single assembly steps at power trains;
- measuring different values of raw and finished parts;
- documenting assembled serial numbers, measured values, and used tools;
- transferring material into stock;
- releasing material from stock according to an order;
- preparing a shelf with all production resources and tools to be delivered;
- loading the truck with all material;
- delivery of all material to the machines;
- simple checking of stock and kanban cards at the machines;
- returning used production resources and tools.

During her holiday working time, Stefanie either works on the assembly line or helps out in the warehouse and delivers production resources and tools, filling out the roles of the employees working there regularly.
Foreman Heinz Bank

Heinz started as an assembly operator at ZF. Since some years he has been a foreman for a group of about a dozen assembly operators.

He sees his work challenged daily by a huge variety of problems he has to react to dynamically. While he does see risks in introducing modern mobile solutions – for example with respect to dependency on technology or refusal by his workers – he does see the business benefits as well. He is positive towards the use of modern technology, but does not want to put his workers at risk. He knows mobile solutions only out of an end-users perspective, using them himself.

The main goal of Heinz is to make sure that his team can fulfill the assembly orders.

Different tasks are necessary for achieving this goal:

- maintaining overview of order status;
- communicating top down, foster bottom up and horizontal communication;
- distributing changes to his employees;
- quickly making decisions if asked by his assembly operators.

The main role of Heinz as a foreman of assembly operators is that of organizer and communicator.

4.2 Usability Requirements

4.2.1 Importance of Usability Factors

In the design of mobile solutions for work in a production context, the four usability factors effectiveness, efficiency, satisfaction, and safety have varying degrees of importance. The following tables showing the results are valid for all work practices and work aspects of the production context as observed during the CI and for all investigated personnel (cf. personas presented in subsection 4.1.4 on pages 54–59).

Table 4.1 on the following page matches the usability factors against important work practices and work aspects. Effectiveness turns out to be the most important usability factor. The second most important factor is marked by a small x. Efficiency turns out to be second most important usability factor.

Table 4.2 on page 61 matches the four usability factors against important work practices and work aspects from the affinity diagram in which efficiency
Table 4.1: Affinity diagram contents matched against the usability factors, effectiveness being most important.

<table>
<thead>
<tr>
<th>Work practice or work aspect</th>
<th>effectiveness</th>
<th>efficiency</th>
<th>satisfaction</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>I get important information in regular group meetings</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need information and help from co-workers (e.g. access rights)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visualization at the planning board (overview) is important for my work</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documentation is multilingual</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My documents are versioned</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Errors can happen because of manual documentation</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I use a lot of different tools and have to copy the results (e.g. measurements) to the documentation</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need to authenticate myself, I am responsible for my work</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexibility in the process is needed</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have to know where to go, as it is not documented</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need to keep in mind what I have loaded, and where I have to go next</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The kanban card is the central element of the logistic process</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>My work follows a fixed schedule</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scanning bar/QR/data matrix codes takes much time and many attempts</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like system support in checking my user input</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is crucial that the documentation is kept clean</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need numbers to identify parts which I have to keep in mind</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need a lot of informal knowledge for my work that I cannot look up</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is very important that the documentation is up to date (changes need to be synchronized)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work steps, tools and parts need to be documented (numbers)</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality control is very important</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Descriptive numbers are used so that I get the meaning</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
is the most important usability factor. The second most important factor is marked by a small x, effectiveness being the most frequently occurring.

Table 4.2: Affinity diagram contents matched against the usability factors, efficiency being most important.

<table>
<thead>
<tr>
<th>Work practice or work aspect</th>
<th>effectiveness</th>
<th>efficiency</th>
<th>satisfaction</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning (reading) RFID codes works well</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lots of my communication happens orally and informal</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A lot of work/time is spent on keeping the process reliable</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Temporal) calculations happen in head or with the help of calculating devices</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I only sporadically need to read/save data from/to a system</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have to be flexible in my work as I have to react to circumstances and different conditions</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work steps are learned by heart within some weeks</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I rely on numbers for material logistics and booking</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The whole process needs to be supported, normally island solutions do not help</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I regularly have to fulfill infrequent special tasks</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (and nerves) are lost by recurrently logging in</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work has to be time efficient</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have to wait for other processes</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have to write down temporary data that is not relevant in the final documentation</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need to search manually for my material</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I spend much time transporting physical documents</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 on the following page matches the usability factors against important work practices and work aspects in which satisfaction is perceived as the most important usability factor. Again the second most important factor is marked by a small x. Effectiveness was found to be covered most often.

The shortest table 4.4 on the next page matches the four usability factors against important work practices and work aspects from the affinity diagram in which safety was seen as the most important usability factor. The second most important factor is marked by a small x too. Most often covered here was effectiveness, followed by efficiency.

Additive table 4.5 on page 63 matches the principles of the ZF PS – presented in section 1.1 on pages 9–10 – against the four usability factors effectiveness, efficiency, satisfaction, and safety. Coverage of all four factors can be seen.

At this abstract level, unsurprisingly, the only result can be that all four factors effectiveness, efficiency, satisfaction, and safety are important in a production context and that thus a newly introduced mobile solution has to improve in – if possible – all four factors. Details depend on the work task which should be supported.
Table 4.3: Affinity diagram contents matched against the usability factors, satisfaction being most important.

<table>
<thead>
<tr>
<th>Work practice or work aspect</th>
<th>effectiveness</th>
<th>efficiency</th>
<th>satisfaction</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparency and understanding of the work status in other process steps is missing</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need immediate feedback from the system</td>
<td></td>
<td>x</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ergonomics are important for my work</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need a calm/quiet environment to work</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I and my co-workers work differently with the same process</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I want to work independently, I’m a human, not a machine</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT systems need to be fast and reliable</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>My user interface needs to be consistent</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need a dedicated input device (keyboard) for my work, touch input for texts does not work well</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teamwork and trust are important</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4: Affinity diagram contents matched against the usability factors, safety being most important.

<table>
<thead>
<tr>
<th>Work practice or work aspect</th>
<th>effectiveness</th>
<th>efficiency</th>
<th>satisfaction</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>I use various chemicals for my work</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I need ruggedized equipment in my work environment</td>
<td></td>
<td>x</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>I wear gloves for my work, which get dirty</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For every assembled part there is a detailed set of documentation available</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I rely on color coding for my work, but it is not used to its full potential</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety is very important (many fork lifters)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

62
Table 4.5: A match of the ZF PS principles against the usability factors.

<table>
<thead>
<tr>
<th>ZF PS principle</th>
<th>effectiveness</th>
<th>efficiency</th>
<th>satisfaction</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee and team orientation</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process orientation in client and supplier relations</td>
<td>x</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standardization and flexibility</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Just in time</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero mistakes</td>
<td>X</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Innovation and KVP</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To flesh out the rather abstract usability requirements presented in table 4.1 on page 60 to table 4.5, and to give an idea how the mentioned improvement could be defined, achieved, and measured, the following subsections give exemplarily concrete usability requirements.

### 4.2.2 Performance Style

- Scanning of a datamatrix code, bar code, or QR code containing a serial number by any assembly worker for the assembly journal must not take longer than three seconds on average.
  
  *Trials showed that copying a six to eight digit number takes a little more than three seconds. Thus to be faster than writing down serial numbers by hand scanning must not take longer than three seconds.*

- Marking a kanban card as missing via the system must not take longer than one minute.
  
  *A rather short time was chosen to eliminate the need for otherwise faster but more disturbing phone calls to colleagues. The exact number would need to be defined by tests.*

- Doing (temporal) calculations in the software is as fast as doing them manually.
  
  *Usually written calculations are done either in the head, with a calculator, or on paper, on the workbench, or on any other additive that can be written on. To motivate people to use a mobile solution it must work at least as fast as doing it in another way.*

- The system used during assembly must be learnable by its users in at most a week.
  
  *Learning how to assemble a power train takes about one to two weeks. By the trime the assembly operators have learned their principal duty, they must know how to use the supportive IT systems as well.*

- Switching from the main process to housekeeping tasks like preparing material and other side tasks does not take more than two interaction commands and not longer than one second.
Flexibility is key, often the employees have to react to circumstances like missing material or waiting for tools and thus work on side tasks like tidying up the assembly area or filling up material. Such sudden work breaks and task switches must be supported by a mobile solution without losing more time. Thus a short time of one second was chosen.

- Logging in must not take longer than two seconds.
  For security reasons devices are locked after 15 minutes of inactivity. As users must thus log themselves in very frequently it must be possible using a convenient method that works fast.

- The application must show the assembly operator the direct and fastest path to material.
  Much time is lost by manual searching for material if the delivery space is too big or not used correctly. A supporting mobile solution could help save time if it directs the assembly operator to the needed material.

4.2.3 Defect Style

- A notification about important information from the regular group meetings must never be overlooked.
  All employees must know the information distributed in the group meetings, thus never was chosen.

- A colleague marked as “free” must always be seen more prominently than “non-free” colleagues from the same department.
  Coworkers are regularly contacted for example to get information about deliveries from other plants. Employees with a presence status of “free” will thus always be preferred for contact.

- The users are always aware of the version of a document they edit and can clearly state if there is a newer version.
  Versioning of documents is very important, normally only the newest version is needed but in rare cases an older version might be needed. Efficient steps must be taken to avoid using an old version by accident if there is a newer one.

- Scanning of a datamatrix code, bar code, or QR code has to work in 75% of all cases on the first try, only 25% of the tries may lead to an inconvenience.
  During the CI it could be seen that scanning often worked only in every second try. To increase usability the target percentage was increased. Problems were categorized according to severity, “inconvenience” for this task would mean that scanning only worked for example after cleaning the code. Tests have to show if the new targets are reasonable.

- Task failures in scanning of a datamatrix code, bar code, or QR code must not happen more than once in 100 scans.
  The severity category “task failure” would mean for this task that a code cannot be scanned within two minutes, even after it has been cleaned, enough lightning is provided, and so on. Workers will then have to copy the number manually. The CI showed that task failures for scanning rarely
occurred. Depending on the exact working task, around hundred scans would result in one assembly journal if detailed assembly documentation is taken, or one working day. One scan failure per day was believed to be acceptable.

- After introducing a mobile e-kanban solution not more than two kanban cards are missing per month. Currently a lot of work and time is spent on keeping the process reliable and still on average one kanban card per week goes missing. Supporting the kanban process better by IT, it seems realistic to be able to halve the number of missing cards, resulting in higher efficiency as well.

- Efficiency problems using the IT system may only arise for not more than 10% of the users. System usage is only a sporadic but recurring task for many employees. Even if only little time is spent using mobile solutions, the low number of defects of 10% was chosen since the usage is repetitive.

4.2.4 Process Style

- In the software process known as “Solution Development”, at least two iterations of prototyping for the GUI must be done, as well as correcting major usability issues found during a heuristical evaluation of the final solution. At ZF a waterfall-based IT project model is used. Two iterations of prototyping were specified to allow the finding of key usability problems during development of the GUI. A heuristic evaluation is suggested as an easy and cheap way to find usability issues.

- Using the agile software development process, each development of a user story touching HCI must be based on at least one usability tested prototype. By requiring at least one prototype for each software component visible to the user, major problems should be found. It is therefore obviously important that the prototype gets user-tested.

- If a mobile software solution is purchased, the supplier has to guarantee that at least two rounds of usability tests were conducted during the development to improve the application. Even if the solution is not developed by ZF, it can be required that usability techniques be used.

- The ZF usability compendium has to be used. The ZF usability compendium was created by Lasinger (2014) as part of her master’s thesis to provide a code of practice about the topic usability during IT projects at ZF. It gives an overview about usability, and how to achieve high usability using appropriate methods at different stages of the IT project management.

- During the software development process, all manual documentation must be investigated during the analysis phase and whenever possible all documentation should be automatized and digitized in the new system.
As manual documentation regularly leads to errors, it should be replaced wherever possible by a system-supported solution.

- If the requirements analysis of an IT project reveals that additives are used to gather or use data that flows to or from the IT system, the availability of digital additives offering data exchange interfaces to the IT system has to be checked and their usability has to be compared to using the manual additives.

  It was found that lots of different tools are used from which measurements often have to be copied manually to the documentation. Using integrated solutions the usability can be increased.

4.2.5 Subjective Style

- Not less than 90% of the employees using the digital assembly documentation must recommend the user input check, if asked. The workers observed during the CI all liked the system support by input checking. A new system should thus achieve a high level of satisfaction among its users, like 90%.

- At least 80% of the assembly operators must recommend to their colleagues scanning the serial numbers instead of typing them manually, if asked. Entering serial numbers is a major documentation task for assembling. A high acceptance is important for wide use the system, which is intended to prevent input errors.

- A minimum of 90% of the workers inspecting fire protection flaps must find the system intuitive and helpful. The inspection work relies heavily on a mobile solution which every inspector uses extensively. Bad usability in a system with such high usage would affect work performance massively.

- The user feedback mechanism of a mobile solution must be rated by more than half its users as good or very good on a scale very bad, bad, average, good, and very good. A finding from the CD process revealed that immediate feedback from IT systems is very important for the users. If the majority of the users perceives no or unhelpful feedback, the system will not be used.

- Buying a navigation system to support the production tools and resources supply drivers, the tendering parties must reveal satisfaction statistics for their solutions and these must be taken into account in the decision for choosing a system. Even if a system is not developed in-house, the satisfaction level can be used to choose a better system. To compare the satisfaction of different systems, standardized tools like the system usability scale (SUS) by Brooke (1996) can be used.

- The mobile solution must offer a user input method preferred by more than half of the users. While for some task touch input was deemed acceptable, it was found that especially for input of longer numbers and texts, users preferred a physical keyboard. If a clear priority in a input method for a specified task can be found, it should be used.
• More than three-quarter of the users of a mobile solution must state that they feel safe using it and do not get distracted by it, if asked. Safety was found to be an important aspect of the work practice and of the usability of systems in such contexts as well. It is believed that a high perceived level of safety in using a system is key for its acceptance.

4.2.6 Design Style

• The new mobile application must include the function of reporting errors in the application as shown in the screen shot in figure 4.34 on the next page. The shown functionality has proved to be a good tool to get to know not only about erroneous data, but also about usability problems. It was thus decided to add it to all future mobile applications.

• A mobile device being purchased must fit into one of the protection casings chosen by ZF. Physical robustness was found to be very important. ZF decided to offer a range of protection cases for smart phones and tablets to conform with the need for resistant devices.

• The application to be developed externally must implement the GUI based on the sketches and prototypes provided by the ZF IT department. A possible solution is to enrich the requirements delivered to an external company and make sure that usability-tested material is used if development does not take place at ZF.

• The start screen of the mobile solution for the assembly worker must pattern the layout of the planning board for the registered user. Visualization at the planning board is mentioned by the assembly operators as being important. To increase consistency and to support encoding by place and color, the GUI should aim for a similar layout as the physical planning boards in the production hall.

4.2.7 Guideline Style

• A mobile application must meet the design guidelines for the respective platform. The guidelines should help to keep the applications consistent, increasing the usability. An example is the Android Style Guide by Google for Android devices.

• The application must use the colors and use them as intended as defined in the ZF corporate design guidelines. The ZF corporate design guidelines specify a set of diverse colors and how to use them based on principles of human perception. The usage will thus help to fulfill basic usability requirements.
4.3 Design Concepts

The following design concepts reflect key principles derived from the data presented above to support implementation of mobile solutions with high usability. Examples are given for each principle in order to understand it better. The sketches were created by various colleagues from IT without a professional background in usability or the work practice investigated. The sketches were developed in the workshop described in section 3.3 on pages 29–30 and their aspects aligned to the respective design concept are highlighted to point out potential ways to implement the design concept.

4.3.1 Easy Learning & Expert Performance

The users learn their work practice within days or a few weeks. They must learn new mobile solutions even faster.

The users know their tasks thoroughly; they are experts in their work. Mobile solutions must be tailored for experts, delivering the greatest performance to them.

Exemplary concrete examples of how to follow this principle are:

- A first usage introduction for an application to support learning of a new application by first time users.
While a list menu showing available data items will support novice users, offering direct data input in addition will increase speed for expert users who know what data items they want to enter.

During the workshop colleagues sketched an indoor navigation and route planning solution using “intelligent parts” to support the delivery of parts at the shop floor halls. The idea was developed because of the waste of time due to inefficient walking and routing, and because of errors due to moved kanban stations in the halls. The users according to the personas presented in subsection 4.1.4 on pages 54–59 were defined as the warehouse man and supply driver Horst Maier and the holiday worker Stefanie Hauser. The task supported is refilling kanban stations from the truck in the context of production tools and resources supply. The mobile solution will also support the ZF PS principles “just in time” and “zero mistakes”. Kanban stations will be equipped with sensors, thus their positions are known. The delivered parts and the storage areas on the truck will also be equipped with sensors so as to be able to give information about which part from the truck lying in which storage area needs to be delivered to which kanban station. The driver can thus get an optimized route for delivery as shown in the upper sketch of a smart phone application in figure 4.35 on the following page. In addition a GUI for smart glasses has been sketched. The bottom part of figure 4.35 on the next page shows a potential routing information on the left hand side and on the right hand side what a highlighting of material and storage areas could look like. By highlighting the places and parts, errors will be minimized as the user sees which part from where on the truck should be put in which place of the current kanban station. Well known principles from widely used private applications, like route navigation, will be transferred to business applications, thus making sure that an application can be learned easily. The user interface is supposed to be minimalistic, for example by only highlighting one material at a time, easing the learning further. Due to doing without nearly all user input by using information provided by different sensors a high expert performance is achieved.

4.3.2 User Control & Guidance

The users are individual human beings and they want to stay in control over their equipment. Mobile solutions must let the users stay in control and support their preferred practices.

The users know that they make mistakes. They demand support and guidance from a mobile solution, to keep them on the right track – without imposing the system’s will on them.

Examples how to achieve user control and guidance include:

- Using the software wizard paradigm to guide users through a sequence of steps, such as filling in an assembly journal, can deliver a feeling of guidance and ensure following the rules of the underlying business process. User control can be increased in such a system through letting the user decide on the order of steps as far as possible by the supported business process.
The observed assembly operators liked checking their user input for validity to minimize the risks of errors.

A mobile training application for holiday workers and new employees was sketched in the workshop. The unfulfilled need of special information for new employees and the current practice of carrying around a lot of physical documents were identified as the main problems to solve. From all the personas, the holiday worker Stefanie Hauser as well as assembly operators even newer than Anton Jung were identified as the main users. The application would be used in the context of assembly lines to fulfill the task of supporting training by guidance videos and a digitized and interactive assembly handbook provided on a tablet as shown in the sketches in figure 4.36 on the facing page and 4.37 on the next page. The solution should be context-aware by offering learning material relevant for the workplace the tablet is currently located in. The user nevertheless can access learning material for other stations as well, to keep the user in control. Guidance of the user happens by offering typical tasks most prominent and offering a frequently asked questions (FAQ) section. The help button in the top right corner would call an experienced stand-by man to offer further help by a human being, giving the user the feeling of safety that they are not at the mercy of a technical device. “Employee and team orientation” is the ZF PS principle supported most by this mobile solution.

4.3.3 Peripheral Attention & Unobtrusiveness

A shop floor is a dangerous environment, making only little attention available for mobile solutions. The system must support selective interaction and limited concentration.

The users have an important task to achieve. Mobile solutions must
Figure 4.36: A sketch of a mobile training system on a small tablet that could be worn on the users arm.

Figure 4.37: Another sketch of a training application guiding the user by highlighting most important work steps.
not hinder them, but stay discreetly in the background and only come into focus when needed.

This design concept can be supported, for example, by following aspects:

- Remembering the current screen or position in an application (if the device is not used for a while) helps users to find their way back to the point where they have left it.

- Systems mounted in a fork lifter should turn off the screen while the fork lifter is moving to prevent from being distracting the driver. Simple notifications can in the meantime be given in other modalities e.g. via audio.

- As currently no hands-free IT system is being used to support provisioning, the idea of optimizing inbound logistics using augmented reality with smart glasses and smart watches or wrist bands was sketched during the workshop. In the context of the warehouse and assembly halls the task of provisioning parts for assembly lines by the warehouse man and supply driver Horst Maier and the holiday worker Stefanie Hauser should be supported by that mobile solution. From the ZF PS principles “zero mistakes” was chosen as most in need of support. As seen in the top left of figure 4.38, while looking through the glasses, the material or the stock ground at the warehouse to be commissioned get highlighted. On the truck used to deliver the material, the storage area is highlighted as is seen in the bottom left part of the same figure. Additional information will be displayed on the watch interface. The sketch on the right hand side of figure 4.38 shows the material to be picked (e.g. @ screws) in the center, below the amount to be picked (three out of four already commissioned), above the location to take it from (box 7), and in the outer circle the work progress of the total commission order. To keep the system unobtrusive, a see through solution using smart glasses was used to only highlight necessary information. Peripheral attention is possible by using vibration feedback on the watch or wrist band if a material has been misplaced.

Figure 4.38: Sketches for an unobtrusive interface using augmented reality to support commission tasks.
4.3.4 Robustness & Resilience

The industrial context is harsh and the users' work is tough. Heavy-duty mobile solutions, usable with protective equipment are needed.

Equipment is missing, an untrained worker stands in for a sick colleague, and stuff got moved. Each day is different; mobile solutions must nevertheless work as usual.

Example solutions offering robust and resilient aspects cover:

- Robust casings and fall back for network connections (by using various networks such as WLAN and mobile networks) offer a stable system to be used in a production hall to transfer data in real time.

- Additional explanations, help texts, and the possibility to log in with any ZF user account can ensure that even a holiday worker can use a system normally used by another more experienced worker.

- Taking the artifact model showing two cable-based bar code scanners (cf. figure 4.20 on page 49) as an inspiration, in the workshop a wireless, all-in-one-code scanner with local asynchronous data transmission was envisioned. Out of the personas presented in subsection 4.1.4 on pages 54–59 the assembly operators Anton Jung and Peter Alt, the holiday worker Stefanie Hauser, and for rare occasions the foreman Heinz Bank were chosen as users to use the device in the context of assembly halls to conduct their task of scanning parts, before assembling them, to provide traceability. The device sketched in figure 4.39 on the next page is a smart phone with a scanner attached pointing to the front and worn attached to the user’s arm. Scanning is activated by tilting the arm or any other gesture that is otherwise not used during assembly. A casing provides robustness and deployment of a spare device was suggested to increase resilience. Different ways of authentication were sketched, including using a smart watch as a near field communication (NFC) tag, equipping the employees batch with a NFC tag, using iris scan of the user, or entering a pin code, making the authentication process resilient. Flexibility in conducting a task is ensured by showing all possible work steps in the bottom of the GUI. This idea was connected to the ZF PS principle of “innovation and KVP”.

4.3.5 Holistic Solution & Background Information

The users work in a process-orientated way. Isolated applications are no help. A continuous, networked, and broad support by mobile solutions is needed.

Users sometimes need additional knowledge and have further inquiries. Mobile solutions must support documents, communication, and more to deliver the needed information.

Exemplary ways to apply this design concept are for example:

- Includeing hall maps to look up the position of fire protection flaps in the mobile application used by the inspection employees and providing
assembly drawings to the digital assembly journal to be able to look up additional details if needed.

- If a digital assembly journal is introduced, the pre-assembly and closing testing have to be included in the conception of the mobile solution to prevent media gaps between the different process steps.

- As teamwork is important and (informal) communication is key, during the workshop a team chat with voice recognition realized as a smart watch application was sketched. Focusing the ZF PS principles of “employee and team orientation”, and “just in time” as well, its aim should be to lower the barrier to document knowledge. In the context of assembly lines the mobile solution should fulfill the task of supporting communication and recording communication history for better knowledge management by the assembly operators Anton Jung and Peter Alt, and the foreman Heinz Bank. The work processes, work places, work tasks, and employees working are known by the work plan as sketched in the center of figure 4.40 on the facing page. This information should be used to dynamically add all concerned employees to a team chat. Fork lifters passing by different work places (sketched on the right hand side in figure 4.40 on the next page) could dynamically be added and removed as well, using their location data collected by sensors. The smart watch interface was designed to work by voice input and transcribing the messages in real time, to display them on the smart watch. A search function was planned too. The solution should be networked between different plants, so that for example in case of quality problems it would be easier to find the root cause.
4.4 Case Study

The CI preparation worked out as described in the literature. An introductory guideline as presented by Holtzblatt et al. (2004, p. 74) was created and successfully used to structure the introduction. Fewer people per work task than suggested by the literature were interviewed to be able to investigate a broader picture of work practices within the production context while meeting time constraints. As a result the formal introduction talk was only sometimes given, when more than one person of the same department was observed. Otherwise the workers being interviewed were introduced individually to the method right at the beginning of the CI.

Interviewing only internal colleagues made the preparation easier as the willingness to help was at a high level. On the other hand the size of the company made it harder as processes were complex and many stakeholders, including the workers’ council, were involved. But the preparation phase was not influenced by the production context itself.

The industrial context created the need to wear special safety shoes for some observations. While this did not directly influence the CI process, it was an additional point to watch out for while planning the CD process.

Due to regulations by the workers’ council it was not allowed to do audio recordings as a back-up to the written notes. But even if it had been allowed, in some of the interviews it would have been impossible as the production context in an industrial shop floor can be rather loud. It was thus necessary to rely on the written notes and come back to the person if necessary for follow-up questions. The dependence on the context in the CD process can be seen as a downside for these cases.

Conducting the CIs was influenced by the production context more strongly time-wise. Holtzblatt et al. (2004, p. 83) suggest about two hours for one CI. Much shorter is said to make no sense as not enough understanding of the work practice can be gained, whereas much longer is too exhausting. Although work processes were not “extremely long” as described by Holtzblatt et al. (2004, p. 70), they sometimes took longer than two hours. Looking at different stages of the process as suggested by Holtzblatt et al. (2004, p. 70) worked only after
an initial overview was gained by following one process in its entirely to identify interesting tasks. It can in general be stated that the percentage of work tasks interesting for the focus of this project compared to the total amount of work was smaller than in most of the example projects by Holtzblatt et al., (2004). Much time was, for example, spent on driving during delivery or manual assembly tasks of a group spur driver, which will not be influenced by mobile solutions in the near future. Some contextual interviews were thus much longer and others much shorter than two hours. One benefit of the CD process was the flexibility to support (unstructured) interviews of different length.

The work was in many cases much more focused on manual tools like drills, screwdrivers, induction heaters, or calipers, than on digital tools, paper forms, data handling, and operating existing IT systems. While the former tools might also be relevant up to a certain degree for future mobile solutions – thinking about concepts like Internet of Things (IoT) or industry 4.0 – more focus during this analysis has laid on the latter. As a result the instructions given in literature on how to structure artifact diagrams had to be handled more openly. As an example, for an induction heater the questions of structure, annotations, its presentation, and current breakdowns were not (that) relevant. Nevertheless it was believed to be a very important artifact, as it emits magnetic waves which can influence electronic devices, and thus future mobile solutions as well. The layout of some artifact models thus does not match the layout suggested by Beyer & Holtzblatt (1998, p. 105).

No influence on the physical models was found to come from the production context.

The data was translated from German to English during interpretation of the CI notes to convert them to affinity notes. The translation was necessary as the interviews were conducted with German-speaking colleagues, but this thesis is written in English. The industrial environment had no influence, except that it shaped the vocabulary used.

The affinity diagram contained about 370 affinity notes, developed from field interviews with eleven people. The number of notes does not match the suggested 550 to 1100 notes for eleven interviews (Holtzblatt et al. 2004, p. 161), but the reason for this outcome is unknown. Nothing indicates that the production context is the reason for the low number of affinity notes. A rivaling theory is, having less experience in the CI method and in interpreting the interviews led to collecting fewer notes.

The greatest advantage of the CD process was gaining a deep understanding of the context, a context which is very different to the office environment of software developers and widely unknown by them.
Chapter 5

Analysis and Discussion

5.1 Contextual Design Process

The goal of the CD process was to gather data for usability requirements and design concepts for mobile solutions in a production context by investigating work in such a context. The results collected by the CD fit into the findings of existing literature covering work in comparable contexts as described in section 2.1 on pages 15–21.

The mobile solution used by the employees to document the inspection of fire protection flaps focused on bridging the physical and digital world as described by Nilsson et al. (2000) and Bowden (2005). The goal was easing the transition between physical inspection and digital documentation, and bringing digital objects or information into their physical location of context (cf. Kondratova 2004, Bowden 2005, Stiefmeier et al. 2008).

Locating material (cf. Huang et al. 2008) and navigation tasks (cf. Emmanouilidis et al. 2009) were recurring tasks observed during power train assembly, as well as production tools and resources supply.

The loss, or fear of damaging, assembly journals as described by Huang et al. (2007) and Qu et al. (2012) could be identified in the current project too.

As can be found in the affinity diagram in appendix A on pages 95–97, missing transparency and understanding of the work status in other process steps and the importance of informal communication was an important topic, also well covered in literature (cf. Nilsson et al. 2000, Davis 2002, Qu et al. 2012).

The need for flexibility in the production context at ZF arose out of two factors, both mentioned in literature. On the one hand, each employee prefers to do their work in a different way, as for example Nilsson et al. (2000) pointed out with respect to operators’ diverse approaches to attention. On the other hand, was it necessary to react to unpredictable changes in the work flow as described by Qu et al. (2012).

As described in section 3.2 on pages 27–29 safety was added to the usability factors as it was found to be an important aspect in an industrial context. The affinity notes relating most strongly to safety, presented in table 4.4 on page 62, substantiate this perspective. That mobile solutions can play a role in improving health and safety of workers has been mentioned in the literature, for
example by Efstratiou et al. (2007) deploying mobile sensors to monitor hand arm vibration.

The importance of saving time and costs maintaining a short ROI was not only found in the literature (cf. Stanford 2002, Bowden 2005, Huang et al. 2007, Maurtua et al. 2007, Huang et al. 2008, Emmanouilidis et al. 2009, Qu et al. 2012) but also in the conducted CD process, as for example is shown by the major topic of time and efficiency in the affinity diagram presented in appendix A on pages 95-97.

While it obviously increases credibility of the data from a scientific perspective, the main outcome of the conducted CD process was not solely to reinforce important aspects of work in an industrial context already described elsewhere. In fact delivering a holistic understanding of the concrete work context and drawing out specific examples of usability issues from work happening in a production context at ZF was very valuable. The knowledge gained will improve the developers' understanding of the users and their work tasks and context. Trust in the information will be high as it is rooted in the company.

Curiosity quickly spread among the IT colleagues when the affinity diagram and work models were put up on the office walls, as they were very visible and the CD method and content were unknown to the team. The visibility helped me to engage in informal discussions with interested colleagues, to inform them about the findings of the CI, thus raising awareness of usability as a topic.

The CIs conducted delivered valuable data. The availability of Holtzblatt et al. (2004) as a way of presenting practical recommendations was very helpful. Nevertheless, it was difficult in the beginning to set a clear focus for the CI process, as Vilpola et al. (2006) experienced as well, and later on it was often still hard to know what to look out for, and what to collect to maintain the set focus. The usefulness of the collected information was sometimes revealed only later on, as described by McDonald et al. (2006) too. More experience in conducting the CD process would have improved the execution.

In addition, as this was a thesis project, almost the complete process was carried out alone, whereas a team with a diverse background would have provided additional valuable perspectives (cf. Fouskas et al. 2002).

Contrary to what was the experience by Fouskas et al. (2002), the interviewed colleagues were all very eager to participate in the contextual observations and to explain their work. The CI even repeatedly created expectations among the interviewed employees that a new mobile solution would be implemented soon to improve their work practices as a result of the project.

The affinity diagram was a great help in providing structured data for the usability requirements and design concepts, although the categorization often seemed partly artificial and a little arbitrary. Then again, the possible ambiguity of the clusters is already mentioned by Holtzblatt et al. (2004, p. 165), who argued that one should not worry about getting the “right” affinity diagram.

The artifact and physical models supported the presentation of the findings especially well, providing a vivid description of the work practice in addition to the textual affinity diagram.

The personas could easily be derived from the collected data. Depending on future usage, additional personas might need to be created in order to include all involved users. The current set of personas as presented in subsection 4.1.4 on pages 54-59 was kept small to provide an overview of the users who participated most.
The subsequent usage of the data affected the CD process. It defined how the CI was conducted with different work practices, and specified the focus for the CI. It also determined which methods of the CD process were used, especially making it possible to skip the later design phases. Nevertheless the CD methodology worked out well and can be recommended for such a project.

5.2 Usability Requirements & Design Concepts

The results of the CD process served as input for the usability requirements and design concepts.

The step of generalizing from the concrete findings of the CI which were only valid for the observed work practices to usability requirements effective for the complete production context was seen to be especially difficult. Finally the two step approach to first compile the most important usability factors from the affinity notes, and then giving examples in six different styles seemed to fulfill the purpose best. The explanations to the examples to understand how they were derived and how similar usability requirements should be formulated are believed to be core aspects of the usability requirements and very important for future projects.

Narrowing down the huge set of data to a limited set of design concepts which would be useful in practice was another challenge. On the one hand the principles needed to be generic enough to fit as many projects in a production context as possible. On the other hand grounding in the context was very important to prevent them from being generic HCI principles, believed to be followed in each project anyway as being formulated very abstract. The examples quoted for each design concept, specially the comprehensive ideas and prototypes developed during the workshop, will facilitate the provision of a good understanding of the idea behind each principle and how it needs to be implemented in such a context in order to deliver a mobile solution with high usability.

An additional data source using a different methodology could have served well in providing more input for formulating the design concepts. A lack of available literature in describing how to scientifically ground and formulate design concepts was evident. Much existing literature is solely based on the individual experience of the researchers, for example Molich & Nielsen stated how they developed their initial version of the (later revised) ten usability heuristics by Nielsen (1995): “This checklist reflects our personal experience.” (Molich & Nielsen 1990, p. 339).

Thus further research in how to develop design concepts, in addition to using the experience of the researcher, is suggested for improving scientific validity and reliability, as well as the practical usefulness of prospective design principles.

As the tables 4.1 on page 60 to 4.4 on page 62 (matching the work practice to the usability factors) show, the various usability factors are of different importance for different tasks. Existing research suggests that the correlation between the usability factors: effectiveness, efficiency, satisfaction, and safety (in this special context), is weak (cf. Frøkjær et al. 2000). This stresses the importance of always keeping all four aspects in mind when a new system is developed to achieve a solution providing high usability.
5.3 Case Study

It is important to note that the focus of the current thesis was not to (re)design one (new) system – which is normally the reason why a CD process is used, according to the literature (cf. examples given by Holtzblatt et al. 2004). Nevertheless Norman (1983) suggested more than 30 years ago that a UCD process should be used to develop design principles for human-computer interfaces. Similarly, the goal of this thesis was to gather usability requirements and to formulate design principles for mobile solutions in a production context. Thus the later tools, visioning and storyboarding, presented by Holtzblatt et al. (2004) were not used; instead other methods as described in section 3.2 on pages 27–29 and section 3.3 on pages 29–30 were needed.

Keeping the above aspect in mind, the case study did not reveal major problems using the CD methodology in an industrial production context. The tools: CI, interpretation and work modeling, affinity diagrams, and personas, proved to be a good approach of the CD process for collecting and analyzing user data, as case studies in other contexts showed as well (cf. the previous research presented in section 2.1 on pages 15–21).

Collecting artifacts for the case study worked out well as the CD process already involved collecting a lot of artifacts. It would have been additionally beneficial to involve more people in conducting the CIs in order to interview them afterwards with respect to the case study. Especially if these people had experience from conducting previous CD projects in different contexts, this could have provided more interesting data.

The case study was conducted successfully and is believed to be a good methodology to add another perspective to the evaluation of a method used in a research project.

5.4 Conclusion and Outlook

The CD process gave an in depth overview of work practice in the production context at ZF, revealing key aspects of work tasks and breakdowns in the use of current IT systems. Important usability requirements for mobile solutions were derived and design concepts for mobile solutions were developed. The case study confirmed the applicability of CD in an industrial production context.

The five design concepts: easy learning and expert performance, user control and guidance, peripheral attention and unobtrusiveness, robustness and resilience, and holistic solution and background information were derived and elaborated by sketched examples out of the production context.

Open points in the current context include

- a complete implementation of a mobile solution following the outlined usability requirements and design concepts, and
- a usability test of such a IT system should be conducted, evaluating the design concepts.

Further research developing a set of scientific methods for formulating design principles seems needed.

Beyond the scope of this thesis, but still very important, is the question how the increased usage of mobile solutions will reshape the work and what
consequences this will have for the employees. Bowden et al. (2006, p 674) conclude that the introduction of technology will require very different skills from the users. Further research needs to be conducted to identify chances and risks of such change in a production context.
Bibliography

URL: https://developer.android.com/design/get-started/principles.html


URL: http://ac.els-cdn.com/S0926580505001263/1-s2.0-S0926580505001263-main.pdf?_tid=64415884-f7a0-11e3-8479-00000acbc362&acdnat=1403175580_7ef65aa09c02acfe30b9a2ccf2001b74
URL: https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/794/3/SarahBowden.pdf


URL: http://www.usabilitynet.org/trump/documents/Suschapt.doc


Canonical (n.d.), ‘Design vision | Ubuntu Design’. 
URL: http://design.ubuntu.com/apps/get-started/design-vision

Cooper, A. (1999), The inmates are running the asylum: Why high-tech products drive us crazy and how to restore the sanity, Vol. 261, Sams Indianapolis.


URL: https://www.uio.no/studier/emner/matnat/ifi/INF5500/h07/undervisningsmateriale/ISJ_case_study.pdf

URL: http://delivery.acm.org/10.1145/590000/585617/p67-davis.pdf?ip=130.238.7.41&id=585617&acc=ACTIVE%20SERVICE&key=747687761D7AE37.DA50417A8F734F4C.4D4702B0C3E38B35.4D4702B0C3E38B35&CFID=359865378&CFTOKEN=55307639&__acm__=1403176393_666eeb9aa627952879c8f7328f90c184

URL: http://iwc.oxfordjournals.org/content/16/1/29.full.pdf


URL: https://www.usenix.org/legacy/events/mobisys07/full_papers/p127.pdf

84


URL: http://download.springer.com/static/pdf/321/art%253A10.1007%252Fs10845-008-0121-5.pdf?auth66=1403358901_9bb2d62c413f62f7663f07288fda6b0c&utm_ext=.pdf


URL: http://delivery.acm.org/10.1145/1300000/1292358/a24-hakkila.pdf?ip=130.238.7.41&id=1292358&acc=ACTIVE%20SERVICE&key=74F7687761D7AE37.DA50417A8F734F4C.4D4702B0C3E38B35.4D4702B0C3E38B35&CFID=359865378&CFTOKEN=55307639&__acm__=1403186619_2986cccd34aacecc8c360ed445b21a1f7

IDC (2013), ‘Worldwide Mobile Phone Market Forecast to Grow 7.3% in 2013 Driven by 1 Billion Smartphone Shipments, According to IDC’.
URL: http://www.idc.com/getdoc.jsp?containerId=prUS24302813


URL: nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?action=rtdoc&an=8914359

URL: http://greenlab1.roma2.infn.it/hcied2008/content/documents/HCIEd2006_larusdottir.pdf

URL: www.researchgate.net/publication/221552276_Six_Styles_for_Usability_Requirements/file/e0b4952568e2003dac.pdf

URL: www.researchgate.net/publication/228763589_A_Wearable_Computing_Prototype_for_supporting_training_activities_in_Automotive_Production/file/d912f50a3602bafbdd.pdf

URL: www.researchgate.net/publication/221248102_Modified_contextual_design_as_a_field_evaluation_method/file/d912f505c3d11834aa.pdf

URL: http://www.ft.com/intl/cms/s/2/d96e3bd8-33ca-11e0-b1ed-00144feabd0.html#axzz1DQNdT4kR

Microsoft (n.d.a), ‘Design principles (Windows Phone Dev Center)’.
URL: http://dev.windowsphone.com/en-us/design/principles


URL: http://heb.freeshell.org/ie662/Molich_Nielsen.pdf


Nielsen, J. (2013), Usability Engineering, Morgan Kaufmann.

URL: http://www.nngroup.com/articles/ten-usability-heuristics/


87


URL: [dlib.anu.edu.au/dlib/july05/khoo/07_notess.pdf](dlib.anu.edu.au/dlib/july05/khoo/07_notess.pdf)


URL: [http://googleblog.blogspot.de/2014/03/sharing-whats-up-our-sleeve-android.html](http://googleblog.blogspot.de/2014/03/sharing-whats-up-our-sleeve-android.html)


URL: [http://delivery.acm.org/10.1145/230000/227615/p1-raven.pdf?ip=130.238.7.41&aid=227615&acc=ACTIVE%20SERVICE&key=74f7687761d7a3e7.d4a50417abf734f4c.4d4f72bce3e8b5.4d4f72bce3e8b3&CFID=482008826&CFTOKEN=20647484&__acm__=1403260329_41d501152cfa83f45e656fcca7408420](http://delivery.acm.org/10.1145/230000/227615/p1-raven.pdf?ip=130.238.7.41&aid=227615&acc=ACTIVE%20SERVICE&key=74f7687761d7a3e7.d4a50417abf734f4c.4d4f72bce3e8b5.4d4f72bce3e8b3&CFID=482008826&CFTOKEN=20647484&__acm__=1403260329_41d501152cfa83f45e656fcca7408420)


List of Figures

4.1 Affinity diagram .................................................. 35
4.2 Artifact noise list .................................................. 36
4.3 Artifact color coding of kanban station ......................... 37
4.4 Artifact material boxes .......................................... 37
4.5 Artifact documentation of material to be picked up ............ 38
4.6 Artifact hall layout .............................................. 39
4.7 Artifact kanban shelf ............................................. 39
4.8 Artifact contacts list ............................................. 40
4.9 Artifact kanban material with kanban card ...................... 40
4.10 Artifact truck ..................................................... 41
4.11 Artifact axis check list ......................................... 42
4.12 Artifact bill of materials ........................................ 42
4.13 Artifact drawings ................................................ 43
4.14 Artifact preassembly journal ................................... 44
4.15 Artifact induction heater ...................................... 45
4.16 Artifact missing times report .................................. 45
4.17 Artifact assembly journal ...................................... 46
4.18 Artifact assembly guidance .................................... 47
4.19 Artifact cog wheel with datamatrix code ...................... 48
4.20 Artifact scanners ............................................... 49
4.21 Artifact empty assembly journal for wear pattern ............ 49
4.22 Artifact used assembly journal for wear pattern ............. 50
4.23 Artifact rejection tag .......................................... 50
4.24 Physical model floor layout disassembly ....................... 51
4.25 Physical model work bench .................................... 52
4.26 Physical model production hall layout ......................... 53
4.27 Physical model workplace assembly island ..................... 53
4.28 Physical model line assembly layout ......................... 54
4.29 Persona 1: Assembly operator 1 ................................ 54
4.30 Persona 2: Assembly operator 2 ................................ 56
4.31 Persona 3: Warehouse man and supply driver ................. 57
4.32 Persona 4: Holiday worker .................................... 58
4.33 Persona 5: Foreman ............................................ 59
4.34 Screen shot report error function .............................. 68
4.35 Example for design principle easy learning & expert performance 70
4.36 Example 1 for design principle user control & guidance ........ 71
4.37 Example 2 for design principle user control & guidance ........ 71
4.38 Example for design principle peripheral attention & unobtrusiveness 72
4.39 Example for design principle robustness & resilience . . . . . . . 74
4.40 Example for design principle holistic solution & background in-
formation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 75
List of Tables

1.1   Market share of smart phone operating systems                11
4.1   Match of the affinity diagram against usability factor effectiveness most important 60
4.2   Match of the affinity diagram against usability factor efficiency most important 61
4.3   Match of the affinity diagram against usability factor satisfaction most important 62
4.4   Match of the affinity diagram against usability factor safety most important 62
4.5   Match of the ZF PS against usability factors                63
Appendix A

Affinity Diagram

• IT hardware and system
  – My IT systems must be fast, reliable and unobtrusive
    * Scanning (reading) RFID codes works well
    * Scanning bar/QR/data matrix codes takes much time and many
      tries
    * IT systems need to be fast and reliable
    * My user interface needs to be consistent
    * Time (and nerves) are lost by recurrently logging in
  – My IT system makes work easier, it guides and helps
    * I need immediate feedback from the system
    * I like system support by checking my user input
  – My hardware must be industry ready and durable/resistant
    * I use different chemicals for my work
    * I need ruggedized equipment in my work environment
    * I wear gloves for my work which get dirty
    * My systems need to be easy to use, without being tiring or crat-
      ing physical pain
    * I need a dedicated input device (keyboard) for my work, touch
      input for texts does not work well
    * Ergonomics are important for my work
    * Safety is very important (many fork lifters)
    * I need a calm/quiet environment to work

• Communication
  – Formal and informal oral communication is important
    * I get important information in regular group meetings
    * Lots of my communication happens orally and informal
  – Teamwork is and has to be important
    * I need information and help from coworkers (e.g. access rights)
* Teamwork and trust are important
  – I need information and an overview over my and other parts of the process
    * Visualization at the planning board (overview) is important for my work
    * Transparency and understanding of the work status in other process steps is missing

• Time/Efficiency
  – I spend a lot of time on side tasks
    * I need to search manually for my material
    * I spend much time transporting physical documents
    * A lot of work/time is spent on keeping the process reliable
  – Efficiency is key for my work
    * Work has to happen time efficient
  – I need to wait as I depend on other peoples work
    * I have to wait for other processes

• Documentation
  – Our customer is expecting a complete documentation in excellent quality
    * It is very important that the documentation is up to date (changes need to be synchronized)
    * It is crucial that the documentation is kept clean
    * Documentation is multilingual
    * My documents are versioned
    * Errors can happen because of manual documentation
    * Work steps, tools and parts need to be documented (numbers)
    * I use a lot of different tools and have to copy the results (e.g. measurements) to the documentation
  – I need temporary documentation
    * (Temporal) calculations happen in head or with additives
    * I have to write down temporary data that is not relevant in the final documentation
    * I need numbers to identify parts which I have to keep in mind
  – High quality is key
    * I need to authenticate myself, I am responsible for my work
    * Quality control is very important
  – The documentation is important, but not my most frequent task
    * I only sporadically need to read/save data from/to a system

• Work organization
  – Flexibility is an important aspect of my work
* I have to be flexible in my work as I have to react on circumstances and different conditions
  * Flexibility in the process is needed
  * I and my coworkers work differently with the same process
  * I want to work self-dependent, I’m a human, not a machine

– In my daily work, I don’t need a work documentation, but it is important as a fallback and for new employees
  * Work steps are learned by heart within some weeks
  * For every assembled part there is a detailed set of documentation available

– Documentation for my work steps is missing
  * I have to know where to go, as it is not documented
  * I need a lot of informal knowledge for my work that I cannot look up
  * I need to keep in mind what I have loaded, where I have to go next

– I use encodings to organize my work
  * I rely on color coding for my work, but it is not used to its full potential
  * Descriptive numbers are used so that I get the meaning
  * I rely on numbers for material logistics and booking
  * The kanban card is the central element of the logistical process

– A holistic solution is needed
  * The whole process needs to be supported, normally island solutions do not help

– I follow a structured work process
  * My work is following a fixed schedule
  * I regularly have to fulfill infrequent special tasks