Designing Smart Services in Production

MASTER’S THESIS

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STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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ABSTRACT

Smart Services in general and Augmented Reality (AR) in particular will potentially revolutionise industrial workplaces, augmenting the unique cognitive abilities and flexibility of human workers. The company Audi Hungaria Motor Kft. (AHM) identified the opportunity to improve processes in assembly, maintenance or logistics by using AR devices. However, they needed a categorised overview of available technologies and potential use cases and a process to map these in order to be able to design a use case at AHM with maximum benefit.

The purpose of this thesis was to develop a process to justify the benefit of AR use cases in the automotive industry and to map potential use cases with technological products. The use case development methodology used in this thesis is based on Service Design- and Engineering frameworks and specifically focuses on Vorraber et al.'s (2014) use case technology mapping framework. For the first time this framework was refined and validated in an industrial context. Based on presentations of the undertaken review of the current practice and challenges, a use case at AHM was selected, user requirements were identified and an appropriate technology was selected based on process- and financial factors. Finally, strategic risks and opportunities in the multi-party network were analysed based on Vorraber & Vössner's (2011) V^2 Value Network Notation.

Noteworthy achievements could be identified. The review categorised 33 AR devices into wearable-, mobile-, and stationary technologies. 31 potential use cases were categorised based on their application in maintenance, assembly or logistics for assistance, training, monitoring or simulation. Based on these results and identified trends, the use case for maintenance remote consultation was selected for being mapped and evaluated. Interviews and process analysis were undertaken to create an initial use case design and to define 21 specific user requirements. Based on a value benefit- and cost benefit analysis, the Microsoft Hololens was selected for this use case. Users and other stakeholders confirmed that the review helped to identify an ideal use case and that the selected technology meets the user requirements well. The Value Network Analysis showed factors which can improve the implementation of the use case.

The results have a significant relevance and open up several opportunities for future work. The presented review results will make it easier for managers to identify potential use cases and the proposed process will enable an effective mapping of use cases and technologies. For further future work constant renewal of the review and the validation of the proposed process in other companies or industries are proposed.

KURZFASSUNG

Intelligente Dienste im Allgemeinen und Augmented Reality (AR) im Speziellen haben das Potenzial, industrielle Arbeitsplätze zu revolutionieren, indem sie auf den einzigartigen kognitiven Fähigkeiten und der Flexibilität von menschlichen Mitarbeitern aufbauen und diese erweitern. Das Unternehmen Audi Hungaria Motor Kft. (AHM) wollte seine Montage-, Instandhaltungs- und Logistik-Prozesse durch AR Geräte verbessern. Dafür benötigte es eine Übersicht von potenziellen Technologien und Anwendungsfällen und einen Prozess, welcher diese gegenüberstellt, um einen idealen Anwendungsfall zu entwickeln.

Der Zweck dieser Arbeit war die Entwicklung eines Prozesses, um den Nutzen von AR Anwendungsfällen in der Automobilindustrie zu begründen und um potenzielle Anwendungsfälle den technologischen Produkten gegenüberzustellen. Die Methodik zur Entwicklung von Anwendungsfällen, welche dieser Arbeit zugrunde liegt, basiert auf Service Design- und Engineering Frameworks und fokussiert sich auf Vorraber et al.'s (2014) Use Case Technology Mapping Framework. Zum ersten Mal wurde dieses Framework verfeinert und im industriellen Umfeld validiert. Basierend auf einer breiten Recherche wurde ein Anwendungsfall bei AHM ausgewählt, Nutzeranforderungen wurden dafür erarbeitet und eine passende Technologie wurde ausgewählt, indem prozessbezogene- und finanzielle Faktoren berücksichtigt wurden. Abschließend wurden strategische Risiken und Chancen durch Vorraber & Vössner's (2011) V^2 Value Network Notation untersucht.

Nennenswerte Resultate konnten erzielt werden. Die Recherche kategorisierte 33 AR Geräte in tragbare-, mobile- und stationäre Geräte. 31 potentielle Anwendungsfälle wurden basierend auf ihrem Einsatz in den Bereichen Instandhaltung, Montage und Logistik in die Kategorien Assistenz, Training, Monitoring und Simulation eingeteilt. Gestützt auf den Rechercheresultaten wurde der Anwendungsfall für Fernkonsultation in der Instandhaltung ausgewählt, um entwickelt zu werden. Interviews und Prozessanalysen wurden durchgeführt, um ein initiales Anwendungsfall-Design zu erstellen und 21 spezifische Nutzeranforderungen zu definieren. Beruhend auf einer Nutzwert- und Kosten-Nutzen-Analyse, wurde die Microsoft Hololens für diesen Anwendungsfall ausgewählt. Die Stakeholder haben bestätigt, dass die initiale Recherche erfolgreich einen geeigneten Anwendungsfall festgestellt hatte und dass die ausgewählte Technologie den Nutzeranforderungen gut entsprach. Die Value Network Analyse hat wichtige Bedingungen für eine mögliche weitere Umsetzung des Anwendungsfalls aufgezeigt.

Die Resultate haben eine signifikante Relevanz und zeigen Möglichkeiten für zukünftige Forschungsarbeit auf. Die Ergebnisse der Recherche werden es Managern erleichtern, potenzielle Anwendungsfälle für ihre Situation zu identifizieren. Der vorgeschlagene Prozess wird eine effektive Gegenüberstellung von Anwendungsfällen und Technologien ermöglichen. Als zukünftige Arbeit wird empfohlen, die hier durchgeführte wissenschaftliche Rechercheübersicht auf dem neuesten Stand zu halten und den vorgeschlagenen Prozess in anderen Firmen oder Industrien zu validieren.

ACKNOWLEDGEMENTS

I want to thank Audi Hungaria for making this thesis possible. Especially I want to thank the head of department László Keller, Sándór Vig and Szilvia Kiss, who have shared their excitement with me about working in the biggest engines plant in the world, have supported me a lot and have helped me to overcome all bureaucratic boundaries.

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TABLE OF CONTENTS

ACRONYMS

AG	Aktiengesellschaft
AR	Augmented Reality
AHM	Audi Hungaria Motor Kft.
CBA	Cost Benefit Analysis
MR	Mixed Reality
OEE	Overall Equipment Effectiveness
TCO	Total Cost of Ownership
VBA	Value Benefit Analysis
VPC	Value Proposition Canvas
VPD	Value Proposition Design
VR	Virtual Reality
VW	Volkswagen

LIST OF FIGURES

LIST OF TABLES

1 Background and introduction

1.1 Company and department

Audi Hungaria Motor Kft. (below called AHM), located in Győr (Hungary), is the biggest car engines producer worldwide with over 2m engines produced per year and a major automotive assembler with over 160.000 automobiles manufactured per year. Over 11.000 employees are working in the leading company in terms of export volume and revenues in Hungary (Hegyi, 2016). The underlying thesis was elaborated in cooperation with the department G/FP-3, which supports the IT systems for the engines production.

1.2 Problem and motivation

László Keller, head of the department G/FP-3, sees a significant potential for using Augmented Reality (AR), the overlaying of virtual objects onto the real world (see chapter 2.1 for detailed definition), in AHM's production and logistics environment. Sven Mosch, CIO of AHM, stated that the human being proves to be essential in industry, thanks to her/his cognitive abilities, versatility and flexibility. Both managers think that assistance systems will be increasingly needed for complex maintenance tasks, interior assembly and complex picking tasks in logistics. In fact, a survey among German manufacturers examined AR smart glasses and showed that 3.4% currently use them and 15.1% are planning to do so in the near future (Plutz, et al., 2016).

AHM did not know which areas were best to focus their AR efforts on; thus, they needed a process which structured all activities from the initial technology review to the final technology selection. The motivation of this thesis is the need for a **consistent categorisation of existing AR devices and their industrial use cases** for a better overview and the need for a **process to map use cases and technologies** in order to **allow AHM to define a use case with maximum benefit**.

1.3 Aim and objectives

In this chapter the underlying aim and objectives leading this thesis are stated.

1.3.1 Aim

The aim is to develop a process to justify the benefit of AR use cases in the automotive industry and to map potential use cases with technological products.

1.3.2 Objectives

In order to achieve the aim presented above, the following objectives were set:

1. **Market review and state of the art investigation** of existing AR applications, reviewing and categorising use cases and technologies
2. Compare use cases and technologies and examine challenges and trends to **elicit relevant use cases**
3. Design and develop a **process to map AR technologies and their use cases** based on specific user requirements and the expected financial benefit
4. **Validation of the proposed process**, methodically defining one use case at AHM, deciding for the most adequate technology
5. For the defined use case, **strategically analyse the multi-party network constellations**

2 Literature review and research questions

In this chapter a literature review on AR technologies and potential use cases, Service Design and Engineering frameworks and monetary assessment frameworks is presented. Based on this, the research gaps are identified and the research questions for this thesis are formulated.

2.1 Review of potential technologies and use cases

In this chapter definitions related to AR are clarified and a possible categorisation of AR devices is proposed for the use in this thesis. Then potential use cases are reviewed. Based on this, trends are identified, which help eliciting potential use cases.

2.1.1 Definitions

There are many definitions of AR. Azuma (1997) states that AR is a variation of Virtual Reality (VR). However, while VR completely immerses a user in a synthetic environment, AR allows the user to see the real world, with virtual objects superimposed upon the real world. Therefore, AR supplements reality rather than completely replacing it. Milgram & Kishino (1994) define AR as a “middle ground” between VR (completely synthetic) and telepresence (completely real). According to Feiner et al. (1997), AR is accomplished through the use of tracked see-through displays that enrich the user’s view of the world.

In contrast to definitions which require the use of see-through displays, this thesis **defines AR as any system which combines real and virtual, is interactive in real time and three-dimensional**. This definition does not limit AR to specific technologies and allows various display devices (head mounted displays, handheld devices, projectors) and the necessary devices for user tracking and force feedback.

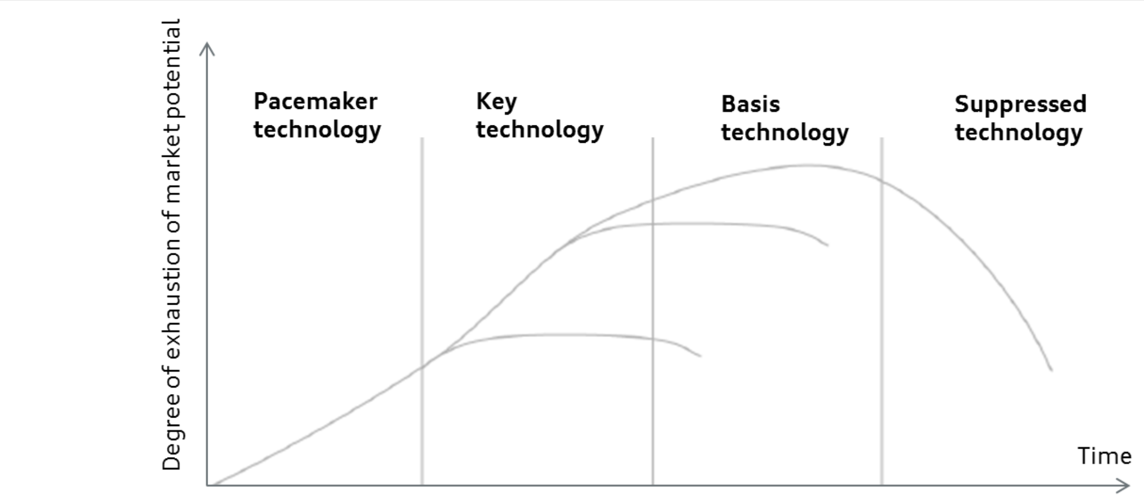
2.1.2 Categorisation of Augmented Reality devices

Due to the fact that there is no consistent categorization in literature of AR devices, in this thesis a categorisation is adapted, which is based on categorisations found in the literature and the Technology Life Cycle.

The literature proposes various categorisations. Dalle Mura et al. (2016) divide AR devices into wearable sensors, mounted on the wrist or arm and remote sensors, placed inside the work environment. Azuma et al. (2001) classify AR displays into head-worn, hand-held and projective.

The A. D. Little Technology Life Cycle (Little, 1993) (see Figure 1) also indicates a possible categorisation of AR devices. It shows the degree of exploitation of market potential over time of a product. The phases are emergence, growth, maturity and degeneration. It shows the technology life cycle and criteria to categorise a certain technology in a certain life cycle phase. Based on these criteria, Augmented Reality devices can be categorised as follows:

- Wearables are in the state between emergence and growth
- Remote sensors are in the state between growth and maturity
- Mobile devices are in the state of maturity



	Emergence	Growth	Maturity	Seniority
Insecurity of technical performance	High	Medium	Low	Very low
Investments in technology development	Low	Maximum	Low	Negliglible
Broadness of potential application areas	Unknown	High	Established	Decreasing
Type of development requirement	Academical	Application oriented	Application oriented	Cost oriented
Effect on cost/benefit relation	Secondary	Maximum	Marginal	Marginal
Number of patent registrations	Increasing concept patents	High, product related	Decreasing, process oriented	
Entry barriers	Academic abilities	Personell	Licences	Know How
Availability	Very limited	Restructuring	Market oriented	High

Figure 1: Criteria to identify the technology life cycle phase based on A. D. Little (Schuh & Klappert, 2011)

Based on the findings presented above, the following categorisation is used in this thesis:

- **Mobile devices**, such as tablet-PCs and smartphones
- **Wearables**, such as Smart Glasses, Smart Gloves or Smart Watches
- **Remote sensor systems**, such as Motion Tracking systems, e.g. Microsoft Kinect

The devices which were reviewed for this thesis were listed based on the above stated categorisation and complemented by relevant technological specifications. The specifications on the mobile- and stationary devices were investigated by the author and the specifications on wearable devices were investigated by the author's colleague Philipp Url.

2.1.3 Review of potential use cases

This chapter summarises the use cases found in the academic literature and other sources such as newspapers. The methodology followed can be found in chapter 4.2.1. A table with the details of all use cases was created. The use cases are categorised based on their application area.

These application areas were defined by comparing the relevant company department and the general function of the use case. The company departments are based on AHM's organisational structure (maintenance, assembly, logistics, R&D, quality control) and the use case functions (assistance, training, gamification, simulation, monitoring, documentation, communication), which were defined together with the department head as shown in Table 1.

Table 1: Definition of use case functions

Use case function	Definition
Training	Planned educative activity, which may include interaction with other humans
Assistance	Human assisted by technology
Gamification	Task gamification for employee motivation
Monitoring	Supervision of correct execution to prevent mistakes
Simulating	Reproduction of process behaviours

Table 2 gives an overview of the application areas and related use cases, which are described in detail below. Use cases which were not found in academic papers (below called "industrial review" in contrast to "academic review") are in italic. This industrial review was not investigated by the author but by his colleague Philipp Url.

Table 2: Overview of use cases sorted by application area

No	Application area	Use case Description	Reference name
1	Assembly assistance	Multi-dimensional measure for determining the complexity of manual assembly operations	(Zaeh et al, 2009)

2		System that assists an operator in assembly operations with an AR HMD by providing visual messages	(Dalle Mura, Dini, & Failli, 2016)
3		RFID-assisted assembly guidance in an AR environment	(Zhang, Ong., & Nee, 2011)
4		Assembly assistance system based on Duplo blocks	(Tang, Owen, Biocca, & Mou, 2003)
5		*Assistance and documentation with HMD*	(Oculavis, 2016)
6		*Assembly assistance and Virtual Workspace*	(Fraunhofer IOSB mAssist, 2016)
7		*Real time feedback from process control systems*	(European Satisfactory Consortium, 2016)
8		*Context sensitive assistance system*	(CIO, 2016).
9		*Hand projection system*	(VW AG, 2016).
10	Gamification	Production game with a tablet	(Korn,2012)
11		Maintenance game with a HMD	(Oliveira, Caetano, Botega, & Borges de Araujo, 2015)
12	Logistics assistance	*Commissioning assistance*	(Assist4.0, 2016)
13		*Pick by vision*	(Oculavis, 2016)
14		*Hands-free barcode scanning*	(Proglove, 2016)
15		*Google Glass logistics assistance*	(Automotive IT, 2016).
16	Maintenance assistance	Context aware AR maintenance assistance system	(Zhu, Ong, & Nee, 2014)

17		AR system on a large screen	(Fiorentino, Uva, Gattullo, & Debernardis, 2014)
18		Remote support system for railway maintenance	(Azpiazu, et al., 2011)
19		System for data integration to improve maintenance management	(Espíndola, et al., 2013)
20		*Remote maintenance consultation*	(Oculavis, 2016)
21		*Maintenance assistance system*	(Produktion, 2016)
22	Quality monitoring	*Gesture recognition at BMW*	(Fraunhofer IOSB mAssist, 2016).
23		*Quality check of welding points*	(Produktion, 2016).
24		*Parts mounting validation*	(VW AG, 2016).
25		*HMD quality assurance and error reporting*	(Oculavis, 2016).
26	Simulation	Virtual CAD models on a stationary display	(Li et al, 2009)
27		Interactive virtual assembly in an augmented scene	(Valentini, 2009)
28	Training	Training platform for assembly and maintenance skills	(Webel et al, 2013)
29		Support and monitoring of operators during maintenance tasks	(Re & Bordegoni, 2014)
30		*Automatic AR annotations and illustrations*	(IOXP Cognitive AR, 2016)
31		*Assembly training with HMD at VW*	(Produktion, 2016).

2.1.3.1 Assembly assistance

Assembly assistance systems help the worker to prevent Performance Shaping Factors, which may cause errors and can be assembly system related, product related or operator related (Dalle Mura, et al., 2016).

1. *D*alle Mura et al. (2016) developed a **system that assists an operator in assembly operations with an AR HMD by providing visual messages** (see Figure 2). A force/torque sensor was placed under a workbench and a pattern recognition technique allowed the error identification. Resultant features were in-process error detection, appropriate recovery procedures and ease of use due to the visual integration.

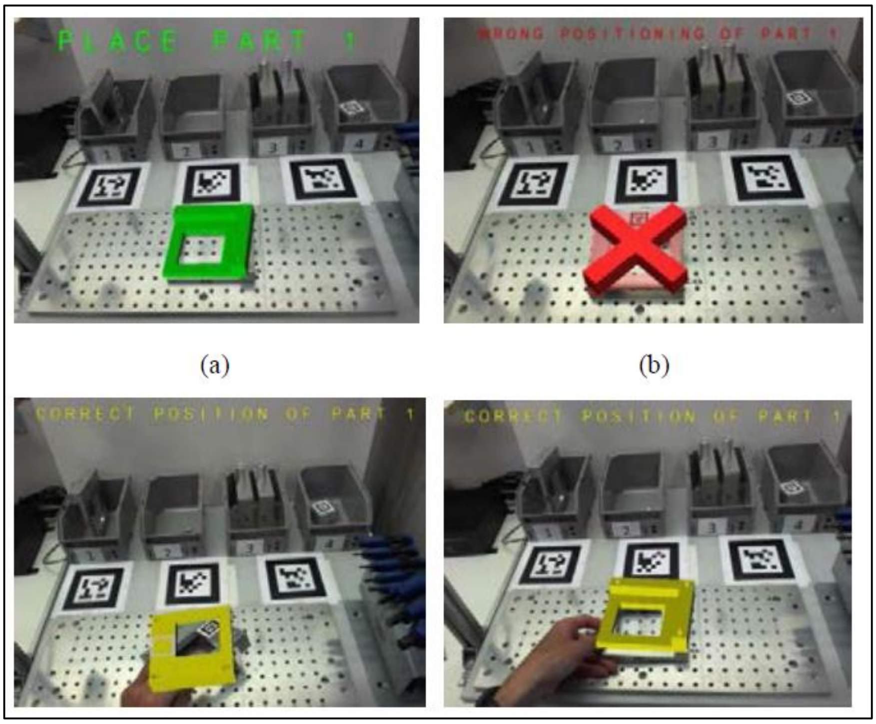


Figure 2: Visual messages by using an optical see-through: suggestions of right position and animations for error recovery (Dalle Mura, et al., 2016)

2. Tang et al. (2003) realised an **assembly assistance system based on Duplo blocks** (see Figure 3). Visual instructions were given on a HMD and voice commands could change the steps. The error rate was reduced by 82 % and the mental work load was reduced compared to traditional media; however, the completion time was not reduced.

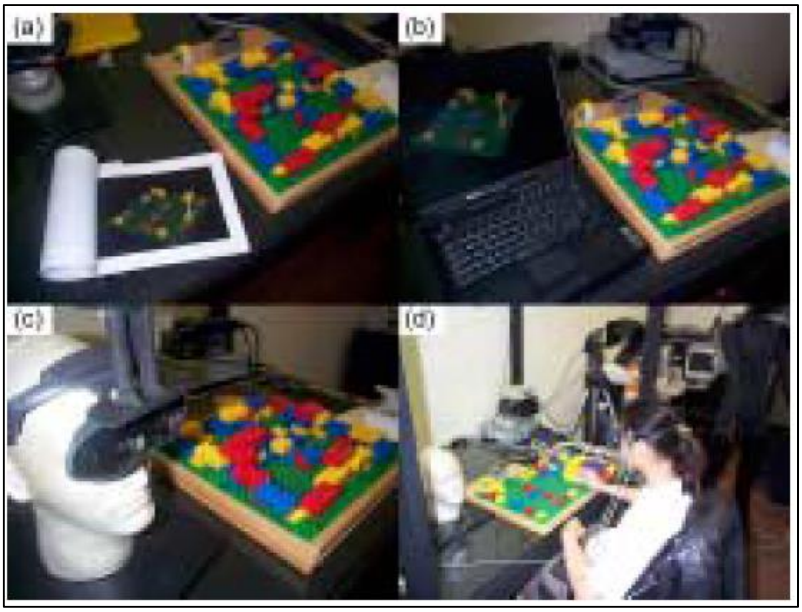


Figure 3: Comparison of different experimental setups in object assembly: (a) printed instructions, (b) instructions on LCD, (c) and (d) two different HMDs (Tang, et al., 2003)

3. Zaeh et al. (2009) realised a **multi-dimensional measure for determining the complexity of manual assembly operations** (see Figure 4). They used an experimental system with motion- and eye tracking, cameras and a projector. Based on this measure the assembly assistance was more efficient and ergonomically better, because the instructional content was adjusted based on human performance and learning effects.

Figure 4: Experimental workplace for displaying assembly instructions, based on a multi-dimensional complexity-measurement (Zaeh, et al., 2009)

4. Zhang et al. (2011) developed an **RFID-assisted assembly guidance in an AR environment** (see Figure 5). They combined an AR HMD, a wearable camera and an assembly activity detector consisting of an RFID reader and a hand movement detector. The system allowed an intuitive information navigation by recognising the component and the finishing of steps and by showing appropriate panels.

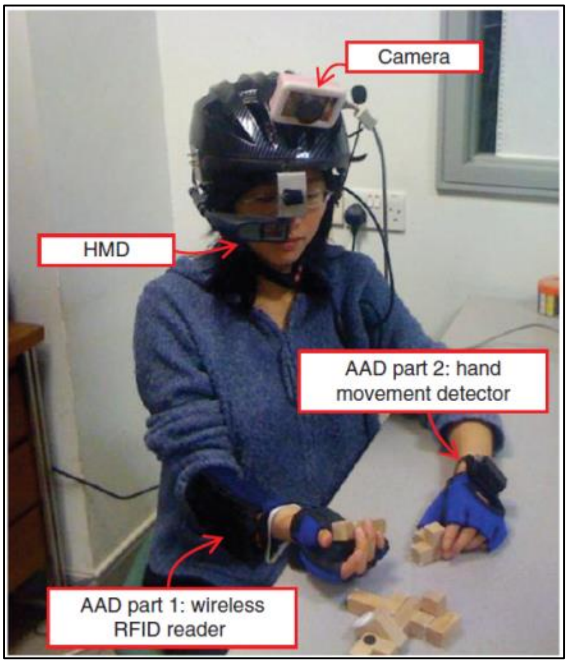


Figure 5: RFID-assisted assembly guidance in an AR environment (Zhang, et al., 2011)

5. The German startup Oculavis developed the **assistance and documentation modules** Oculavis.assist and Oculavis.document**.** **Oculavis.assist** speeds up manual production processes up to 30% and reduces error rates of assembly tasks up to 94%. This is enabled by animated context-sensitive instructions on tablets, smart phones or smart glasses. **Oculavis.document** documents and analyses product-, process- and error data (Oculavis GmbH, 2016).
6. The **Fraunhofer IOSB Institute** developed **mAssist** and combined motion- and people-recognition with an AR projection and a beamer. The workflow was evaluated and optimized in real time. Another application of Fraunhofer IOSB was the **Virtual Workspace**, which identified and tracked people, enabled multiple work environments on one screen and provided individually tailored work environments (Fraunhofer IOSB, 2016).
7. The European Satisfactory Consortium (2016) realised a system that provides **real time feedback from process control systems**. This improved the workflow with reduced attention switching and enabled someone with less prior experience to perform the task.
8. BMW Munich developed a **context-sensitive assistance system** on a smartwatch. It gives an alarm (vibration or lighting display) when a car with exceptional requirements is coming, e.g. with a different number of screws (CIO, 2016).
9. VW created a **hand projection system** for assembly assistance, which projected tasks on the hand of the worker. This speeded up manual processes (VW AG, 2016).

2.1.3.2 Gamification

According to Korn (2012) above 63% of German manufacturing companies would consider a system that contains motivating elements as "attractive". Stieglitz (2015) however, recommends to avoid that gamification elements suppress the intrinsic motivation of employees. According to Stieglitz it is difficult to keep gamification elements constantly attractive for employees, they can seem redundant after long use and employees react differently upon different incentives.

10. Oliveira et al. (2015) developed a **maintenance game with a HMD.** He proposed different Graphical User Interfaces for visualising personal performance, equipment- and sensor data, task instructions and potential risks. Examples are shown in Figure 6 and Figure 7. Better user experience and engagement could be achieved by giving financial or virtual rewards.

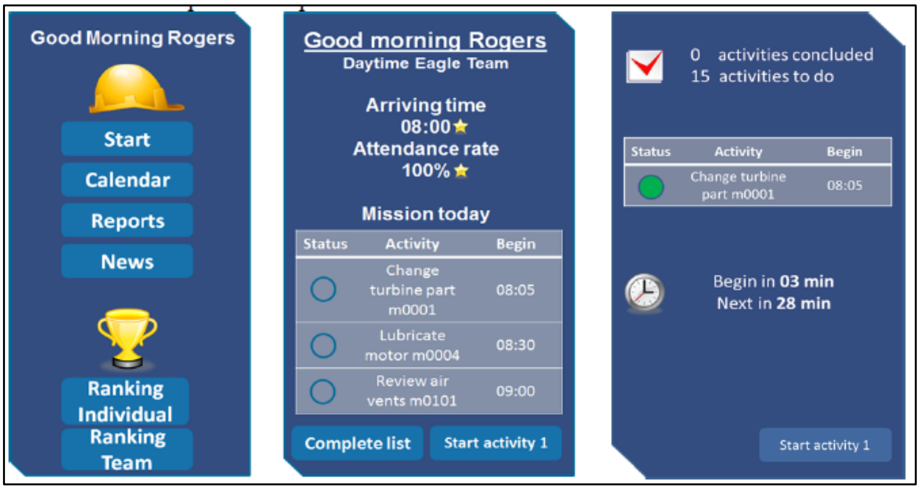


Figure 6: Proposal of different gamification GUIs: (A) initial system UI, (B) daily routine UI, (C) task initiation UI (Oliveira, et al., 2015)

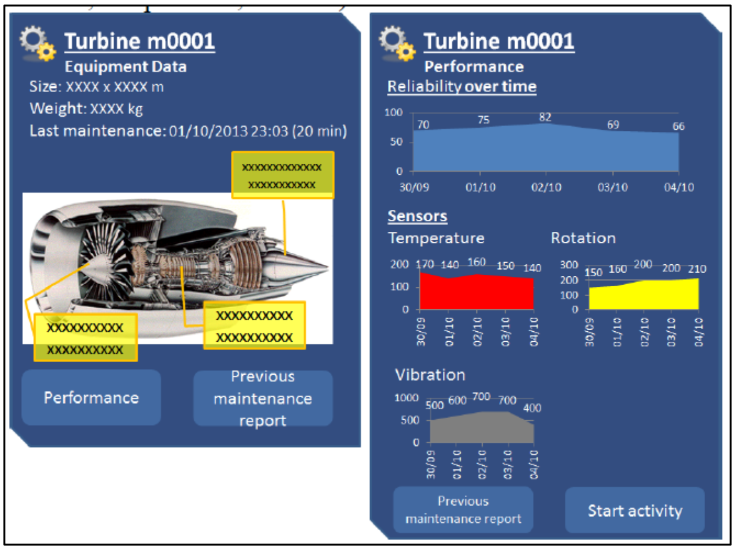


Figure 7: Proposal of UI for complex data and information about an equipment (Oliveira, et al., 2015)

11. Korn (2012) created a **production game with a tablet** to improve motivation and work quality for low skilled elderly and impaired assembly workers and repetitive high frequency tasks. Motion recognition monitored the work environment in real time, visualised by bricks in a puzzle game. Rewards were given based on the velocity and compared to the personal performance. Figure 8 shows the developed GUI.

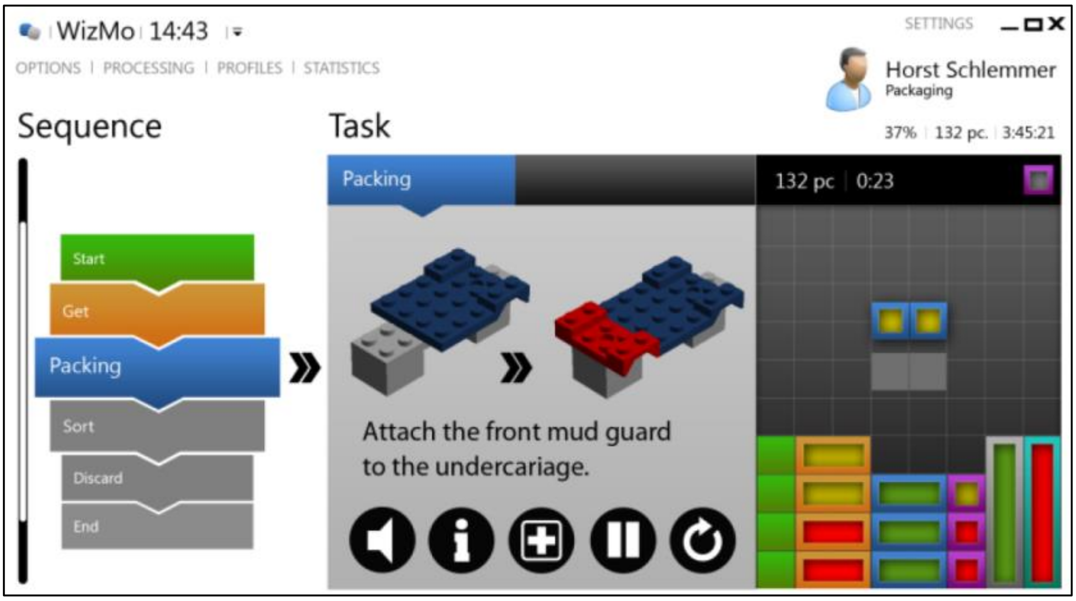


Figure 8: Gamification element on tablet (Korn, 2012)

2.1.3.3 Logistics assistance

Logistics assistance systems support logistics workers in their picking, barcode scanning and commissioning tasks. Productivity increases, mistakes are minimised and automatic documentation is enabled.

12. Within the Assist4.0 (2016) project for Mobile Production Assistance, tasks, machines and tools were continuously analysed and matched by using RFID and picture analysis. Tasks were given to the nearest employees and **defect-free commissioning** was enabled. Within the same project, the **Knapp KiSoft Vision** solution was realised: an HMD indicated the number of parts and their location, quality checks were done by RFID and optically, employees could navigate through the tasks and all the process was automatically documented.
13. Oculavis realised **oculavis.pick** (Oculavis GmbH, 2016), a pick-by-vision-solution, which increased the efficiency by 25% by giving visual instructions and providing the possibility to confirm tasks.
14. The startup **Proglove** (2016) developed a smart glove, which allowed **hands free barcode scanning**. A scanner was mounted directly on a glove and enabled hands free operation to scan and identify tools or parts. A pilot project has started at Audi in Ingolstadt.
15. An alternative replacement of handheld devices was done by **VW: 20 Google Glass HMDs** are in use in various sites. They are used to visually provide the location of parts, scan bar codes hands-free and confirm tasks with gestures. Commissioning was performed faster and with less errors. Significant problems were the Android OS, which was not released within VW, the Google terms and conditions, which were not compliant, and the user acceptance problem with especially older employees (Automotive IT, 2016).

2.1.3.4 Maintenance assistance

In maintenance, AR increases the effectiveness of the operator activity and it consequently speeds up the whole workflow. The underlying concept is to virtually represent instructions, so no paper manuals are required any more. This mostly reduces user errors, mental workload and execution time (Re & Bordegoni, 2014).

16. Zhu et al. (2014) developed a **context aware AR maintenance assistance system** with an AR Head Mounted Display (HMD) (see Figure 9). Different information, such as instructions, alerts and equipment information, can be provided tailored to the users’ needs.

Figure 9: Context aware AR maintenance assistance (Zhu, et al., 2014)

17. Fiorentino et al. (2014) created an **AR system on a large screen** assisted by multiple mobile and stationary cameras (see Figure 10). This allowed interactive maintenance instructions, such as visual labels, 3D virtual models and 3D animations. The execution time and error rate were significantly reduced.

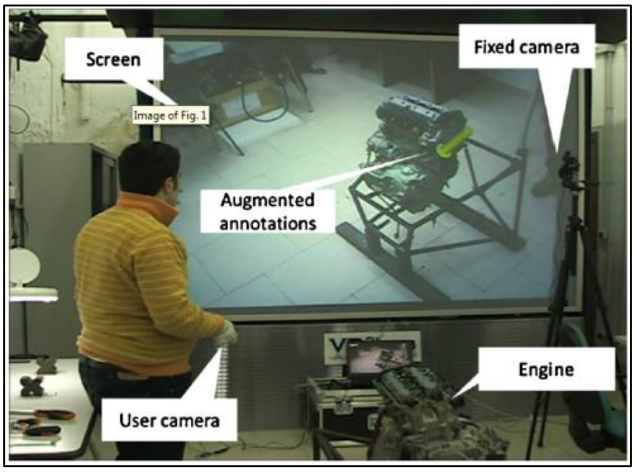


Figure 10: Interactive augmented reality instructions on large screen (Fiorentino, et al., 2014)

18. Azpiazu et al. (2011) developed a **remote support system for railway maintenance** with a HMD (see Figure 11). It allowed the communication between an on-site worker and a remote expert. Many subsystems and information sources were integrated. The corrective maintenance tasks were significantly quicker and more efficient.

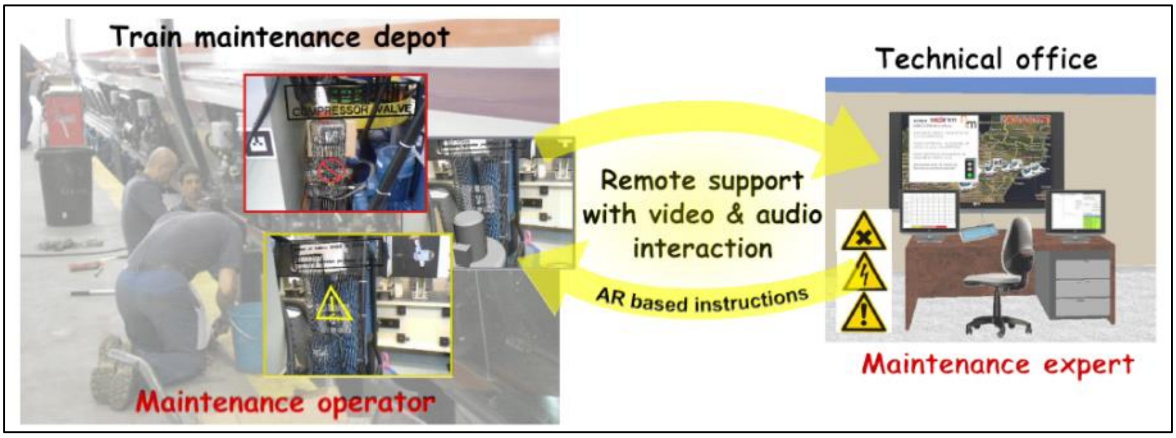


Figure 11: Remote interaction for train maintenance (Azpiazu, et al., 2011)

19. Espíndola et al. (2013) developed a **system for data integration to improve maintenance management** (see Figure 12). A CAD- and maintenance system were integrated by Mixed Reality, e.g. integrating names for the CAD system with graphics from the maintenance system. The results were time and cost savings with better operating time, safety and operability compared to the conventional and virtual solutions.

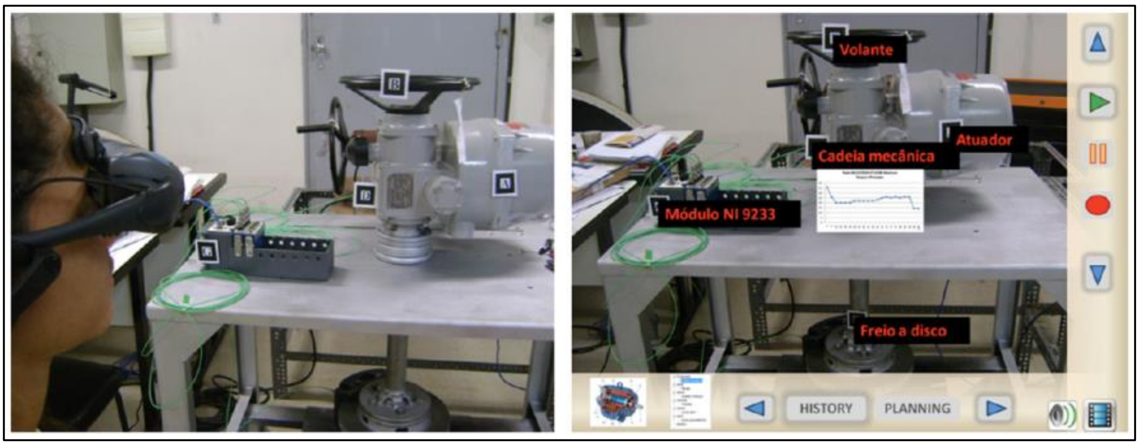


Figure 12: Data integration to improve maintenance management by Mixed Reality (Espíndola, et al., 2013)

20. The **remote maintenance consultation** Oculavis.share (Oculavis GmbH, 2016) allowed customer audits, sharing of information across physical borders or supporting customers in maintaining defect machines. The effect was a significant reduction of travel costs and machine downtime, waiting time for the worker and movement for the expert.
21. VW developed a **maintenance assistance system** for car repairs. It guides with marker less tracking on a tablet through a camera to the right position and displays work steps (Produktion, 2016).

2.1.3.5 Quality monitoring

22. The Fraunhofer IOSB Institute realised in collaboration with BMW a system for gesture **recognition for quality assurance**. It allowed the audit or failure analysis at bumpers: failures could be marked with a gesture directly on the bumper and were three-dimensionally documented. With a beamer the marked defects were directly visualised on the part to avoid undiscovered defects and time-consuming searching for documented failures. According to a Fraunhofer IOSB researcher, the biggest challenge was the interface with the CAD system (Fraunhofer IOSB, 2016).
23. Volkswagen realised a similar system for the **quality check of welding points**. Welding spots were localised and visualised automatically to avoid their manual look up (Produktion, 2016).
24. In another use case Volkswagen **validated if parts were mounted correctly** with a hand camera and the automatic comparison of the images with CAD data (VW AG, 2016).
25. Oculavis realised two systems with an AR HMD in this area. **Oculavis.imaging improved quality assurance** by integrating processes for detecting geometrical and thermal product- and process features. **Oculavis.listen improved error reporting** by preventing undetected error messages of machines. OPC-UA connections sent messages directly on the smart device of the person in charge to allow an immediate reaction (Oculavis GmbH, 2016).

2.1.3.6 Simulation

26. Li et al. (2009) displayed **virtual CAD models on a stationary display** combined with a camera. This allowed a sooner simulation and verification of assembly feasibility. As an effect the product quality increased whereas development periods and costs were reduced. The interface is shown in Figure 13.

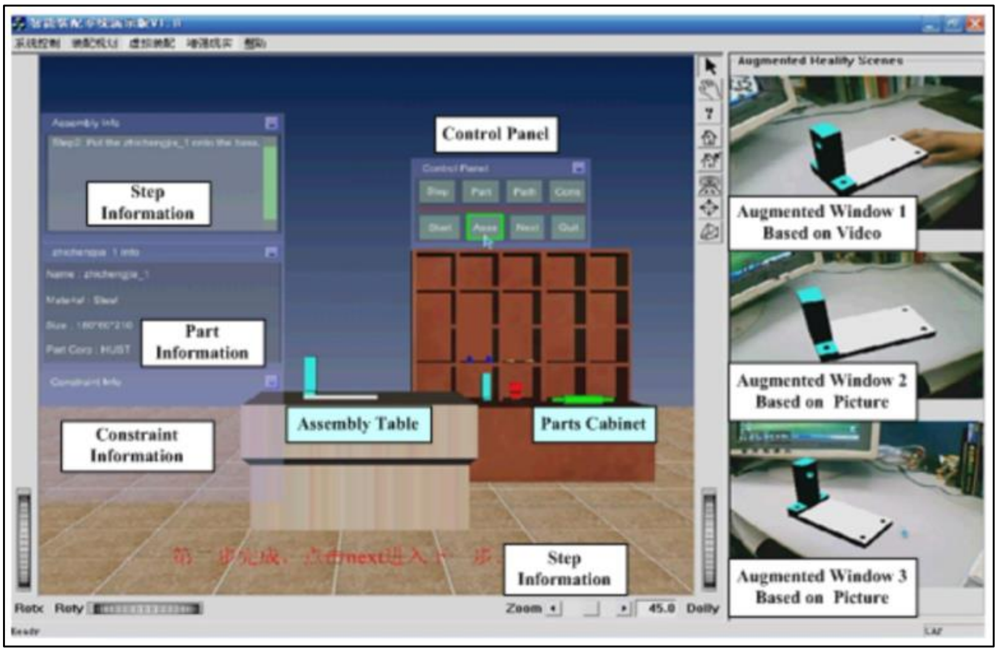


Figure 13: Interface of MR-based assembly platform (Li, et al., 2009)

27. Valentini (2009) developed an **interactive virtual assembly in an augmented scene**. He combined sensor-equipped gloves and a HMD. Figure 14 shows the simulation of the assembly of a cylindrical component into the hole of a plate. The effects were a sooner simulation and verification of assembly feasibility, improved product quality, a shortened period of development and reduced cost.

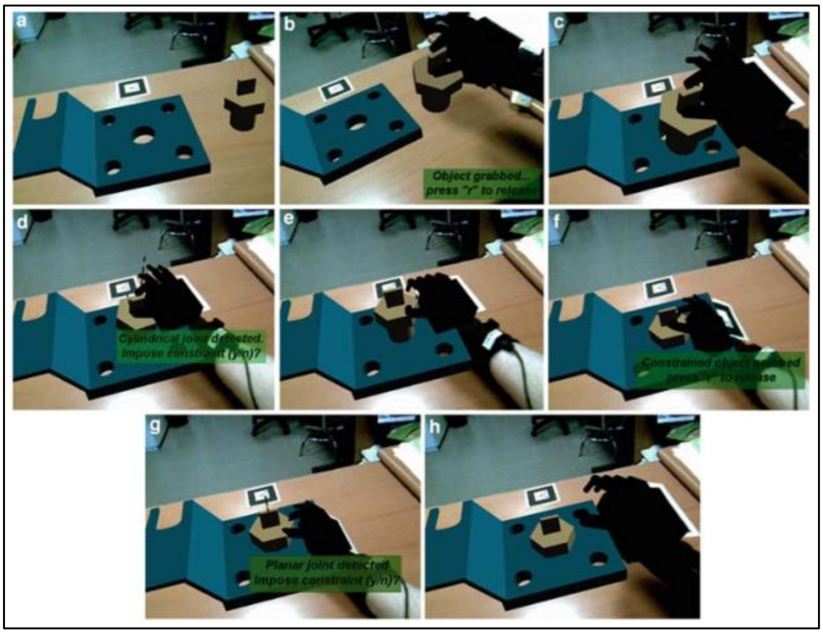


Figure 14: Snapshots of interactive virtual assembly in AR (Valentini, 2009)

2.1.3.7 Training for assembly or maintenance

Efficient AR training systems accelerate the technicians' acquisition of new procedures. They improve the adjustment of the training material for new scenarios and enable the reuse of training material (Webel, et al., 2013). Training on service maintenance with AR tools results in a low number of unsolved errors and training time compared to traditional training. In addition, it was perceived more positively (Borsci, et al., 2015).

28. Webel et al. (2013) developed a **training platform for assembly and maintenance skills**. Task instructions were shown on a tablet, a haptic bracelet gave vibrotactile feedback and instructions, as shown in Figure 15. The training content could be adjusted to the individual performance and location. Tele-consultation features were created, as visualised in Figure 16, where the trainer can give annotations to video images, enabled by authoring. While the performance time and the number of solved errors was not significantly different from the control group, the number of unsolved errors was significantly smaller in comparison to the control group.

Figure 15: Mobile AR component including a haptic bracelet (Webel, et al., 2013)

Figure 16: Authoring / tele-consultation-tool (Webel, et al., 2013)

29. Re and Bordegoni (2014) **supported and monitored operators during maintenance tasks**, as shown in Figure 17. The use of traditional instruction material was avoided and less training was required, tasks were performed faster and more precisely. However, a significant drawback was the time-consuming tracking with markers.

Figure 17: User frames machine with tablet (left) and looks at the instructions by means of the tablet (center and right) (Re & Bordegoni, 2014)

30. **IOXP Cognitive AR** (2016) allowed the **automatic creation of AR annotations and illustrations**. The work environment was analysed and appropriate annotations helped the user. Manuals and instruction videos were created based on the analysis.
31. At **VW, assembly workers for the Amarok model** were trained with AR content with a HMD. The trainer was able to constantly control and adapt the content via a tablet. This allowed faster learning and hands free operation (Produktion, 2016).

2.1.4 Trends identified during the review of potential use cases

In this chapter the academic- and industrial review are summarised. First, trends between the two are analysed. Secondly, the devices are mapped to the use cases and their functions. In contrast to the above review, below the company departments and the functions are analysed separately for a categorisation which is mutually exclusive and collectively exhaustive.

2.1.4.1 Overview of relevant company departments

Figure 18 illustrates the number of use cases associated to each company department, for both the academic and industrial review. This figure was developed as follows. The use case review matrix had one column called company departments. Every reviewed use case was associated to specific departments.

- In total most use cases were found for assembly (11), maintenance (8) and logistics (4); compared to all departments (2), quality control (4), R&D (2)
- In the industrial review some broad use cases were found, which were applied in all company departments
- In the reviewed academic use cases, quality control systems were mostly combined with general assistance systems; however, in the industrial review many use cases were identified which were only controlling quality
- In the academic literature there is a slightly stronger emphasis on the maintenance area compared to the industrial applications
- For the R&D department only academic and no industrial applications were found

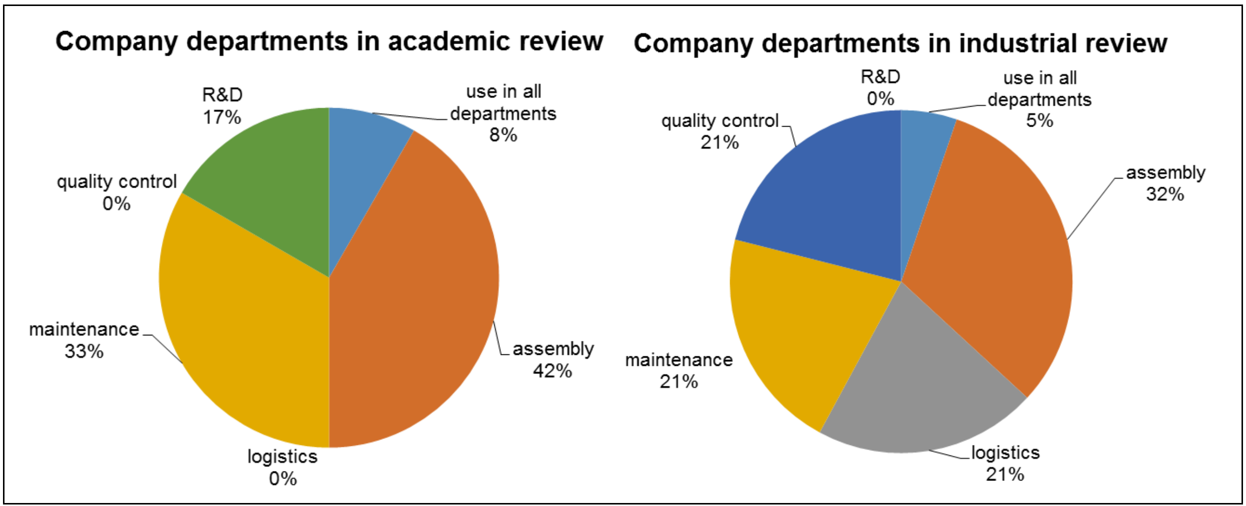


Figure 18: Comparison of company departments in academic and industrial review

2.1.4.2 Overview of general functions where AR devices were used

Figure 19 compares the **general functions** where AR devices were used for both the academic and the industrial review. This figure was developed as follows. The use case review matrix had one column called general functions. Every reviewed use case was associated to one specific general function.

- **Assistance** systems dominate in both areas
- The **communication** function was only found in the industrial review. This might be due to its relatively unchallenging technological features
- The **gamification** function was only found in academic reviews. This might be due to the fact that it is not fully socially accepted in industry (Stieglitz, 2015)

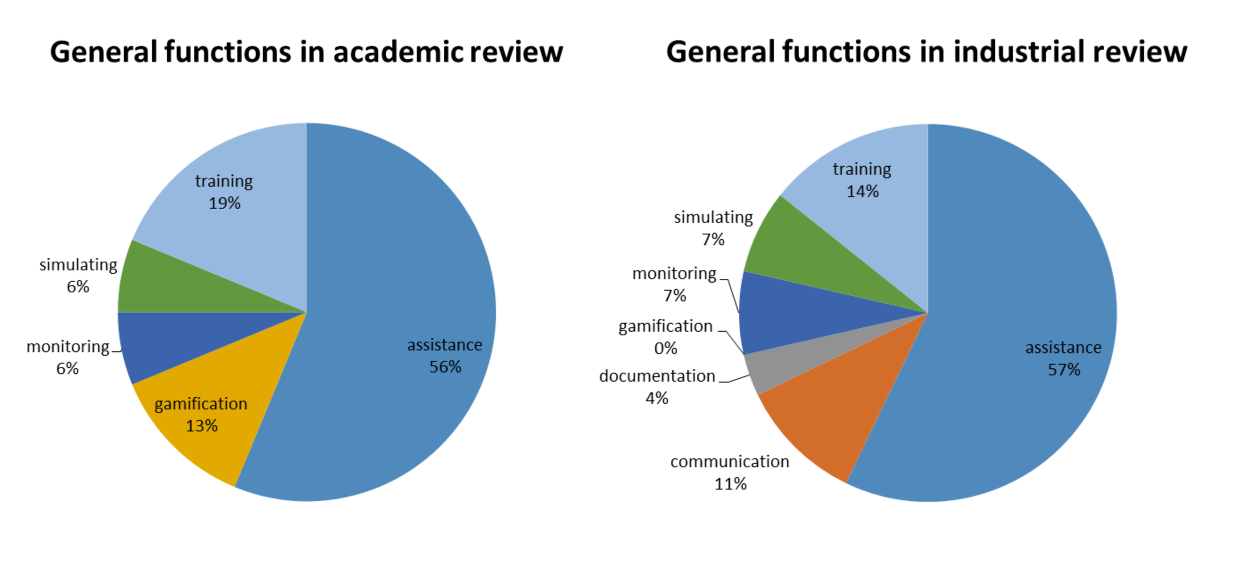


Figure 19: Comparison of general functions in academic and industrial review

2.1.4.3 Comparison between applications and technologies

In Table 3 all reviewed use cases are mapped to the AR technologies that were applied. Again, industrial use cases are listed in italic and the academic ones are not.

- This shows that the most popular AR technologies were **HMDs, tablet PCs and stationary projective systems**
- **Mobile devices** such as tablet PCs and mobile phones are more used in the industrial applications than in the academic ones
- Industrial applications have the tendency of using **finished hardware** (e.g. smart watches), whereas in the academic literature there is a tendency of **building hardware themselves** (e.g. displays in combination with smart bands)

Table 3: Mapping of reviewed use cases and technologies

		Wearables devices					Stationary devices		Mobile devices	
No	**reference: name**	**HMD**	**Projectors**	**Smart Watch**	**Smart Gloves**	**Smart Bands**	**Projective systems**	**Smart Displays**	**Smart phones**	**Tablet PCs**
1	(Zaeh et al, 2009)						1			
2	(Dalle Mura, Dini, & Failli, 2	1								
3	(Zhang, Ong., & Nee, 2011)	1				1				
4	(Tang, Owen, Biocca, & Mo	1								
5	*(Oculavis, 2016)*	1							1	1
6	*(Fraunhofer IOSB mAssist,*						1			
7	*(European Satisfactory Con*	1								
8	*(CIO, 2016).*			1						
9	*(VW AG, 2016)*		1							
10	(Korn,2012)									1
11	(Oliveira, Caetano, Botega,	1								
12	*(Assist4.0, 2016)*	1		1					1	1
13	*(Oculavis, 2016)*	1								
14	*(Proglove, 2016)*				1					
15	*(Automotive IT, 2016)*	1								1
16	(Zhu, Ong, & Nee, 2014)	1								
17	(Fiorentino, Uva, Gattullo, &							1		
18	(Azpiazu, et al., 2011)	1								
19	(Espíndola, et al., 2013)	1								
20	*(Oculavis, 2016)*	1								
21	*(Produktion, 2016)*									1
22	*(Fraunhofer IOSB mAssist,*						1			
23	*(Produktion, 2016).*						1			
24	*(VW AG, 2016).*		1							
25	*(Oculavis, 2016).*	1								
26	(Li et al, 2009)							1		
27	(Valentini, 2009)	1			1					
28	(Webel et al, 2013)					1				1
29	(Re & Bordegoni, 2014)									1
30	*IOXP Cognitive AR*	1								
31	*(Produktion, 2016)*	1								
	Academic review	8	0	0	1	2	1	2	0	3
	Industrial review	9	2	2	1	0	3	0	2	4
	Total	**17**	**2**	**2**	**2**	**2**	**4**	**2**	**2**	**7**

As follows the applied technologies are mapped to the general functions of the use cases (shown in Figure 20). Again, this graph was developed based on the use case review matrix.

- **Assistance**:
    - Due to the fact that most devices were found in the application area of assistance and most of them are suitable to be used in this context, many different technologies were applied in this area
    - Stationary systems such as projective systems, body tracking and other stationary devices are widely used, because mobility is not necessarily needed in a stationary environment
- **Quality monitoring**: stationary devices are used, because the environment often allows a stationary setup
- **Communication**: AR HMDs and mobile devices are mostly used, because here mobility is crucial and hands-free communication is a significant advantage
- **Training and simulation**: VR HMDs are often used, because VR allows simulating environments before they exist physically and therefore e.g. reduces time to market

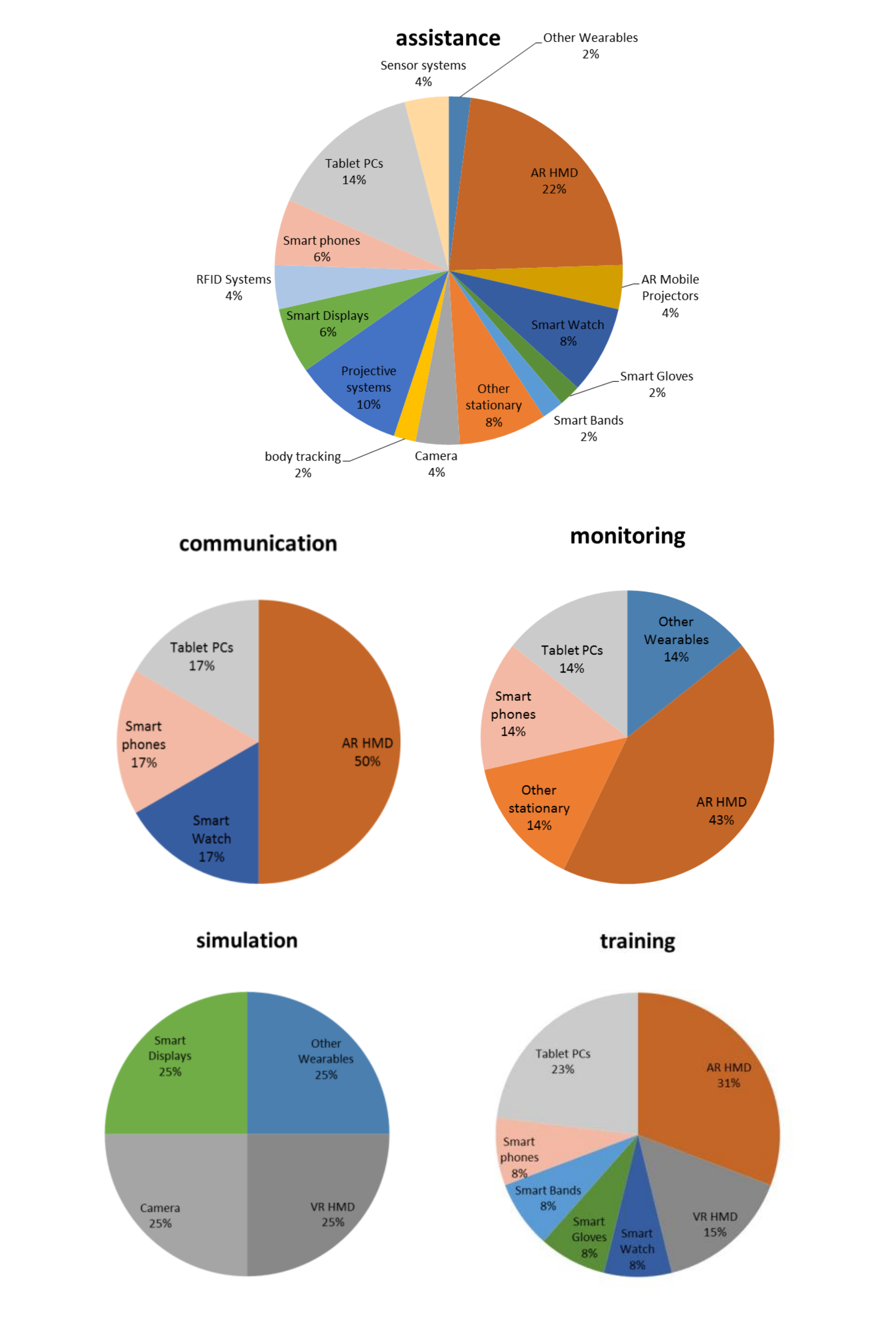


Figure 20: Distribution of devices for the different functions

2.2 Review of Service Design and Engineering frameworks

AHM was lacking an appropriate process to map AR technologies and their industrial use cases. Therefore, in this chapter a review of existing Process- and Service Design methodologies is presented.

Lichtenegger (2015) describes the **process of independent architecture design** with the four steps analysis, synthesis, design and evaluation. Figure 21 shows the four steps and corresponding tools and content. In the analysis phase, potential use cases are segmented and scenarios are analysed. In the synthesis phase improvement leavers are identified and main building blocks of a possible solution are defined. The technology penetration point is the point when a technology is selected. This should be after the synthesis of use cases in order not to focus too early on a specific technology and to base the technology selection on the requirements of the use case. Then the concrete system is designed and evaluated. This process was applied in the public safety area by Vorraber et al. (2015).

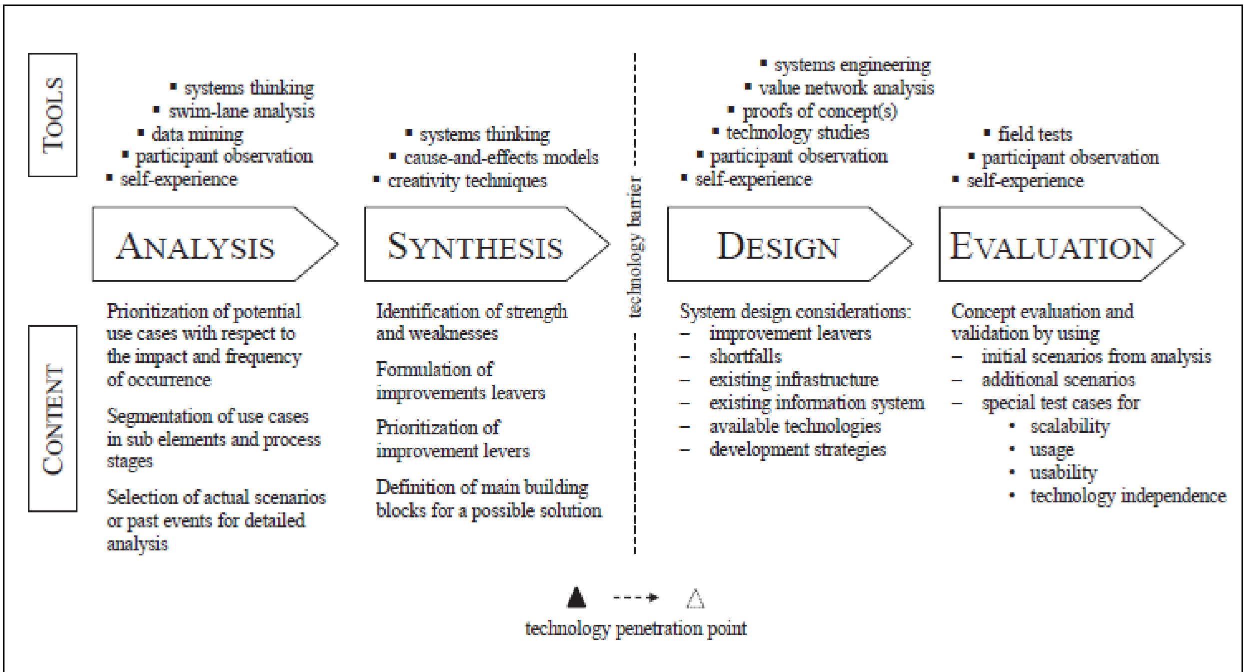


Figure 21: Guideline for independent architecture design (Lichtenegger, 2015)

Stickdorn & Schneider (2010) describe **Service Design Thinking** as a systematic and iterative process that integrates user-oriented, team-based, and interdisciplinary approaches and methods in ever-learning cycles. They describe the process along the four iterative phases exploration, creation, reflection and implementation, as shown in Figure 22.

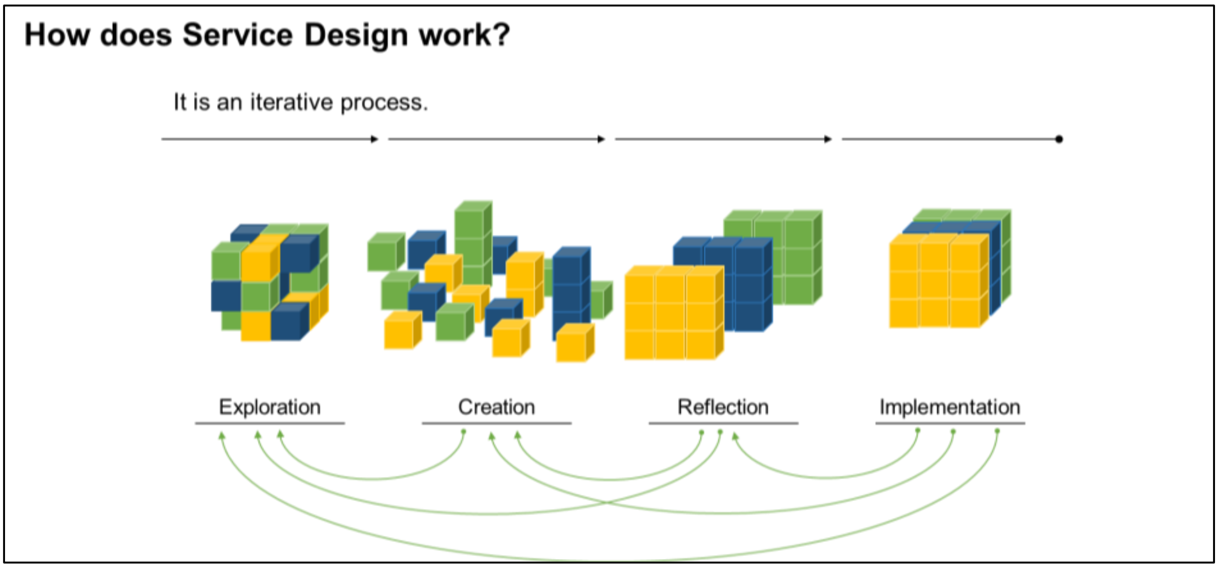


Figure 22: The Service Design Thinking Process (Stickdorn & Schneider, 2010)

Value Proposition Design (VPD) is a customer-focused methodology focusing on creating value instead of products and features. The VPC is a tool, which zooms in in two building blocks of the Business Model Canvas (Osterwalder & Pigneur, 2009): the customer profile and the value map. Figure 23 shows and explains the components of the VPC. On the right side the customer profile describes this customer segment in a structured way, broken down into its job, pains and gains. Each customer segment needs its own Value Proposition Canvas. On the left side the value map describes the features of a specific value proposition, broken down into products and services, pain relievers and gain creators. Ideally, there is a Fit between both sides, meaning that the value map addresses the pains and gains of the customer segment (Kyhnau & Nielsen, 2015).

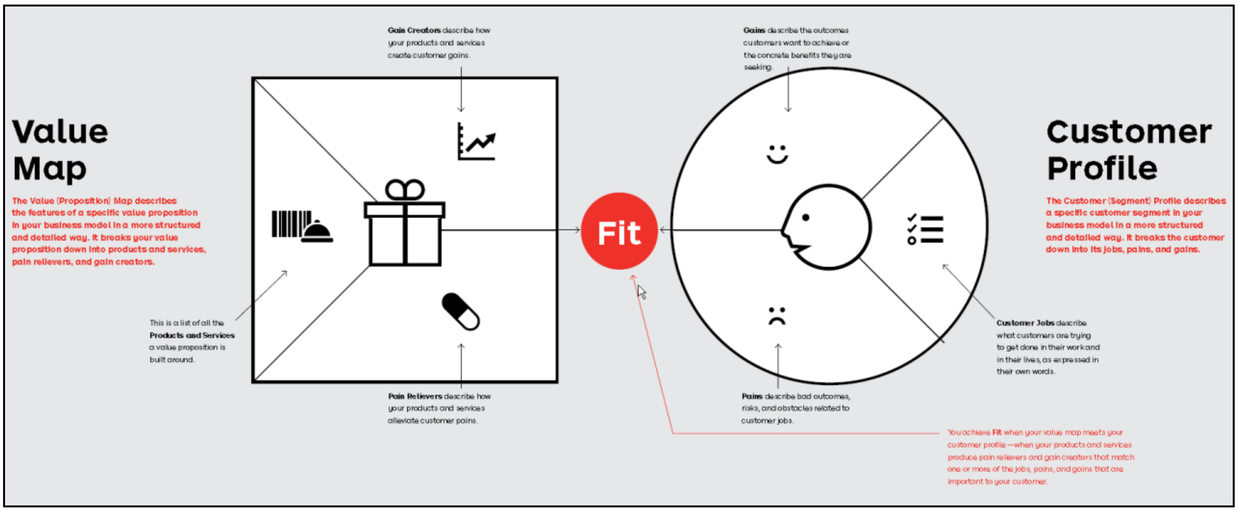


Figure 23: The Value Proposition Canvas (Kyhnau & Nielsen, 2015)

Vorraber et al.'s (2014) **classification scheme for use cases**, illustrated in Figure 24, maps use cases and technologies. It was applied for a use case of an AR-HMD in the medical context. They followed a three-step approach. In the first step they identified several potential areas of improvement through systematic Requirements Engineering. For the second step they developed a classification scheme to identify commonalities and differences of use cases to abstract them. The third step was to map these abstracted use cases to technical solutions. This abstraction scheme could be used as a process innovation tool by mapping various property combinations of the scheme to possible new use cases.

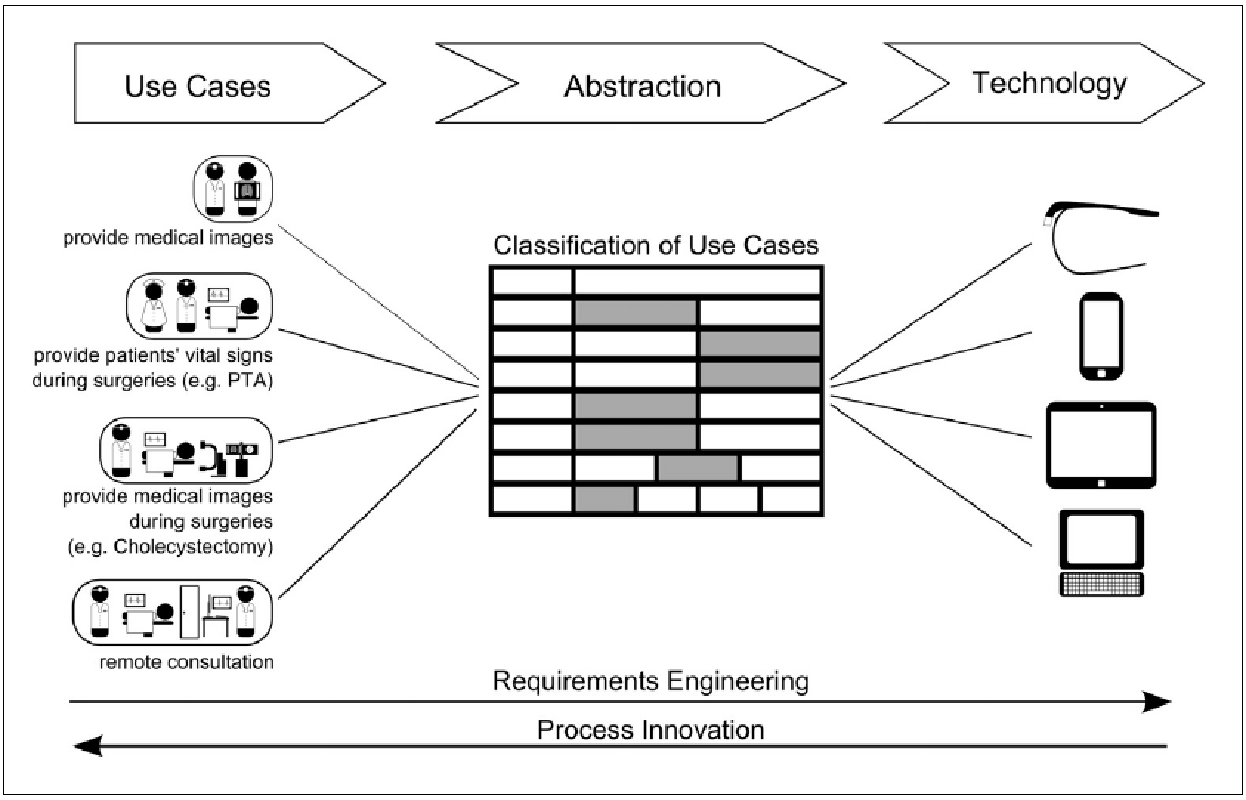


Figure 24: Use Case Technology Mapping (Vorraber, et al., 2014)

The **Second Generation Stage Gate Process** by Cooper (1994) breaks product innovation into a predetermined set of stages, consisting of prescribed, cross-functional and parallel activities. Gates control the process and serve as checkpoints. Compared to the first generation process, Cooper extended the second generation with more cross-functionality, more up-front-research, a stronger market orientation and more parallel activities. Even though it looks like a linear process, there are iterative cycles in between.

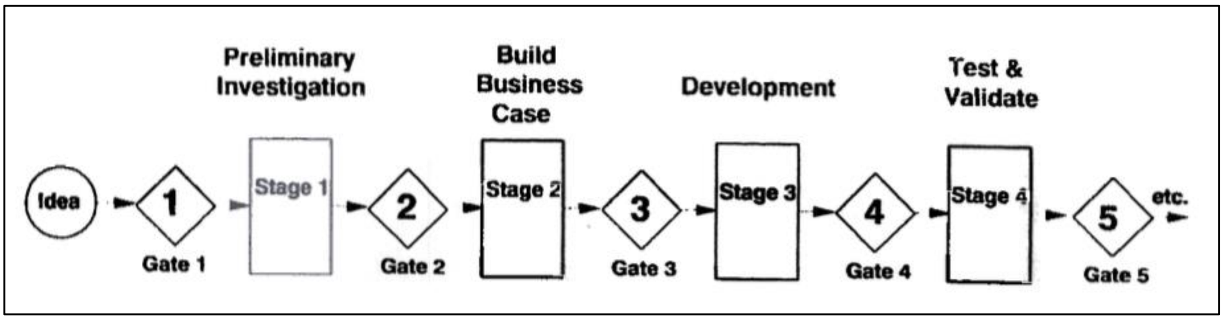


Figure 25: Second Generation Stage Gate Process (Cooper, 1994)

The **V² Value Network Notation** (Vorraber & Vössner, 2011) is a visual notation for value networks to be used for analysis and strategic planning. For every actor it describes the assets, capabilities, needs and includes the endogenous motivation and exogenous forces; therefore, it enables analysing multi-party network constellations. Vorraber (2016) enhanced this notation with the explicit consideration of ethical aspects and a networked view on needs of all actors. He stated that the following aspects should be covered during value network analysis and design:

- Functional needs (FN): describe what system should be able to accomplish (Partsch, 2010)
- Non functional needs describe the human side of needs and can be further classified into:
    - Technical non functional needs (TNFN): need to be fulfilled by the system (Rupp, 2009)
    - Social economic needs (SEN): how actors want to be perceived by others in economic terms (Osterwalder, et al., 2014)
    - Social human needs (SHN): needs for doing good to others or the environment
    - Ethical needs (EN): need for complying with an actor's ethics theory (Pavie, et al., 2014)
    - Safety needs (SN): need for preserving the actor's safety when using the service
    - Legal needs (LN): need for complying with legal regulations

2.3 Review of monetary assessment frameworks

AHM needed an assessment of the cost and benefit of potential AR use cases. Even though many researchers state that monetary assessments at this early development stage are risky and insecure (see below), in this chapter relevant monetary tools are presented.

Haag et al. (2011) recommend the **implementation of monetary models after a pre-selection based on qualitative assessment methods**. Hofmann & Orr (2005) states that an assessment of young technologies based on monetary methods is generally less useful, because they are **not mature yet and their attributes are often not quantifiable by traditional methods.**

2.3.1 Cost Benefit Analysis

Schuh & Klappert (2011) state that the aim of the **cost benefit analysis** is to compare non-monetary-figures (e.g. reliability) through the transformation in monetary figures. The result is the net benefit of the specific technology. Especially in early development phases empirical analysis and expert opinions need to be considered, because of the difficulty to transform effects in monetary values. It is normally divided into the following steps (Schuh & Klappert, 2011, p. 329f):

- Identification of cost and benefit
- Selection of the calculation interest rate
- Calculation of the net benefit
- Listing of monetarily not sizeable conditions
- Assessment of the alternatives

2.3.2 Total Cost of Ownership Model

According to Schuh & Klappert (2011, p. 342ff) Gartner's **Total Cost of Ownership (TCO) Model** can be used for the long-term, lifecycle-expanding analysis of occurring costs. The isolated TCO analysis does not consider qualitative factors. Figure 26 shows categories of costs based on the TCO model.

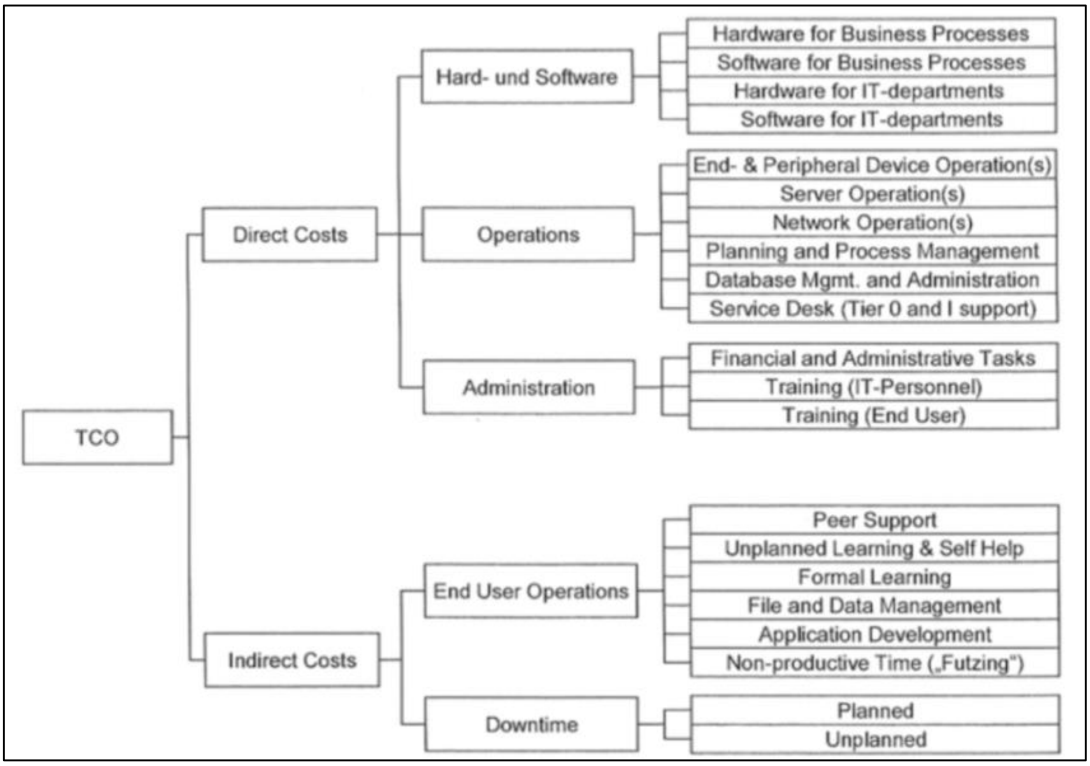


Figure 26: Gartner's Total Cost of Ownership Model (Redman, et al., 1998)

2.4 Research gaps

Based on the performed literature review, the following gaps were identified:

1. The research gap was identified that there was **no consistent categorisation found for AR use cases and technologies in automotive industry** (see chapter 2.1), even though AHM needed a comprehensive and categorised overview to identify potential use cases.
2. At AHM there was a need for a **process to map potential use cases and technologies**. The use case technology mapping framework of Vorraber et al. (2014) was up to now only used in the health care context (see chapter 2.2). Thus, the identified research gap is that **validation and refinement of this framework does not exist in the automotive context.**
3. Even though many researchers state that assessments of potential costs and benefits in early development stages are risky and insecure, AHM needed a monetary assessment of the impact of potential AR use cases. The identified gap is that there is **no consistent process to estimate costs and benefits for potential and early-stage AR use cases in automotive industry**.

2.5 Research questions

Based on the gaps identified above, the following research questions arose. The Conclusions will refer back to these questions.

1. **How can AR use cases and technologies which are relevant for automotive production and logistics be consistently categorised and abstracted?**

2. **Is the use case technology mapping framework** (Vorraber, et al., 2014) **also applicable in automotive industrial context and how would an application work?**

3. **How can potential costs and benefits be considered in the assessment of a potential AR use case for automotive production or logistics?**

.

3 Research methodology

The methodology of this thesis follows the Design Science Paradigm as described by Hevner et al. (2004). The process is based on Lichtenegger's (2015) structure along the phases analysis, synthesis, design and evaluation. The underlying thesis is focusing on the analysis and synthesis phases and ends with the selection of the technology. Furthermore, it is based on Stickdorn & Schneider's (2010) iterative Design Thinking phases exploration, creation, reflection and implementation. Tools from this Service Design Thinking and Value Proposition Design (Kyhnau & Nielsen, 2015) were applied during the whole process of this thesis. The research process is structured along seven stages, based on the Stage Gate Process (Cooper, 1994). The stages follow Vorraber et al.'s (2014) use case technology mapping scheme, which is illustrated in Figure 24. Up to now, this scheme has only been applied in a medical context. Within this thesis for the first time it was applied in an industrial production environment.

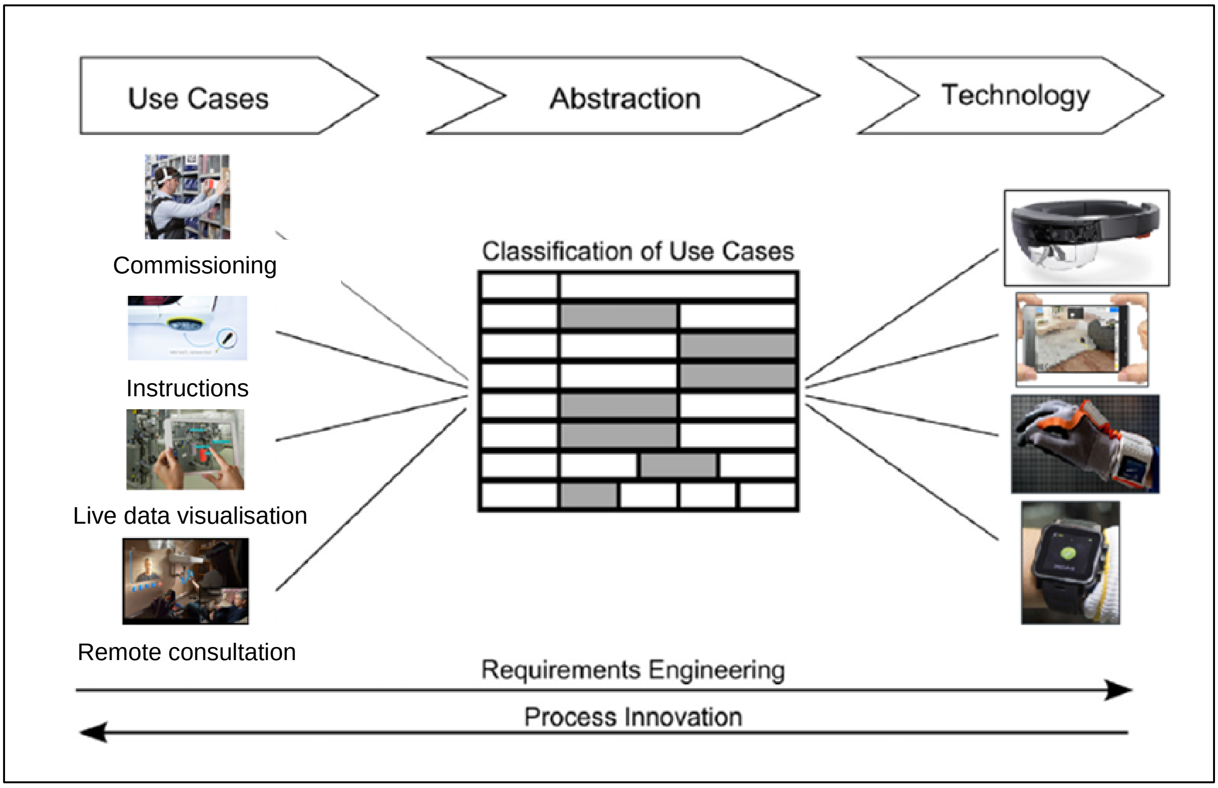


Figure 27: Underlying use case technology mapping framework, adapted from Vorraber et al. (2014)

Figure 28 illustrates the research process for this thesis along the following seven stages. In addition, Figure 29 lists relevant stakeholders and activities carried out for each stage. As follows an overview of each stage is given and each stage will be further explained below.

- **Stage 1 – Scope definition**: Statement of aim and objectives with all stakeholders.
- **Stage 2 – Use case and technology review**
  - **Technology review**: The analysis started on the right side of the use case technology mapping framework in Figure 27, which was adapted from Figure 24 (see chapter 2.2). Relevant AR devices and their specifications were identified and categorised.
  - **Use case review**: The analysis proceeded on the left side of Figure 27. Possible use cases were identified, categorised and analysed.
- **Stage 3 – Use case selection**: Selection of potential use case based on review and internally perceived potentials.
- **Stage 4 – Requirements definition**: For the selected use case, interviews and process analysis were used to define, document and validate the requirements. This Requirements Engineering Process is shown in the bottom of Figure 27.
- **Stage 5 – Technology pre-selection**: The requirements defined above were weighted in collaboration with the potential users. Based on these requirements the detailed specifications of the technologies were defined for a group of relevant technologies (see right side of Figure 27). Comparing the different technologies resulted in a few most adequate technologies, which were suitable for a financial analysis.
- **Stage 6 – Final selection of technology**: For the pre-selected technologies comparing costs and benefits resulted in a potential net benefit. This net benefit led to a final decision for one technology alternative. Step 5 and 6 are illustrated in the centre of Figure 27.
- **Stage 7 – Evaluation:** Existing industrial processes are potentially improved, which results in process innovation (see bottom of Figure 27). Stakeholders were asked for their opinion on the effectiveness of the mapping and the initial Proof of Concept
- **Stage 8 – Value network analysis:** A value network map was created in order to get an overview of the strategic risks and opportunities

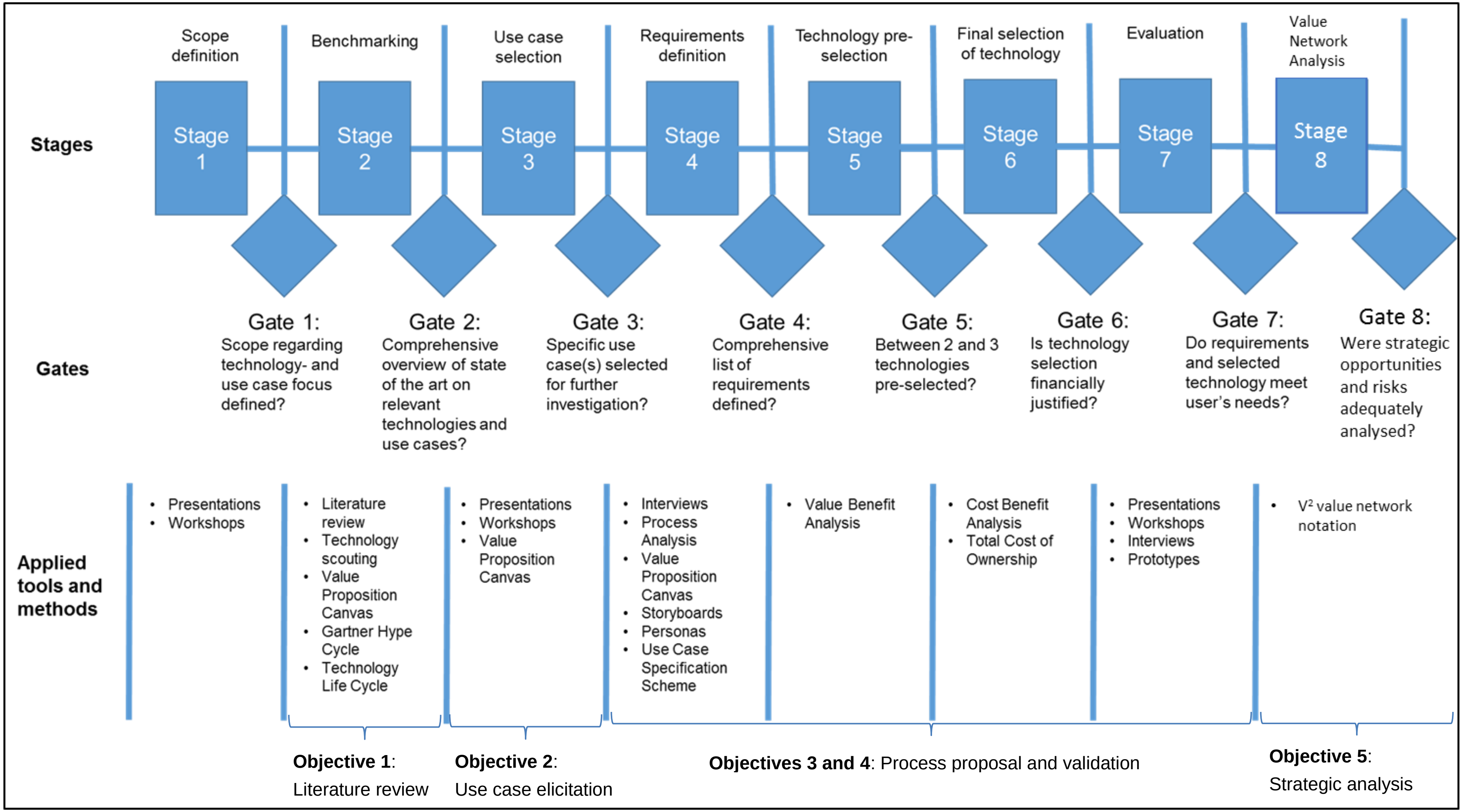


Figure 28: Stage Gate Process illustrating Research Methodology with stages, gates and applied tools and methods

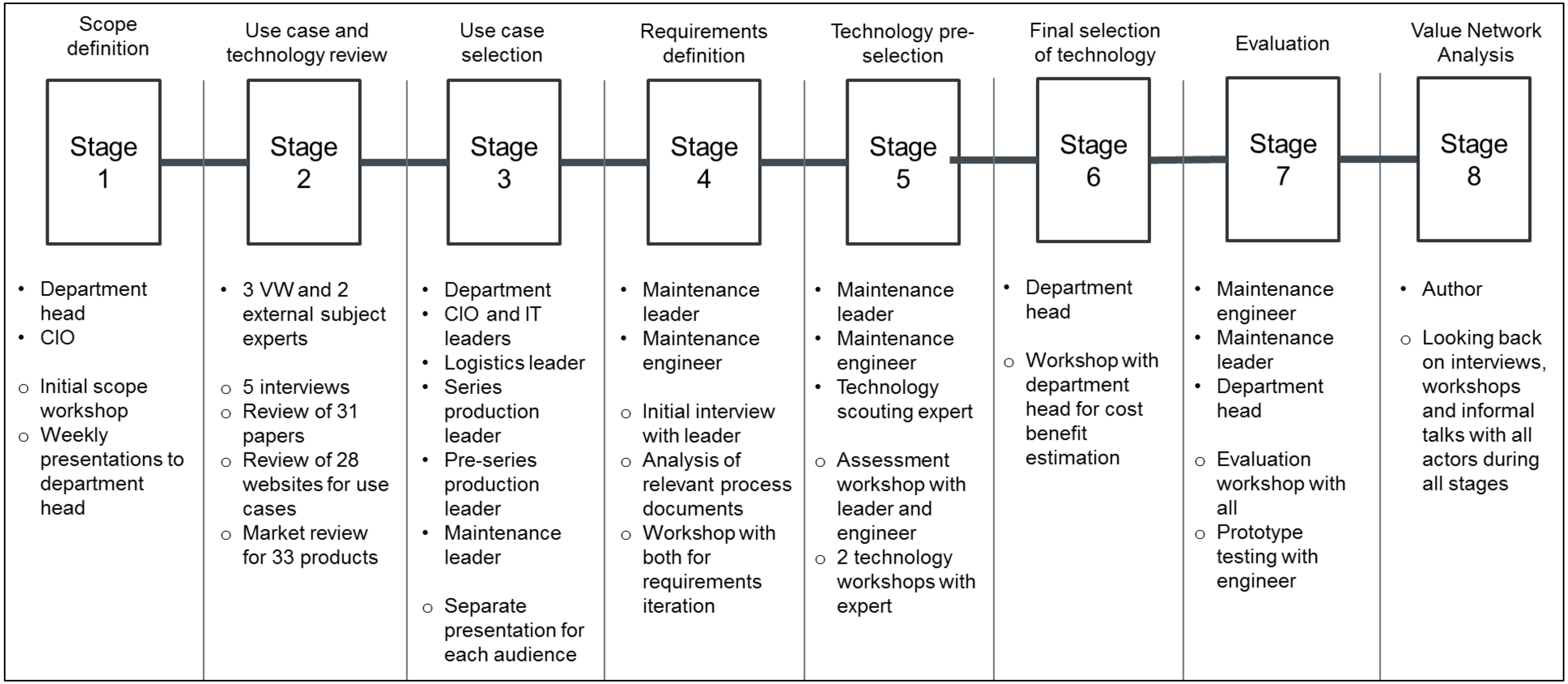


Figure 29: Relevant stakeholders and carried out activities in each stage of the Research Methodology

4 Case Study – use case mapping and evaluation

The process of mapping and evaluating the selected use case of maintenance remote consultation is presented in Figure 30. It was structured along the following 8 stages, which are shortly described as follows and detailed below.

- **Stage 1 – Scope definition:** The scope was iteratively narrowed down from smart devices to AR.
- **Stage 2 – Use case and technology review:** The review summarised the current practice and challenges.
- **Stage 3 – Use case selection**: Presenting the current practice and challenges to managers within AHM and comparing them in workshops to internal company-specific needs allowed choosing one specific use case for being mapped and evaluated: remote consultation for maintenance.
- **Stage 4 – Requirements definition:** By conducting interviews and process analysis the use case outline was detailed, which allowed the definition of 21 requirements.
- **Stage 5 – Technology pre-selection:** A Value Benefit Analysis was conducted for four technology alternatives compared to the current situation. The two technologies Microsoft Hololens and Dell Venue 10 Pro were selected for further investigation due to their high Value Benefit Score.
- **Stage 6 – Final selection of technology:** For the two selected technologies the financial net benefit was estimated; however, it was decided that the assessment was too insecure at this early technology stage.
- **Stage 7 – Evaluation**: In a workshop with the department head and the process stakeholders it was confirmed that the user requirements were met.
- **Stage 8 – Value Network Analysis:** Strategic aspects which need to be considered for the use case implementation were derived.

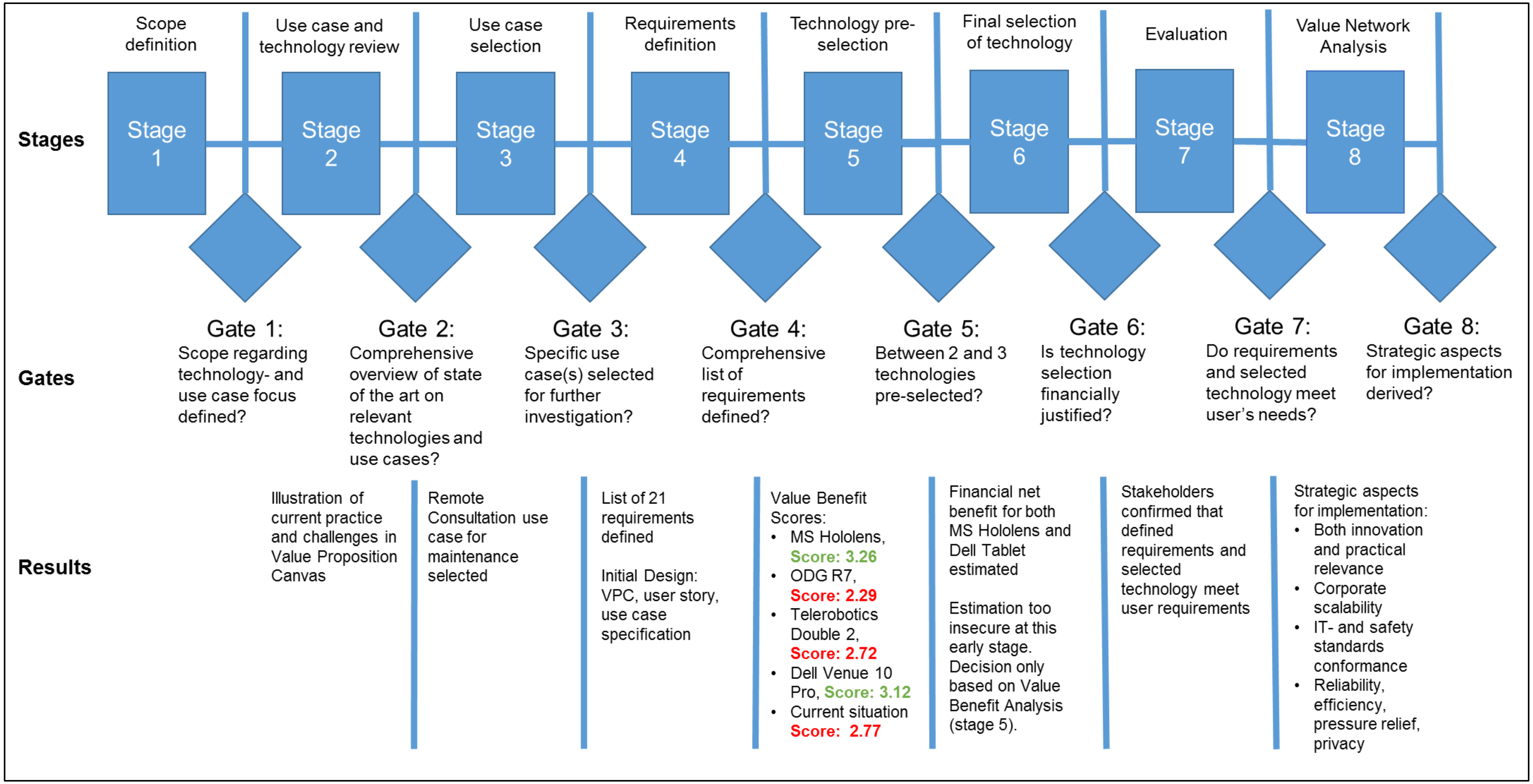


Figure 30: Case study overview – mapping and evaluation for the selected use case

4.1 Stage 1 – Scope definition

At the beginning of the project the aim and objectives of this thesis were defined and iteratively redefined during the first weeks. Every week there was a progress presentation to the direct supervisor Mr. Keller, who initially wanted to focus on smart devices in general. Iteratively the focus shifted to AR, because during the literature review phase this was identified as the most promising field in the area of smart services.

4.2 Stage 2 – Review on technologies and potential use cases

The review was first conducted and then presented. As follows, these two phases are presented in detail.

4.2.1 Conduction of review

For the academic review, Table 4 (see next page) gives an overview of the sources and their relevance. Various search platforms, such as Google Scholar, Science Direct and Springer Professional were reviewed. The reviewed journals included high-ranked publications such as Lecture Notes in Computer Science (H Index 177), International Journal of Production Research (H Index 91) and Computers in Industry (H Index 73). The search was based on the following categories of search terms:

- “Augmented Reality” or “mixed reality” or “sensors” or “HMD” or “wearables”
- And “assembly” or “quality” or “logistics” or “maintenance”
- And “training” or “assistance” or “communication” or “documentation” or “monitoring”

The reference lists of each article were reviewed in detail to find additional articles.

The author first read the abstract of all articles, then he identified relevant papers (n = 14 articles of 31 preselected). Papers were narrowed down excluding papers which did not describe a technical implementation of an AR use case, e.g. only a theoretical investigation. The researcher then read all these selected articles in full text. Subsequently, the main findings of each study were recorded in a table (see chapter 2.1 for summary).

Table 4: Details on sources for academic literature review

No	Reference: name	Reference: journal	Journal: H index	Search key words	Search platform
1	(Zaeh et al, 2009)	Production Engineering, Volume 3, Issue 4-5	18	assembly, man machine system	SpringerProfessional
2	(Dalle Mura, Dini, & Failli, 2016)	Proceedings of the 48th CIRP Conference on Manufacturing Systems	-	augmented reality, assembly, error detection	ScienceDirect
3	(Zhang, Ong., & Nee, 2011)	International Journal of Production Research, Vol. 49, No. 13,	91	assembly guidance, augmented reality	Google Scholar
4	(Tang, Owen, Biocca, & Mou, 2003)	CHI '03 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems	-	augmented reality, instruction	Google Scholar
10	(Korn,2012)	Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems - EICS '12	-	gamification, augmented reality	Google Scholar
11	(Oliveira, Caetano, Botega, & Borges de Araujo, 2015)	Lecture Notes in Computer Science, Volume 9173	177	augmented reality, gamification, maintenance	SpringerProfessional
16	(Zhu, Ong, & Nee, 2014)	International Journal on Interactive Design and Manufacturing (IJIDeM), Volume 8, Issue 4	12	augmented reality, maintenance	SpringerProfessional
17	(Fiorentino, Uva, Gattullo, & Debernardis, 2014)	Computers in Industry 65	73	augmented reality, maintenance	ScienceDirect
18	(Azpiazu, et al., 2011)	CARVI 2011: IX Congress on virtual reality applications	-	augmented reality, maintenance, communication	Google Scholar
19	(Espíndola, et al., 2013)	Computers in Industry 64	73	maintenance, mixed reality	ScienceDirect
26	(Li et al, 2009)	Lecture Notes in Computer Science, Volume 5622	177	mixed reality, assembly	SpringerProfessional
27	(Valentini, 2009)	International Journal on Interactive Design and Manufacturing (IJIDeM), Vol. 3, Issue 2	12	augmented reality, assembly	SpringerProfessional

28	(Webel et al, 2013)	Robotics and Autonomous Systems 61	82	augmented reality, maintenance, training	ScienceDirect
29	(Re & Bordegoni, 2014)	Lecture Notes in Computer Science, Volume 8526	177	augmented reality, maintenance	SpringerProfessional

The industrial review identified 28 use cases. A comprehensive research of internet resources was conducted. Personal contact to key researchers at VW Group and to external companies was made (see Table 5). Within the VW Group, AR use cases had been implemented in the past (see use cases no. 9, 15, 21, 23, 24, 31 in chapter 2.1.3); however, during all semi-structured interviews only publicly available information was shared with the author. The primary sites used were automotiveit.eu, cio.de, and automotiveworld.com.

Table 5: Interview contacts for initial review

Firm / Department	**Responsibility**
Audi Production Lab, Ingolstadt	Head of Lab
VW Wolfsburg Plant	VW Lead for Smart Devices
VW Production Lab, Wolfsburg	Mobile and Wearable Computing
Fraunhofer IOSB	Researcher
Proglove	CEO

The 28 identified use cases were narrowed down to 17 by excluding very similar applications and applications which were not directly related to AR. For an overview of the 17 selected use cases, see the use cases in italic in Table 2 in chapter 2.1.3.

4.2.2 Structure of presentation of review

In order to visually present the information gathered during the review to relevant stakeholders, a Value Proposition Canvas (VPC) (see chapter 2.2) was used for each targeted customer segment. This workload was divided as follows: the author created the VPC for assembly and his colleague Philipp Url created the VPCs for maintenance and logistics.

The use cases found during the review were summarised in a table, where they were categorised based on the VPC and its categories and areas, as Table 6 illustrates.

Table 6: Structure of the tables for the use case categorisation

VPD Category	**VPD Area**	**VPD Subarea**	**Fields**						
Customer Profile	Customer Jobs	Company department	R&D	assembly	maintenance	logistics	quality control		
		Task description							
		User							
		Environment							
	Customer Pains		defects	over-production	waiting	transport	movement	inappropriate processing	
	Customer Gains		inventory reduction	hands free operation	PR	motivation	satisfaction	less fluctuation and sickness	
Value Map	Pain Relievers								
	Gain Creators								
	Products and Services	General Function	gamification	training	assistance	communication	documentation	monitoring	simulation
		Provided information	operational data	master data	task instructions	localisation data			
			text	audio	visual	graphs	spreadsheets	vibration	

For the technology review the main categories were first defined and then within each category the most relevant products were listed with relevant specifications.

Table 7 shows the technology categorisation, specifications and possible fields.

Table 7: Structure of technology review categorisation

Category	Sub-category	Fields						
Technology category	Type	Wearables	Remote/ stationary devices	Network devices	Mobile devices			
Technology lifecycle	Technology lifecycle state	emergence	growth	maturity	degeneration			
Gartner Hype Cycle	Hype Cycle phase	technology trigger	peak of inflated expectations	through of disillusionment	slope of enlightenment	plateau of productivity		
	Duration until plateau state	0	<2	2 to 5	5 to 10	>10	obsolete before plateau	
Mounting location		head	arm	hand	shoulder	wall	floor	ceiling
Product Data	Company - Product Name							
	Sensors / Specifications							
Product Categorisation	Abstract functionality	output	input	communication				
	Use concept	active	passive					
Specifications	Programming effort	no	low	high	service			
	Availability	to buy	in development					
	Initial Investment for PoC	<500	500 to 2000	>2000				
Limitations/ Advantages	Limitations							
	Advantages							

4.2.3 Presentation of review and thereby elicitation of potential use cases

The results were presented to relevant stakeholders at AHM using the Value Proposition Canvas (VPC), which helped identifying a relevant use case.

Due to the fact that most use cases were found for maintenance, assembly and logistics, one VPC was created for each of these segments. All the information gathered during the use case review was structured in a table based on the VPC fields. This made it easy to illustrate this tabular data in a visual VPC.

For all three customer segments the same methodology was used. In the customer jobs' section all tasks and roles, which appeared in the examined use cases, were listed. The pains and gains were based on Ohno's Seven Wastes, which are addressed in the Toyota Production Principle, and complemented with issues identified in the literature. The number of ticks under each pain or gain describes how often a specific pain or gain is addressed by pain relievers or gain creators in the reviewed use cases. This indicates the importance of the pain or gain. In the Value Map all applied technologies are listed. Often several technologies are combined. The subcategories of use cases are grouped in pain relievers and gain creators.

In the **maintenance segment** (see Figure 31), the most significant user pains were inappropriate processing, movement and waiting. This was addressed by the pain relievers remote consultation- and instruction services. The most significant user gain was motivation, which was addressed by the gain creators gamification and virtual training.

In the **assembly segment** (see Figure 32), again the biggest pains were inappropriate processing, defects, movement and waiting. In addition to remote consultation and instructions they were addressed by quality warnings and workflow optimisation. The most significant gains were satisfaction and motivation. These were addressed amongst others by assistance systems which reduced the mental workload.

In the **logistics segment** (see Figure 33), inappropriate processing, movement and waiting were the most important pains. They were addressed amongst others by commissioning assistance systems. The biggest gain was hands free use, which was achieved by hands free barcode scanning.

In all segments HMDs and tablets were the most used devices. A good fit was identified between the value map's products and services and the customer segment's pains and gains. Especially in assembly, stationary systems were often used. Often many devices were combined in one AR system, e.g. HMDs and smart bands.

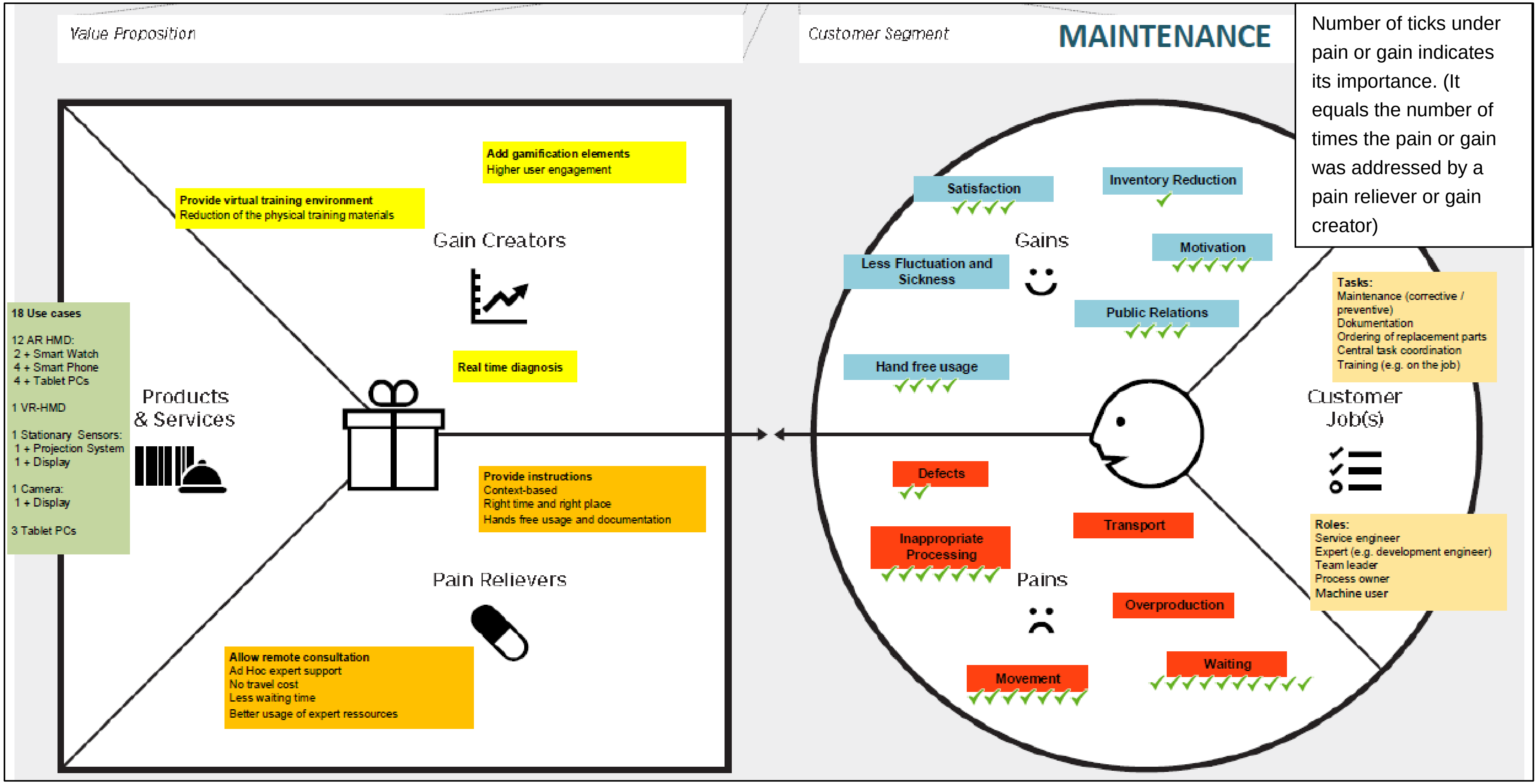


Figure 31: Value Proposition Canvas for the maintenance segment (adapted from (Kyhnau & Nielsen, 2015))

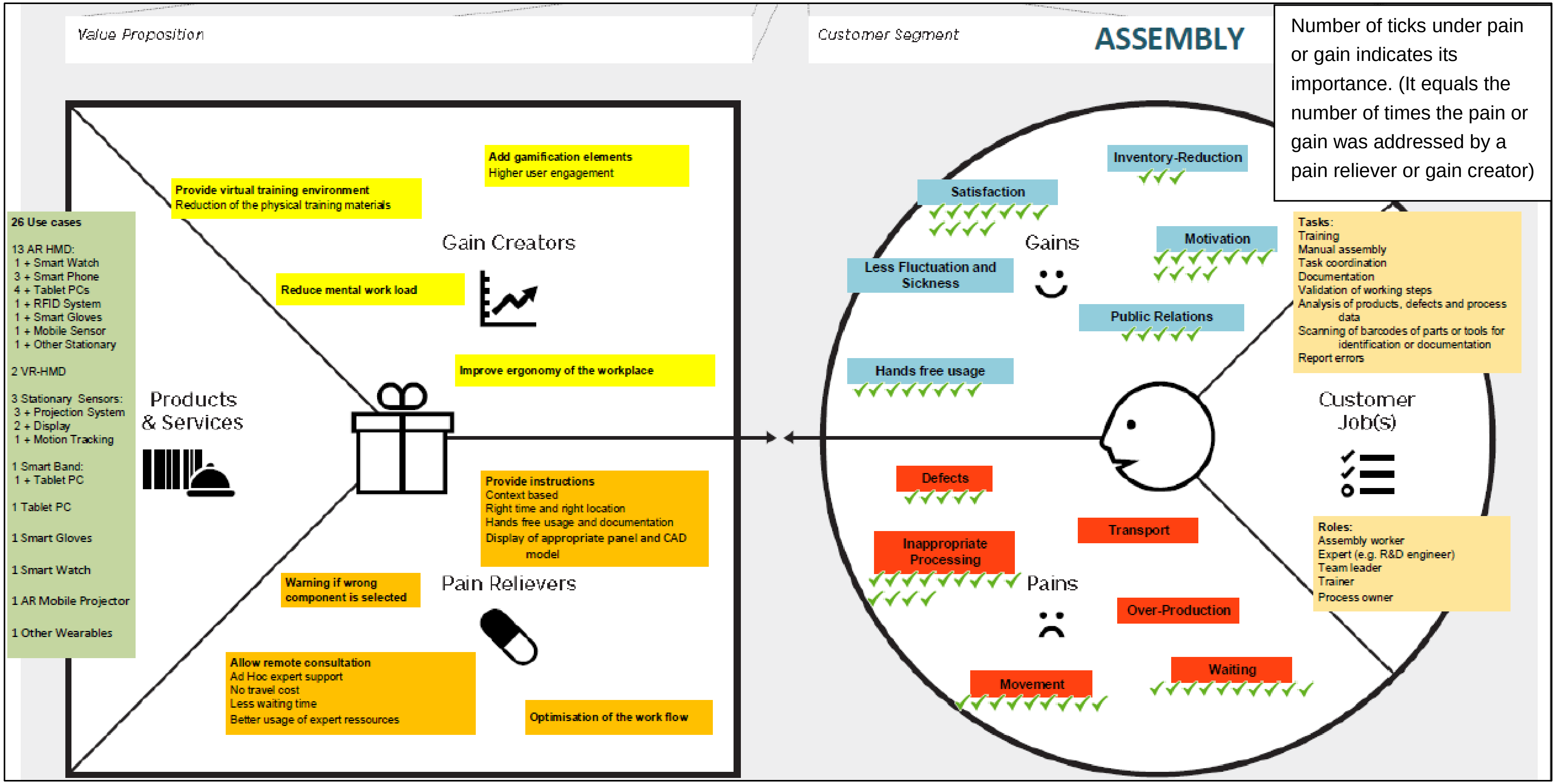


Figure 32: Value Proposition Canvas for the assembly segment (adapted from (Kyhnau & Nielsen, 2015))

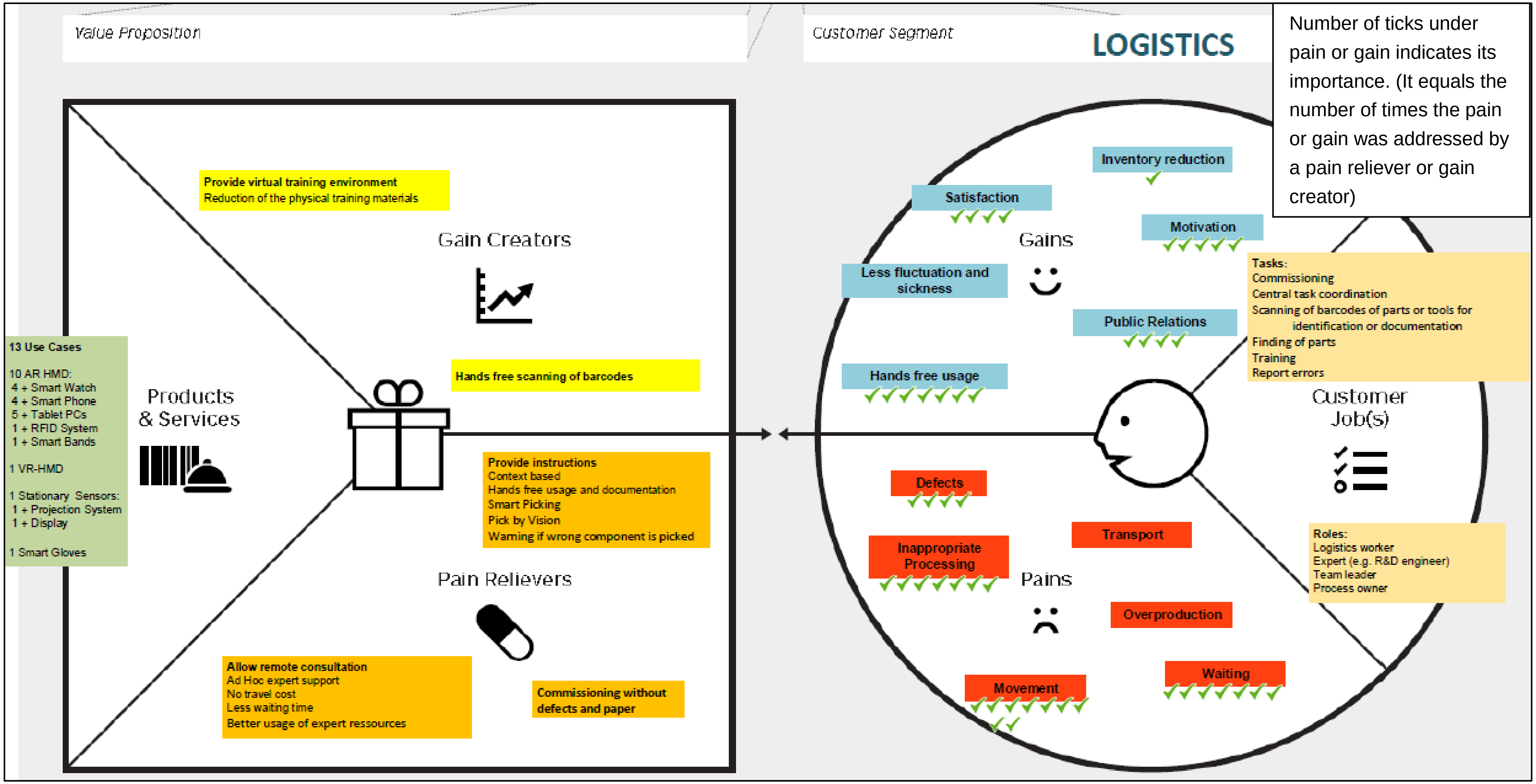


Figure 33: Value Proposition Canvas for the logistics segment (adapted from (Kyhnau & Nielsen, 2015))

4.3 Stage 3 – Use case selection

The initial overview was presented to potential customers and stakeholders shown in Table 8. This allowed identifying potential use cases, which were selected for further examination.

Table 8: Stakeholders and their remarks on potential use cases

Audience	Description	Remarks and feedback
G/FP-3 department	Project owner; departmental head with international experience in IT and manufacturing	Satisfied with presented review; especially interested in HMD and smart watch
CIO and IT leaders	CIO with international experience in IT	Saw big potential for assisting complex maintenance tasks, interior assembly and complex picking tasks
Logistics leader	Leader with experience in logistics	Interested, but currently no resources available at department
Series production leader	Leader with experience in production	Interested, but currently no resources and no appropriate test environment available
Pre-series production manager	Manager with international experience	Especially interested in assistance systems for maintenance and assembly assistance; good test environment available
Maintenance leader	Leader with long operational, but relatively short managerial experience	Saw significant savings potential in assisting maintenance workers

The project owner selected the **maintenance remote consultation use case** for further development, because this can be potentially applied in all the three areas maintenance, assembly and logistics. Moreover, the literature review had shown a high potential for communication- and assistance use cases (see chapter 2.1.4.2).

4.4 Stage 4 – Requirements definition

For the maintenance remote consultation use case selected above, the requirements were defined with an iterative approach of elicitation, documentation and validation described below. These requirements were defined together to the author’s colleague Philipp Url, who was working on a similar use case. First, interviews and process analysis were performed with relevant process stakeholders (see Table 9). Based on this information a set of requirements was iteratively defined.

Table 9: Overview of interviews and process analysis with process stakeholders for requirements elicitation

Role description	Remarks and feedback
Leader for Total Productive Maintenance	• Explained organisational structure and performance measurement • Sent documents for process analysis: job descriptions, flow charts, task instructions
Experienced maintenance engineer	• Explained his role and tasks and later gave feedback on requirements

Based on the performed interviews and process analysis, a VPC and a storyboard specific to this use case were created (see Appendix A and B). A use case specification scheme based on Requirements Engineering (Rupp, 2009) summarised the use case (see Table 10).

Table 10: Use case specification scheme for maintenance remote consultation

Name	Remote Assistance for Maintenance
Short Description	The use case describes the process of line engineers getting interactive remote assistance from an expert
Actors	"Meng": Maintenance engineer (line), "Mexp": Maintenance expert (internal or external)
Precondition	Augmented reality device (AR-HMD), server (PC running inside of network with started server application), Tablet/computer to display the viewpoint of the Meng to Mexp
Trigger	Meng decides to ask for assistance
Typical Process	- Meng stands at specific machine and needs to perform a preventive/corrective maintenance action - Meng realises that he needs assistance - Meng puts on and starts the AR-HMD - Meng selects problem category in the system - System selects most appropriate expert based on qualification and availability - Mexp sees problem category, task description (if available) and gets problem description from Meng - Mexp may open in parallel data sheets, other instructions or other documents - Mexp sees viewpoint of Meng and gives instructions verbally - Mexp indicates a task by giving graphical annotations (e.g. drawing at specific object) - Meng performs all tasks correctly - Meng thanks Mexp - Recording is saved for future documentation - Mexp decides whether he wants to use recording for future training; asks Meng for permission
Additional Constraints	- It shall be visible for others if video or voice recording is active or if a picture is taken. - Meng needs to agree to use of recording for not anonymous storage

Based on this information a first draft of requirements was created. This was then presented to the process stakeholders (see Table 9 for process stakeholders), iterated and defined in Table 11.

Table 11: Elicited requirements and their definitions

Category	No	Requirement	Definition
Technology	1	Long Availability (Connectivity)	Constant and long availability of technology due to multiple connection capabilities
	2	Ergonomically long usable	Uninterrupted long use is ergonomically possible
	3	Hands-free operation	Allows hands to be focused on work
	4	Small and light	User effort for carrying
	5	Useable with gloves	Can be operated with gloves; does not interrupt work flow
	6	Low maintenance effort	E.g. load battery, calibrate, clean
	7	Robustness	Against physical influences
	8	Long battery duration	Usage time of technology before charging is required
	9	Visualisation capabilities	2D or 3D, texts, graphics, holograms
	10	Control capabilities	Offers easy and intuitive control possibilities
	11	Recording capabilities	Speech, pictures, videos
	12	Audio quality	Quality of the audio output capabilities
Process-relevant	13	Start-up effort	The required to start the product before every usage
Organisation	14	User acceptance	User will most likely accept technology
	15	Privacy	Respects the privacy of the user
	16	IT infrastructure compatibility	Integration in Microsoft Platform
	17	Workplace security standards	Effort to fulfil workplace security standards
	18	IT security standards	Fulfils existing IT security standards
	19	PR Potential	Influences public relations in a positive way
Start-effort	20	Development effort	Initial one-time programming, calibration, configuration
	21	User Training	Effort for training and learning

4.5 Stage 5 – Technology pre-selection

In this stage various technology alternatives were assessed and thereby pre-selected based on the requirements defined in the previous stage.

The whole process is based on the Value Benefit Analysis. It allows a quantitative comparison of technologies through qualitative criteria (Schuh & Klappert, 2011, p. 327ff). It consists of the following four steps:

4.5.1 Weighting of requirements

Based on the information gathered from the process stakeholders (see Table 9), the requirements defined above were relatively assessed. In this assessment matrix, shown in Table 12, only the right side of the diagonal was manually filled with a 1 if the row element was considered more important than the column element or with a 0 if not.

Table 12: Assessment matrix of Value Benefit Analysis

		Technology												Proc	Organisation						Start			
	Assessment Guideline: 0=less important than other criterion 0,5=equally important as other criterion 1=more important than other criterion	Long Availability (Connectivity)	Ergonomically long usable	Hands-free operation	Small and light	Useable with gloves	Low maintenance effort	Robustness	Long battery duration	Visualisation capabilities	Control capabilities	Recording capabilities	Audio quality	Startup effort	User acceptance	Privacy	IT infrastructure compatibility	Workplace security standards	IT security standards	PR Potential	Development effort	User Training	Sum of Points	Weighting [%]
Technology	Long Availability (Connectivity)		0	0	1	0	1	1	0.5	0	0	0	0	0.5	0	0	0	0	0	1	1	0.5	**6.5**	**3.1**
	Ergonomically long usable	1		0	1	1	0.5	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	**7.5**	**3.6**
	Hands-free operation	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	**18**	**8.6**
	Small and light	0	0	0		0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	1	0.5	0	**3**	**1.4**
	Useable with gloves	1	0	0	1		1	1	1	0	0	0	0	0.5	0	0	0	0	0	1	1	1	**8.5**	**4.1**
	Low maintenance effort	0	0.5	0	1	0		0.5	0.5	0	0	0	0	0	0	0	0	0	0	1	1	0.5	**5**	**2.4**
	Robustness	0	0	0	0.5	0	0.5		0	0	0	0	0	0	0	0	0	0	0	1	1	0	**3**	**1.4**
	Long battery duration	0.5	0	0	0	0	0.5	1		0	0	0	0	0	0	0	0	0	0	1	1	0.5	**4.5**	**2.2**
	Visualisation capabilities	1	1	0	1	1	1	1	1		1	1	0	1	0.5	0	0	0	0	1	1	1	**14**	**6.5**
	Control capabilities	1	1	0	1	1	1	1	1	0		1	0	0	0	0	0	0	0	1	1	0.5	**11**	**5.0**
	Recording capabilities	1	1	0	1	1	1	1	1	0	0		0	0	0	0	0	0	0	1	1	0.5	**9.5**	**4.6**
	Audio quality	1	1	0	1	1	1	1	1	1	1	1		0	0	0	0	0	0	1	1	0.5	**13**	**6.0**
Proc	Startup effort	0.5	1	0	1	0.5	1	1	1	0	1	1	1		0	0	0	0	0	1	1	1	**12**	**5.8**
Organisation	User acceptance	1	1	0	1	1	1	1	1	0.5	1	1	1	1		0	1	0	0	1	1	1	**16**	**7.4**
	Privacy	1	1	0	1	1	1	1	1	1	1	1	1	1	1		1	0.5	0.5	1	1	1	**18**	**8.6**
	IT infrastructure compatibility	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0		0	0	1	1	1	**15**	**7.2**
	Workplace security standards	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0.5	1		1	1	1	1	**19**	**8.9**
	IT security standards	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0.5	1	0		1	1	1	**18**	**8.4**
	PR Potential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	**2**	**1.0**
Start	Development effort	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	**0.5**	**0.2**
	User Training	0.5	1	0	1	0	0.5	1	0.5	0	0.5	0.5	0.5	0.5	0	0	0	0	0	0	1		**7.5**	**3.6**
																							209	**100.0**

This assessment matrix resulted in a weighting of requirements, which is illustrated in Figure 34.

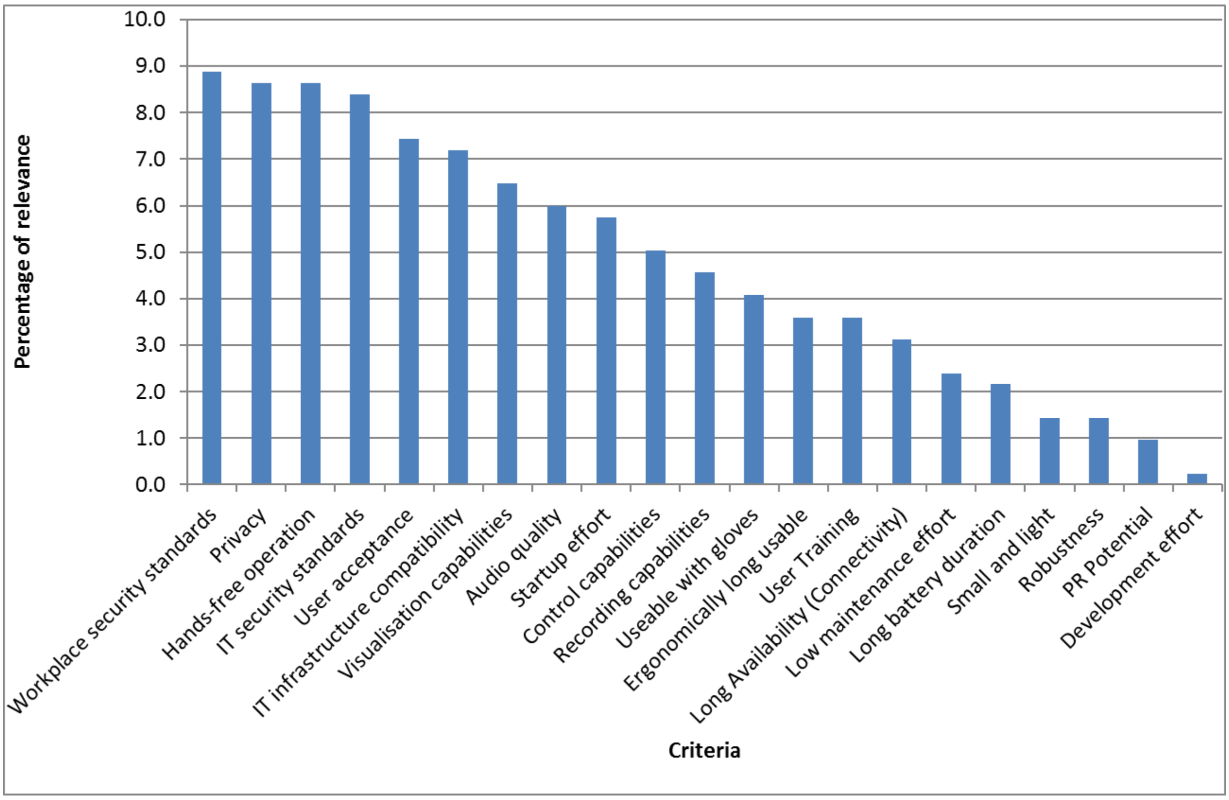


Figure 34: Relative importance of requirements based on use case needs according to process stakeholders

4.5.2 Definition of value scale for requirements

For all requirements a value scale was defined in order to assess the technology alternatives (see Table 13). This value scale was defined in a workshop with a technology scouting expert at AHM.

Table 13: Value scale for assessment of requirements

	0 Unsatisfactory	1 Barely acceptable	2 Satisfactory	3 Good	4 Very good
Long Availability (Connectivity)	no connections	1 connection (WIFi or Bluetooth or 3G/LTE or USB	2 connections	3 connections	> 3 connections
Ergonomically long usable	less than 10 min	10 min < x < 1 h	1h - 24h	one work day	unlimited
Hands-free operation	no hand free	sometimes 1 hand free	1 hand always free	sometimes 2 hands free	always 2 hands free
Small and light	> 2kg	1 - 2 kg	0,5 - 1 kg and well balanced weight	up to 500 g and well balanced weight	no force effort
Useable with gloves	can not be operated with gloves	problems with gloves	gloves possible	gloves possible + 1	3 possible (gloves, glasses, no cable)
Low maintenance effort	x	every hour	daily	every 2 days	weekly
Robustness	not usable long-term in production	quite sensitive	office standard	higher office standard	industrial standard (water, dust, oil)
Long battery duration	< 1 h	1 - 4h and no changeable battery	1 - 4h and battery is changeable	4 - 24h	>=1 day
Visualisation capabilities	no display	only pictogramms / signals	only big text and symbols	lots of text readable	also details readable, e.g. 3D holograms or videos
Control capabilities	no	only through special device	1 (speech, or gestures or touch or keyboard)	2	3 or more
Recording capabilities	no	x	audio or video	x	audio and video
Audio quality	no audio	bone conduction transducer	mono	stereo	integrated spatial sound
Startup effort	> 30 min	15 - 30 min	5 - 15 min	1 - 5 min	immediately ready
User acceptance	unlikely - new and hardly acceptable	x	likely - new but interesting	x	very likely - known and used to it
Privacy	users have no controll about collected data	x	partially in control of the users	x	data is in full control of the users
IT infrastructure compatibility	incompatible with Microsoft platform	x	other than Windows Microsoft but compatible with effort	x	Microsoft Platform
Workplace security standards	not fulfilled product adaptations required	x	additional user trainging required	x	fulfilled no additional effort required
IT security standards	not fulfilled Cloud / external Server	x	partially fulfilled (additional integration effort required e.g. Android OS)	x	fulfills standard IT security policies (e.g. Microsoft platform)
PR Potential	no public interest	x	sellable	x	big publicity expected
Development effort	external programming	internal programming	external config + calibration only; no programming	internal config + calibration only; no programming	no effort
User Training	longer special training	x	only short inhouse training required	x	no training required

4.5.3 Selection of technology alternatives and definition of technology specifications

In the above mentioned workshop with the technology scouting expert, four technology alternatives were selected. The initial review had made it clear that HMDs and tablets had the biggest potential and best fit with the process requirements. The HMDs Microsoft Hololens and ODG R7 were selected based on their capabilities and market availability. The Dell Venue 10 was selected as tablet, because it was used as a standard at AHM and due to its low price. The Telerobotics Double 2 was selected as another tablet alternative, because the technology scouting expert saw it as an interesting solution for Remote Consultation.

4.5.4 Technology assessment

In a different workshop with the technology scouting expert the alternatives were assessed. Table 14 shows the assessment of the technology alternatives and the current situation using mobile phones. It is based on the above value scale and the technology specifications.

Table 14: Technology assessment matrix

		HMD				Telerobotics		Tablet PC		Current situation	
		Microsoft Hololens		ODG-R7		Double 2		Dell Venue 10		Mobile phone	
Criteria	**Weighting**	Assessment	Weighted	Assessment	Weighted	Assessment	Weighted	Assessment	Weighted	Assessment	Weighted
Long Availability (Connectivity)	3.1	3	0.09	4	0.12	2	0.06	1	0.03	4	0.12
Ergonomically long usable	3.6	3	0.11	3	0.11	3	0.11	3	0.11	2	0.07
Hands-free operation	8.6	4	0.35	2	0.17	3	0.26	2	0.17	2	0.17
Small and light	1.4	2	0.03	1	0.01	4	0.06	2	0.03	3	0.04
Useable with gloves	4.1	3	0.12	4	0.16	3	0.12	4	0.16	1	0.04
Low maintenance effort	2.4	2	0.05	2	0.05	3	0.07	3	0.07	2	0.05
Robustness	1.4	2	0.03	2	0.03	2	0.03	3	0.04	3	0.04
Long battery duration	2.2	1	0.02	1	0.02	3	0.06	3	0.06	3	0.06
Visualisation capabilities	6.5	4	0.26	3	0.19	3	0.19	3	0.19	2	0.13
Control capabilities	5.0	3	0.15	3	0.15	3	0.15	3	0.15	2	0.10
Recording capabilities	4.6	4	0.18	1	0.05	4	0.18	4	0.18	4	0.18
Audio quality	6.0	4	0.24	4	0.24	2	0.12	2	0.12	4	0.24
Startup effort	5.8	4	0.23	4	0.23	4	0.23	3	0.17	4	0.23
User acceptance	7.4	2	0.15	2	0.15	2	0.15	4	0.30	4	0.30
Privacy	8.6	4	0.35	0	0.00	2	0.17	2	0.17	2	0.17
IT infrastructure compatibility	7.2	4	0.29	2	0.14	2	0.14	4	0.29	2	0.14
Workplace security standards	8.9	2	0.18	2	0.18	2	0.18	4	0.35	4	0.35
IT security standards	8.4	4	0.34	2	0.17	4	0.34	4	0.34	2	0.17
PR Potential	1.0	4	0.04	4	0.04	2	0.02	2	0.02	0	0.00
Development effort	0.2	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
User Training	3.6	2	0.07	2	0.07	2	0.07	4	0.14	4	0.14
	Sum	**3.26**		**2.29**		**2.72**		**3.12**		**2.77**	

Figure 35 shows the assessment results of the five technology alternatives. The Microsoft Hololens HMD and the Dell Venue 10 Tablet had the highest Value Benefit Score and were therefore selected for a financial estimation, which will be described in stage 6.

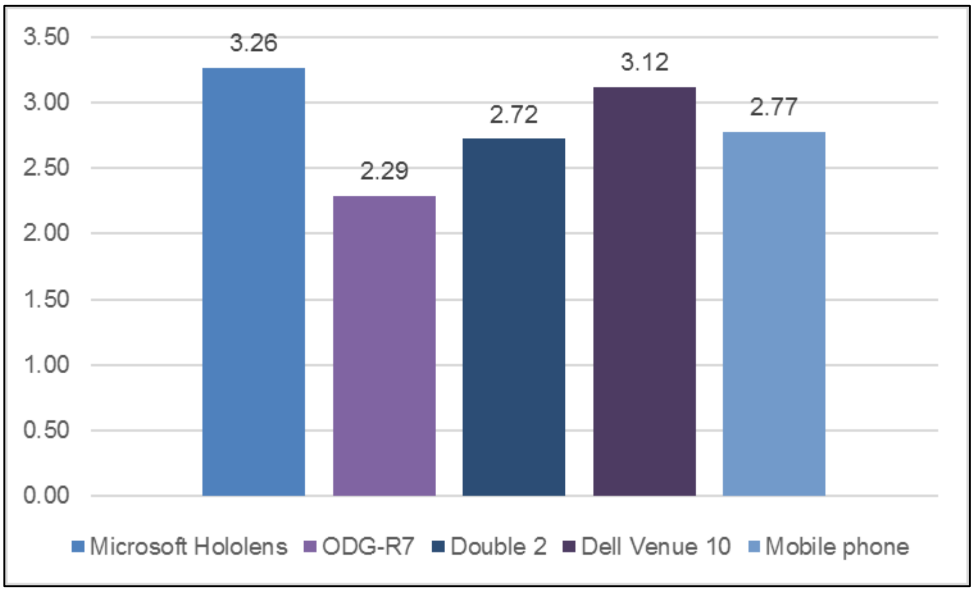


Figure 35: Technology assessment based on use case requirements

4.6 Stage 6 – Final selection of technology

The key stakeholders of this thesis project decided to undertake a rough cost benefit analysis for the most promising technologies analysed in the previous step and to base the final decision on it.

The cost benefit analysis model presented in chapter 2.3.1 was adapted to this use case. The structure of the analysis is shown in Table 15.

Capital costs were neglected, because most figures relied only on assumptions, and monetarily not sizeable conditions were neglected as well, because they had already been considered during the value benefit analysis. Therefore, the net benefit of each specific technology was calculated following these steps:

- Identification of cost and benefit
- Calculation of the net benefit
- Assessment of the alternatives

The costs were estimated based on the Total Cost of Ownership Model (see chapter 2.3.2): both direct and indirect costs were considered. For both the Microsoft Hololens and the Dell Venue 10 Pro a net benefit was estimated with a lower- and an upper boundary.

Table 15: Structure of cost benefit analysis (Schuh & Klappert, 2011)

Category name			Category definition	Method of estimation or assumption
Cost (TCO)	Direct Costs	Hardware	Device and infrastructure	Current price known
		Software	Additional software cost	Standard development cost estimated
		Operations	Device maintenance, IT system maintenance, training, energy, operation cost	Number of lost workdays per year estimated
		Administration	Other admin (standard overhead)	Always neglected for investments at AHM
	Indirect Costs	End User Operations	Employees loosing time due to new system (e.g. Open Office introduction)	Number of lost workdays per year estimated
		System downtime	Due to not-availability	Percentage of potential savings assessed, which is not realised
Benefits (Potential savings)		Machine downtime	Machine waiting for repair	Percentage of OEE increase estimated
		Personnel cost	Employees waiting time, training, documentation, less movement	Percentage of cost of a work year estimated
		Travel cost	Travel for expert	Mean travel cost estimated and number of users assumed
		Error reduction	Due to misunderstandings, time pressure	Percentage of OEE increase estimated

The cost benefit analysis was internally done; however, it was concluded that it is too difficult to estimate costs for this very new technology. This cost benefit analysis can be seen as a basis for possible further evaluations, such as a pilot test run.

4.7 Stage 7 – Evaluation

The results of the previous sections were presented to the process stakeholders and the head of the author's department. In this one-hour session these stakeholders were asked for their opinion on the effectiveness of the mapping.
Moreover, the pre-installed Hololens Skype application was used as a first Proof of Concept and tested by the maintenance engineer.

The process stakeholders confirmed that the mapping was successful in their opinion. According to them the requirements described the process needs appropriately and the selected technology addressed these requirements well.
László Keller, Head of IT Customer Order Process and owner of this thesis project within Audi Hungaria, stated: *"In my view the defined requirements and selected technology fully reflect the needs of a maintenance engineer during a remote consultation."* When the maintenance engineer tested the Hololens Skype application he said: *"This technology would be able to improve my work significantly."*
Everybody agreed that a more detailed and realistic evaluation is only possible with a prototype test run.

4.8 Stage 8 – Value network analysis

In chapter 2.2 the enhanced V^2 Value Network Notation was described based on Vorraber & Vössner (2011) and the recent enhancements (Vorraber, 2016). In this chapter a Value Network Analysis is presented for the remote consultation use case described above.

Table 16 gives an overview of all direct actors, which are more actively involved, and the indirect actors, which are more passively involved in the interactions. All categories of capabilities, assets and needs described in chapter 2.2 are represented in this overview, except the social human- and legal needs, which were not identified for the relevant actors. Based on this tabular overview a map was created, which is shown in Figure 36, to visually present the known network constellations. The interconnections were shown with the exchange of transfer objects, endogenous motivation and exogenous influence.

This Value Network Analysis will be the basis for the further use case implementation, such as a possible pilot project. As follows some observations are made:

- The project owner department wants to be both innovative and practically relevant. Thus, early practical relevance of the use case will need to be assured, so the project owner department will be able to promote itself as an innovative and satisfying partner.

- The corporate headquarters of VW AG and Audi AG have the need of the use case to conform to corporate regulations and to be scalable. This means that the use case should be able to potentially be applied to lots of other corporate plants.
- The clearance from internal and external IT- and safety regulators is crucial for the success of the use case implementation. Their needs are the fulfilment of IT security standards (e.g. both sides identification) and workplace safety standards.
- The employees' acceptance will be crucial for the success of the pilot project and possible further phases. Their most important needs are the reliability and efficiency of the service, a relief of pressure instead of additional workload through the service and finally the employees should be in control of the data they are sharing.

To conclude, the employees' acceptance of the service will be the most important factor. They need to be convinced that they are in control of their own privacy and that their job will become easier using this service. Moreover, the managerial support from Audi AG and VW AG depends on not only the scalability, but also the strategic fit of this use case in the corporate innovation portfolio.

Table 16: Overview of actors and their properties in the V^2 Value Network of the remote consultation use case

		Actor	Capabilities (C)	Assets (A)	Needs				
					Functional (FN)	Non functional			
						Technical (TNFN)	Social economic (SEN)	Ethical (EN)	Safety (SN)
Direct Actors	1	AHM Technischer Service (internal maintenance team)	Know process/machine Measure and report KPIs (e.g. OEE)	Process experience and documentation	Getting support by experts for maintenance tasks Both sides identification User in control of data sharing	Fast and intuitive use	Promote themselves as innovative	Privacy (anonymised data) Relief of pressure	Safety Privacy
	2	AHM MAC (production)	Support testing and know processes	Machines/equipment Engineers/operators	Both sides identification	High machine availability	Promote themselves as innovative	Efficient use	IT security
	3	AHM Motor IT G/FP-3	Manage Project Establish contacts/credibility	Personell IT projects- / -process knowledge	Integration in IT environment	Provision of services with relevance	Promote themselves as innovative Satisfied partners and leaders	Innovation Practical relevance	IT security Safety
	4	TU Graz (MBI)	Lead development and testing	Methodical-/ scientific knowledge Personell with view from outside	Integration in IT environment (e.g. TPM 4.0)		Promote themselves as good academic partner with high industrial relevance	High academic quality High industrial relevance	
	5	External partner 360 World	Develop software Help providing Hololens	Experience in AR software development Good contacts to Microsoft	Running app		Foster cooperation with Audi and Microsoft by showing industrial relevance of technical capabilities		
	6	Machine suppliers / experts	Know machine in detail	CAD drawings Specific problem knowledge	Good integration with their databases and organisational structure		Promote themselves as innovative and responsible Foster relation to Audi	Reliability	IT security
Indirect Actors	7	VW Wolfsburg / Audi Ingolstadt / AHM Leadership	Control Support Expand	Money Information Contacts	Good brand representation Good integration in own services	Scalability Improved processes across all plants (higher availability and higher OEE)	Promote themselves as innovative Acceptance of employees / work council	Corporate responsibility Conformance to regulations	
	8	IT Security (G/FP-1) / IT Infrastructure (G/FP-5)	Validate technology and application	Clearance Information	Both sides identification	IT clearance (appropriate level of security)	Promote themselves as innovative	Standards conformance Infrastructure integration	IT security
	9	Microsoft	Produce hardware: Hololens Produce software: Win10, Skype	Hardware Software	Show relevance of Hololens functionalities		Industrial application for Hololens (PR) with well-known industrial partner Foster contact to Audi	System integration	
	10	Workplace security and employees' safety groups	Validate technology and application	Clearance Information		No health impairment	Meet safety standards Privacy needs of employees considered	Health Ergonomics	Safety Privacy

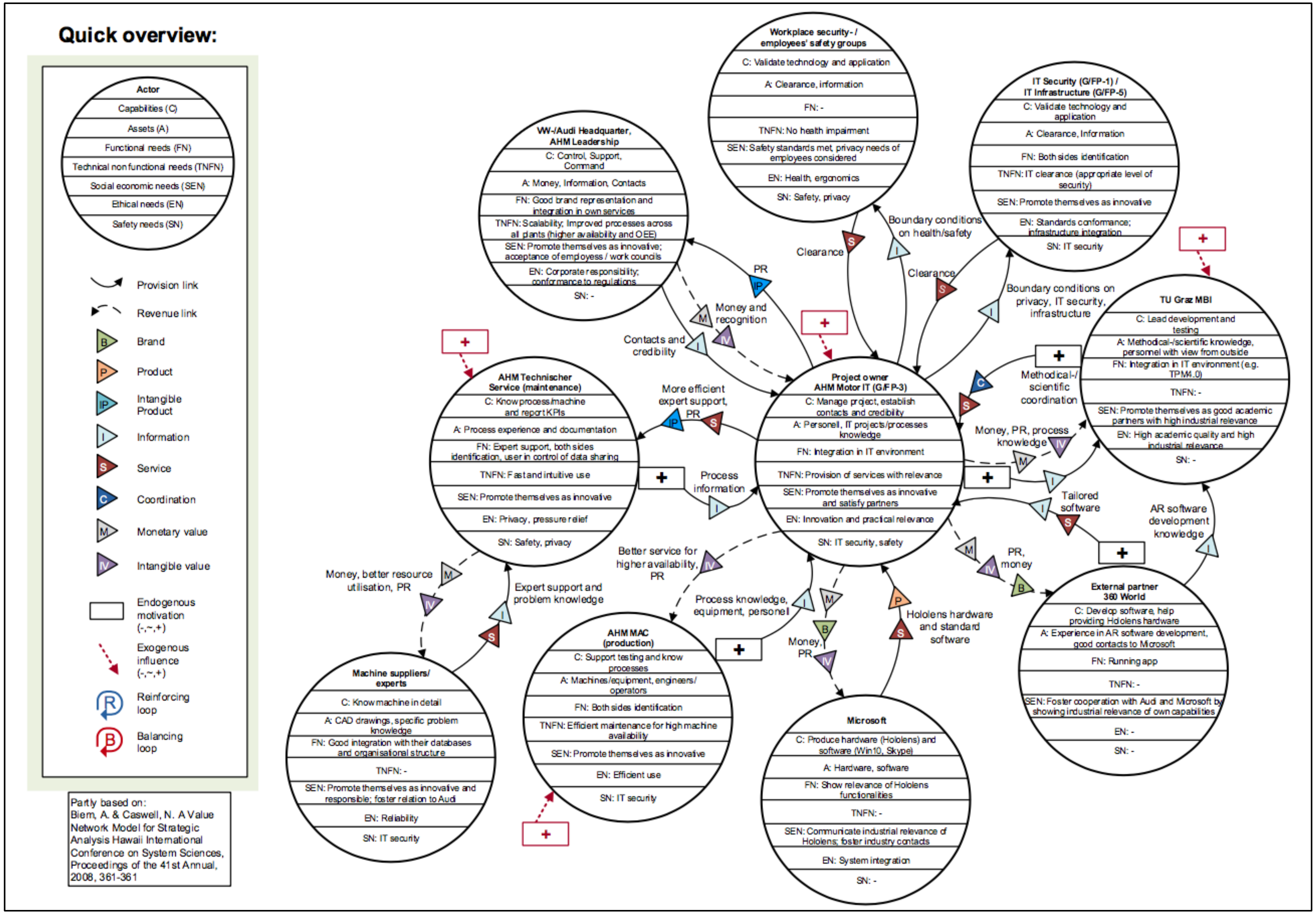


Figure 36: V² Value Network Map for the remote consultation use case

5 Discussion

In this chapter the research questions are answered and the achievement of the industrial challenges is discussed. The relevance within the academic context is discussed. The methodology is discussed and recommendations for similar projects are given. Finally, the results are explained and interpreted.

The **research questions** could be answered successfully and thereby the **industrial challenges** were addressed.

- The first research question asked how AR use cases and technologies relevant for automotive industry can be abstracted and categorised. A categorisation of devices into wearable, mobile and remote and a categorisation of use cases based on the company department (assembly, maintenance, logistics etc.) and the function (training, assistance, monitoring, etc.) was proposed. Thereby AHM's need for a comprehensive overview could be addressed and reflecting this with internal conditions allowed selecting a use case at AHM, which was maintenance remote consultation.
- The second research question asked how Vorraber et al.'s (2014) use case technology mapping framework can be applied to the automotive industry. This framework was successfully applied to the industrial environment in AHM by developing a process that bases the technology selection on process requirements and financial factors. Thereby AHM's industrial challenge of identifying the appropriate technology for the use case was successfully addressed by identifying Microsoft Hololens as the best option.
- The last research question asked how potential costs and benefits can be considered in the consideration. Various authors described the difficulty of assessing monetary factors for such young technologies at this early development stage. Nevertheless, a scheme was proposed for assessing Total Cost of Ownership and potential benefits. By that, AHM's industrial need for a rough financial outlook could be addressed.

This research sets itself apart from similar research in the **academic context**. Dini & Dalle Mura (2015) and Nee et al. (2012) also proposed an overview of AR use cases and technologies. However, they analysed tools and applications separately and focused more on the technical challenges of tracking, registration, portability etc., whereas the focus in this thesis was on the process and the user. With more and more mature AR hardware and software the difficulty is more to understand the process and the user. Nee et al. (2012) stated in their Future Trends section "The crucial factor is to identify applications which will benefit the user […] to carry out work more efficiently." Livingston (2005) asked: "How can we know which applications will benefit users until good interfaces exist?" The answer this thesis proposed is the orientation on user- and process requirements and needs. This was achieved by applying Vorraber et al.'s (2014) and (2015) IT service development procedure in the automotive industry and by analysing strategic risks and opportunities with the V^2 Value Network developed by Vorraber & Vössner (2011).

In general, the followed **methodology** was good and effective, but there was some potential for improvement. The following **recommendations** can be given for similar future projects. Even though the author tried to work iteratively, there should have been more iterative cycles in the followed Stage Gate Process, e.g. by involving the user earlier and more often. Due to time limitations, the definition and weighting of user requirements was only done with two process stakeholders. Ideally it should be done with a bigger user group and users with more different backgrounds. It was good to leave the technology selection to the end in order not to restrict the use case to specific technology specifications.

The presented **results** can be **explained and interpreted** as follows:

- The first part of the results were the current practice and challenges:
    - The quality of these results depends on the quality of the analysed literature. Only an extract of the existing AR use cases could be evaluated, trying to make this extract as representative as possible.
    - The most significant pain relievers, gain creators and used technologies were identified for every user segment; however, this is not exhaustive, amongst others because technology and processes evolve rapidly.
    - The selected use case was elicited for AHM through presentations to potential users. The selected use case was most appropriate at that moment based on AHM's constraints, but this might change over time.
- The second part of the results was the proposed use case technology mapping process:
    - The list of requirements depends on who was asked. If e.g. managers were asked, the requirement "PR" would be more important than for potential users.
    - The technology assessment was only done by the author with a technology expert; ideally more people would assess this independently.
    - The biggest insecurity of the process lies in the cost benefit analysis, which was therefore not considered in the technology selection. Only a prototype test run can give more accurate results.
    - The positive feedback from key company stakeholders confirms the effectiveness of the mapping process.
- The last part of the results was the V^2 Value Network specific to the derived use case:
    - This was based on past interviews, workshops and informal conversations; thus, the quality of this analysis partly depends on the subjective interpretations of the author.

6 Conclusions and future work

In this chapter the achievement of the aim and objectives is concluded and opportunities for future work are presented.

The aim of developing a process to justify the benefit of AR use cases in the automotive industry and map potential use cases with technological products was achieved overall.

1. The objective of carrying out a review of the state of the art was successful and the current practice and challenges were identified and analysed.
2. Use cases and technologies were compared, challenges and trends were examined. Relevant information was visually displayed and presented to relevant stakeholders. The maintenance remote consultation use case was elicited by reflecting the current practice and challenges with the internal company constraints.
3. A process to map AR technologies and use cases was successfully developed by refining and validating a scheme proposed by Vorraber et al. (2014).
4. The proposed process was validated with the selected use case at AHM. The process resulted in the selection of Microsoft Hololens as the most appropriate technology. The key stakeholders in AHM confirmed the effectiveness of the proposed process.
5. Strategic risks and opportunities for the developed use case were analysed developing a V^2 Value Network Map.

There are many opportunities for future work. An expansion of this use case to the areas of quality control and pre-series assembly will be analysed. The review of the current practice and challenges needs to be constantly updated. The followed methodology for structuring the review, based on VPC, can be applied to areas other than AR. The proposed mapping process can be validated in other companies of the automotive industry or adapted to other industries, e.g. the aerospace industry.

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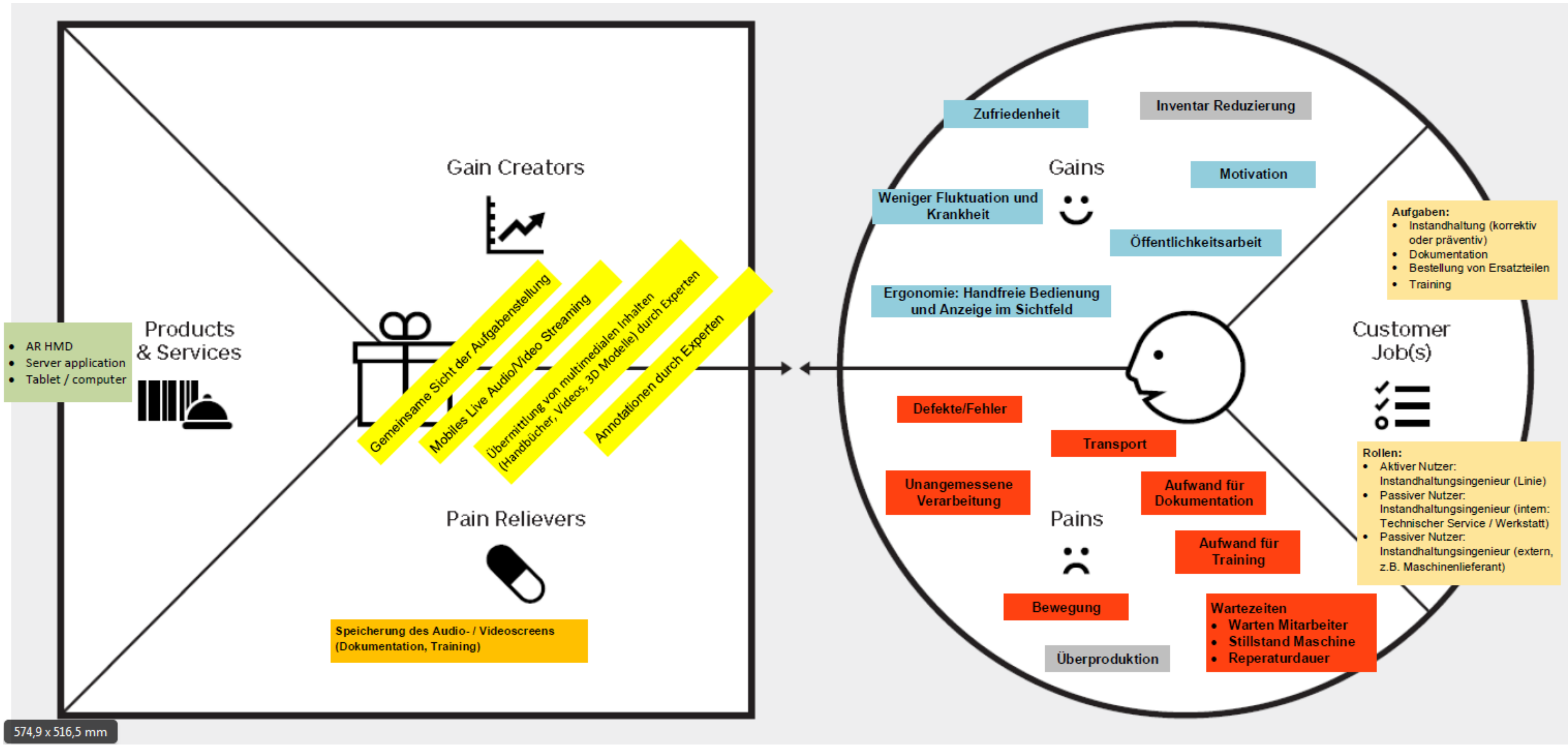
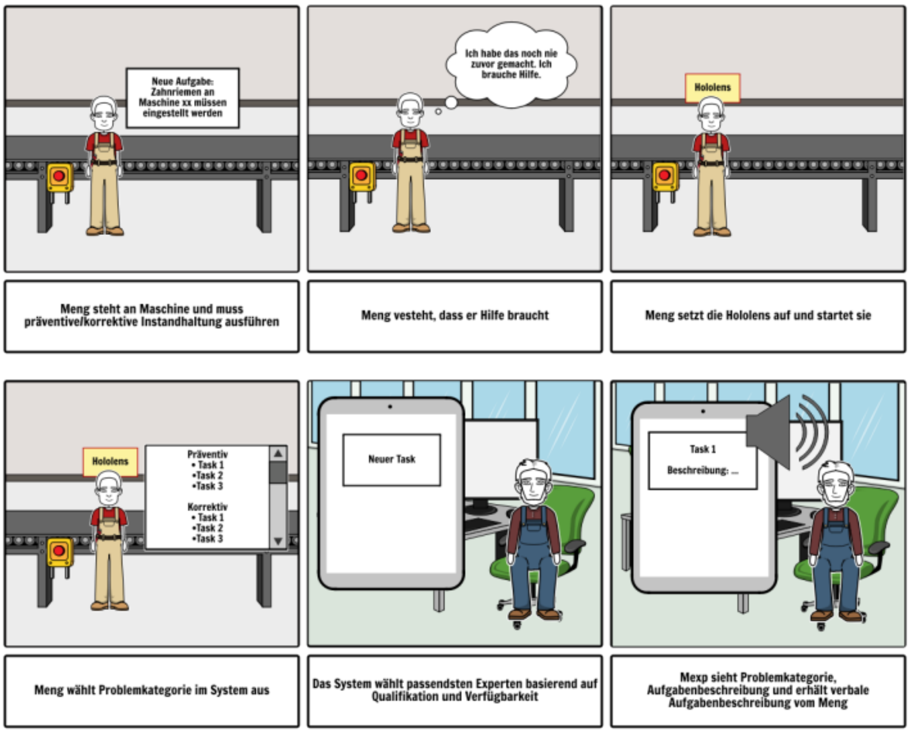
APPENDICES

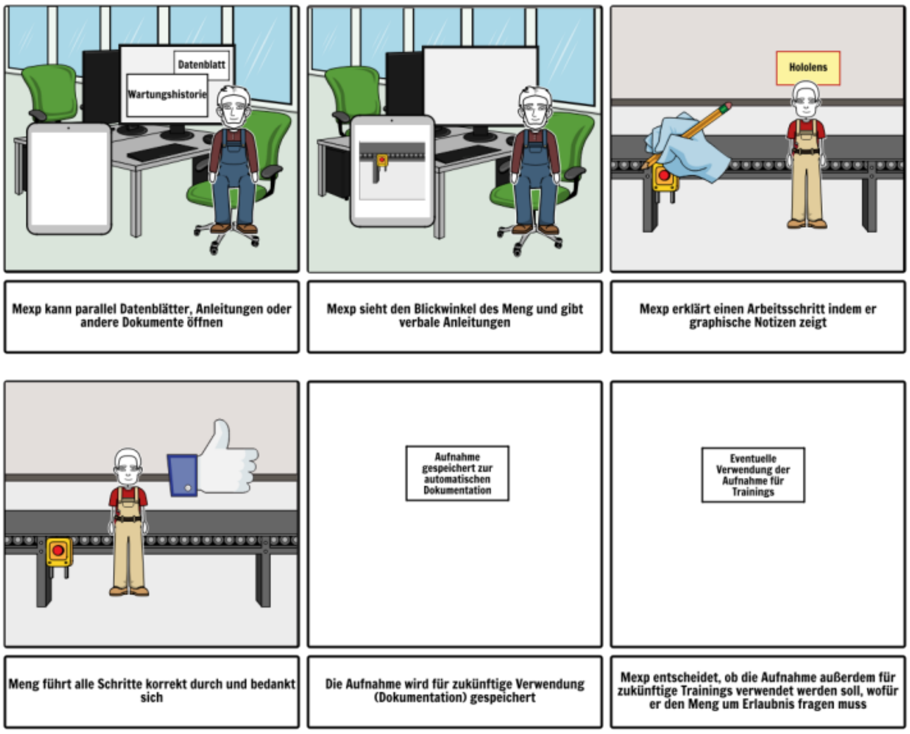
Appendix A - Value Proposition Canvas for maintenance remote consultation use case



Appendix B – Storyboard for maintenance remote consultation use case



Create your own at Storyboard That



Create your own at Storyboard That