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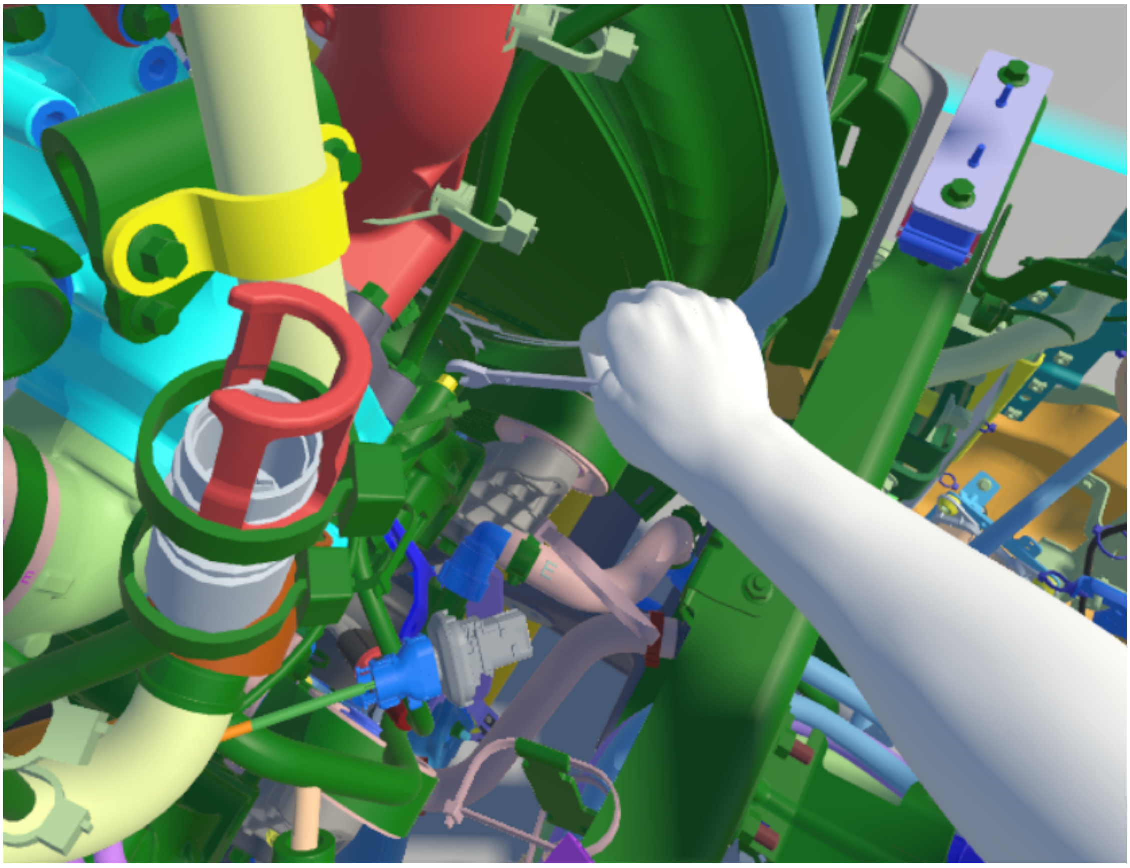

Virtual Reality in Maintainability

Case study of the possibility to support challenges at Volvo GTT AMT with Virtual Reality

Master's thesis in Production Engineering

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

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Abstract

After-sale products and services have become an important part of the vehicle business. Service solutions, which are sold with the product, are a large part of the revenues connected to the product. The focus on the maintainability aspects of the product is then important.

The study presented in this master's thesis is performed at the department of Aftermarket Technology (AMT) at Volvo Group Trucks Technology (GTT) in Gothenburg. Volvo GTT is aiming to give the customers as much up-time as possible by offering service-solutions as an additional product to the sold truck. The service solutions are based on maintainability analyses performed during the development process of the truck. Physical prototypes are built during the process, which are today used by AMT to perform maintainability analyses. Volvo GTT wants to shorten the development process and decrease the number of physical prototypes produced, which requires a new way to perform maintainability analyses. The new way need to give the ability to detect problems and make robust decisions earlier in the development process to shorten its time. The purpose of this master's thesis is to investigate the use of Virtual Reality as a supportive tool in the area of maintainability.

A literature review was conducted in order to investigate earlier research within the field. An empirical study was designed and conducted to identify challenges connected to virtual work in the current process at Volvo GTT AMT. Based on the identified challenges was a Virtual Reality environment built in the software Unity3D with a Head Mounted Display and Leap motion as used technology. Usability tests were conducted with participants from AMT and product development in the Virtual Reality environment to evaluate if Virtual Reality could be used as a supportive tool at Volvo GTT AMT.

The conclusions stated in this master's thesis are that Virtual Reality could support the communication, accessibility analyses and CAD data analyses performed in the development process.

Keywords: Virtual Reality, Virtual Maintainability, Aftermarket, Volvo Group Trucks Technology.

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Per Andersson & Johan Andreasson, Gothenburg, June 2017

Abbreviations

VR Virtual Reality

VE Virtual Environment

CI Contextual Inquiry

HMD Head Mounted Display

DMU Digital Mock-Up

RE Requirement Engineer

SE Service Engineer

VS Virtual Specialist

PD Product Development

GTT Group Trucks Technology

AMT Aftermarket Technology

SEIM Service Engineering And Information Management

R&D Research and Development

Contents

1
Introduction

In this study is the use of Virtual Reality in an aftermarket context investigated. This chapter includes a background to the subject, case company information, purpose and research questions and delimitations of the thesis.

1.1 Background

The level of competitiveness that exist on the global market today addresses companies to develop new strategies and think different (Peng et al., 2012). During the last decades, a trend among industrial manufacturers is to focus on additional services to their products. Investing efforts in this area is a factor for long-term growth, complementary to the traditional product business focus (Jacob & Ulaga, 2008). The area of services and maintainability in a product life-cycle is one of the areas who has a lot of economic potential (Vujosevic et al., 1995).

According to Peng et al. (2012) is maintainability "The degree to which a product can be maintained or repaired easily economically and efficiently". Maintainability and product after-sale services represent more than 30 percent of the total revenues for industrial manufacturing companies, and this is a growing part (Bundschuh & Devane, 2003).

The conventional traditional approach to maintainability with respect to the product development cycle is to perform the activity as a serial activity. The serial approach makes the development cycle longer, increases costs, and makes it harder to change potential design issues (Zhou et al., 2011). The traditional approach of maintainability and maintainability analysis requires a need of physical prototypes which implies economical costs, and a longer cycle for the analysis which leads to that the maintainability lags behind in the product development cycle. Further, the lag makes it harder to detect and change design issues early enough in the development process. There is a risk that some of the maintainability issues remain undetected until the product is manufactured and used by the end customer (Zhou et al., 2011).

By performing the maintainability analyses as parallel activities in the product development process, concurrent engineering, could design issues be detected in earlier phases. The use of virtual maintenance technology supports the concurrent engineering process (Zhou et al., 2011). There is a lack of physical prototypes in the early phases, which creates a need for other tools to perform maintainability analyses. The use of visualization and virtual tools, such as Virtual Reality, makes it possible to facilitate communication, perform control of the product and perform product maintainability validation (Peng et al., 2012). The research field of virtual maintenance is not fully studied and contains a lot of challenges (Zhou et al., 2011).

1.2 The Case Company

The company that will be studied is Volvo Group Trucks Technology (GTT). They are the second-largest heavy-duty truck brand in the world and make vehicles that are sold and serviced in more than 140 different countries all over the world (Volvo Group Trucks Technology, 2017). The case study will be performed at the department of Aftermarket Technology (AMT). AMT is a department under Volvo GTT Complete Vehicle.

Volvo GTT is operating in a competitive global market which implies a lot of challenges. Volvo GTT is offering service agreements as a complementary product to the truck to let the customers have as much up-time of their truck as possible by performing preventive maintenance of the truck. Services is a lucrative area for the company and the business focus is moved towards revenues from services and spare parts rather than revenues from manufactured and sold trucks.

The business of service offers requires maintainability analyses during the product development process. In order to estimate the cost of services, there is a need to perform maintainability analyses to make it possible to design for maintainability. It must be possible to repair, replace parts and perform services on the truck. Since Volvo GTT is selling the up-time based on service offers, has the cost for service moved from an external cost for the customer to an internal cost for the company which makes it necessary to ensure the maintainability requirements to perform cost efficient services.

1.2.1 Aftermarket Technology (AMT)

Volvo GTT AMT has the responsibility for spare parts, repair information and the maintainability possibilities connected to the truck. The case study was performed at the Service Engineering And Information Management (SEIM) which is one of the functions of Volvo GTT AMT.

The different work roles at AMT investigated in this study are the Service Engineer (SE), Requirement Engineer (RE) and the Virtual Specialist (VS). These roles work close together to satisfy the aftermarket requirements and create high quality repair information. The RE:s work is to ensure that the design satisfies the maintainability demands for the aftermarket. The SE:s work is to develop service and repair information which will be used in the workshops where the service of the truck is performed. The VS:s work is to provide the two earlier mentioned roles with CAD data and perform maintainability analyses and simulations based on CAD data.

The maintainability analysis is an important process for AMT and Volvo GTT since the results are used to set requirement to the design department to let the product to be designed to satisfy the requirements for the aftermarket solutions sold with the truck. Volvo GTT wants to decrease the number of physical prototypes in the product development process which implies more requirement on the use of virtual tools for maintainability analyses.

1.2.2 Earlier Virtual Reality studies at AMT

An earlier period for evaluation of Virtual Reality at SEIM has given an understanding of how Virtual Reality can be used as a tool to work more virtually. The conclusions are that the technology has advantages and limitations. The interest from other departments within Volvo GTT has been huge and it is obvious that this technology brings a new dimension to the CAD data. From the evaluation period are the possibilities with Virtual Reality at SEIM seen and they would like to continue to investigate the possibilities with this technology in the maintainability area. AMT is though not convinced that the tested software setup and equipment used for the evaluation meet the aftermarket needs. The next step is to initiate a master's thesis in the Virtual Reality area to identify possibilities with the current technology and areas where it could be used to support the work within AMT.

1.3 Purpose and research questions

The purpose of this master thesis is to investigate the possibilities to use Virtual Reality as a tool at Volvo GTT Aftermarket Technology to support identified challenges in their current process.

The following research questions are stated to achieve the purpose of this study:

- How is the Virtual Reality technology used in the industry today?
- Which are the main challenges connected to virtual work in the work process at AMT?
- How could Virtual Reality support the challenges in the current work process at AMT?

1.4 Delimitations

The empirical case study is performed at one company. It's limited to investigate the work roles RE, SE and VS at Volvo GTT AMT.

2

Theory

This section presents theory connected to the area in focus. Previous research within the area, important areas in maintainability and Virtual Reality are presented.

2.1 Previous Research

To get an overview of the existing research and limitations in the field of study, have a sample of articles and master theses been reviewed. In this section are the findings presented.

Virtual Reality is a tool recognized in the manufacturing sector to reduce development time and ensure quality of new products. The technology has also been used to obtain information about the product maintainability aspects from disassembly operation simulations (Wo et al., 2010). In maintenance is disassembling an important factor which sets high demand on the technology to perform complex simulations (Zimmermann, 2008). There are a lot of virtual tools available that cover path planning operations in a digital mock-up (DMU). The path planner calculates a collision free path for the part, but do not consider the reachability, visibility and accessibility aspects. Additional space could be required for maintenance operations, e.g. required space for the mechanic's body and tools (Purschke et al., 1998). In manufacturing assembling there are more possibilities to implement sequences that are intelligent, but in maintenance there is sometimes need to elaborate to find a good way to minimize the effort in the operation (Zimmermann, 2008).

Maintenance operations are performed in a limited space, with a limited amount of time, where the operator's body is constrained by the environment. The actions that the operator performs are constrained by clashes between parts, tools, body and other components. Virtual maintenance can help to prevent these problems and address them before they appear on the physical product. Virtual maintenance systems have been applied in maintenance process simulation. Zachmann et al. (1999) state that Virtual Reality is a tool that can be used to obtain quick answers in an intuitive way already in the concept phase of a product. The design is often changed in early phases, simultaneously there is a lack of physical prototypes which requires quick answers based on rough data. Although, Virtual Reality systems needs to be further developed in order to be integrated into existing systems. Murray et al. (2004) set up an immersive virtual prototyping environment, which was designed to support the product maintenance and assembly. The environment provides realistic interaction between the operator and components, the user selects a component and the computer calculate the geometrical feasible disassembly sequences which are able to be performed by the user. The authors state that there is need to extend the system to take into account needed tools and path planning to assess the ease of part removal.

Galileo by Law et al. (1998) is a software used in the aircraft industry which let the user interactively fly through a digital virtual jet engine. It is possible to automatically determine paths for removal of parts for maintenance simulations. VREALISM is an object-oriented system proposed by Li et al. (2003). The software provides the user a desktop environment, to practice disassemble for maintenance for certain components. Liu et al. (2013) have designed a virtual hand to the virtual maintenance system, the results indicate that a virtual hand can improve the flexibility of virtual maintenance systems. Abate et al. (2009) presented a solution, where Virtual Reality technologies are combined with haptic feedback to simulate machine assembly maintenance in the aerospace industry. The most of the users of the solution highlighted the potential with haptic feedback in the maintenance of the industry. The operations in maintenance are inherently hand based and the success of task is often related to the haptic ability. There are though need to investigate further how a two handed system could bring even more realism to the interaction.

Peng et al. (2011) address the need for effective collaboration between product engineers and maintenance technicians throughout the product design process in their work. The author's highlight that, as a result of that verification of activities often is carried out when the physical product is manufactured are problems not found and corrected in time, which is costly and time-consuming. They present a desktop Virtual Reality system where maintainability related work can be performed. Their results show that it was possible to use the Virtual Reality environment to detect problems early in the process and in the process of giving feedback to the product development department. The findings show that Virtual Reality technology can be used to facilitate the communication, coordination, control and integration of maintainability validation and improvement activities.

Peng et al. (2011) and Dong et al. (2011) state that Virtual Reality-based system gives a more intuitive control over the interaction activity, which speeds up the maintenance checks along with offer the design solutions to be better adapted to the maintainability point of view. The virtual maintenance technology focuses on how the virtualization of the product can improve the product design process, performance design with concurrent engineering and provide feedback interaction. Peng et al. (2011) states that further effort has to be concentrated on physical-based modeling methods and the implementation of a virtual human in the simulation. Shiguang et al. (2013) have conducted a research which focuses on the relationship between the virtual human and virtual objects to analyze if the operator is able to perform the activity without collision with objects. The designed system has though constraints when the operator needs to be in complex postures to perform the activity, then the tracking system is not able to recognize the operator with used sensors.

A thesis found and analyzed was Incorporating Maintainability into the R&D process by Andersson and Ericson (2013). The main purpose of the thesis by was to investigate how maintainability can be better integrated into the R&D-process. The research was conducted at a Swedish defense company where a specific product was investigated. Less optimal design solutions had been identified very late in the testing and verification phase, which has caused large costs and late deliveries. The authors have conducted a review of documents, interviews and observations. The maintainability has been low prioritized and a reason could be that there are many consultants that had a lack of proper understanding of the products. They are responsible for small areas but do not know what happens outside it. Therefore, they have to trust the CAD data and wait for physical prototypes. Lack of clearly defined requirements gives that decisions are taken without sufficient background maintainability information being considered. The formulation of the requirements was seen as one possible issue since the knowledge transfer and communication between different departments can be difficult. This can result in confusing and misunderstanding which will affect the prioritization. The requirements are written to give the designer maintainability prerequisites, which are interpreted with extensive knowledge and understanding about the unit and how it should be repaired. The authors suggest that good visualization tools could benefit the process of transfer knowledge, communicate and avoid unnecessary iterations and redesigns later in the project.

The previous research indicates that there are benefits to implement Virtual Reality in the process to be able to perform analyses in early phases and communicate the findings. The studies mainly focus on real-time driving of maintenance activities, some studies also cover the possibility to include the human body while performing the analysis. But few focus on the relationship between the operator, physical behavior of virtual objects in combination with the accessibility and visibility of hands and tools needed for the analysis. This relationship is very important and cannot be ignored during a maintainability operation.

2.2 Maintainability

There is a need to understand the maintainability area to investigate where challenges could occur. Maintainability is the level of required maintenance, tools, manhours, logistic cost, and skills needed to perform service activities on a manufactured product (Dhillon, 1999). By considering maintainability in the design and development process of a product, the total life-cycle cost of a product could be decreased (Vujosevic et al., 1995). To avoid costly design changes in the design process, maintainability needs to be considered early in the design process (Vujosevic et al., 1995). Below are important areas that have to be taken into consideration while designing a product for maintainability.

2.2.1 Accessibility

Accessibility is meant by if a part can be reached and maintained from the standing point of the technician (Dhillon, 1999). The maintainability is affected by poor accessibility, the lead time to perform the operation is increased. If the technician is not able to reach the parts there may be need to eject other parts in the surrounding environment first. Accessibility includes the body of the operator, needed tools and movement of them both together. Accessibility should be considered in a product design to avoid unnecessary down-time for the customer, when the truck is in the workshop, and also operation times for the workshops performing the operation. The part that needs to be replaced most frequently should then be able to replace without unnecessarily removing of other parts (Dhillon, 1999).

2.2.2 Visibility

Visibility is the level of how the concerned parts requiring maintenance can be seen by the technician. The technician is able to perform visible analyses of the components in interest to see if there are any visible problems. There is also need to see where the activity will be performed to understand how the operation will be performed. If the field of view is blocked by other parts could the required time to perform the maintenance operation increase which leads to increased down-time for the customer (Dhillon, 1999).

2.2.3 Tools for maintainability analysis

There are various tools that are used during a maintainability analysis. Depending on how far the project is conducted, there are different amount of available data to use in the analysis. Physical prototypes are used during the development process to bring maturity to the project and reduce possible uncertainties while technical and marketing professionals work together (Dieter , 2013). In the 80's became CAD systems used to visualize solids and surfaces which have brought a fundamental change in the way of managing product design. During the 90's was feature modeling introduced in CAD systems to overcome limitations related to simple and pure geometric models used for representing complex products (Fucci, 2011). Knowledge was then added about the design of the product, its assembly, and measurements. The component designed in CAD software is possible to use to perform maintainability analyses. When the physical product is not available there is need for tools that can be used to analyze the CAD data instead.

The CAD data is also available to use with the modern 3D printers. Prototypes of parts are easy to print and use when the real manufactured part is not available. 3D printers can produce products that hold quality measures comparable to the products manufactured in conventional manufacturing technologies (Petrick & Simpson, 2013). Bogue (2013) states that 3D printing may change the fundamental in the process of how the products are developed and produced. 3D printing has been present since the 80's but not until now is the technology reaching its fully potential (Goldberg, 2014).

2.2.4 Product Life Cycle

The maintainability has a central part in a product life cycle. It is important to understand where it is possible to affect the maintainability properties of a product and what it affects. The life cycle of a product is presented in Figure 2.1 below. The maintenance and service perspective are represented in the use phase. A trend in manufacturing industries is that the sell-margin has decreased and the manufacturing companies see opportunities in after-sale services and maintenance. Efforts are focused on the use-phase to offer other types of products that could increase the revenues (Bundschuh & Devane, 2003). This includes different types of service contracts and spare parts.

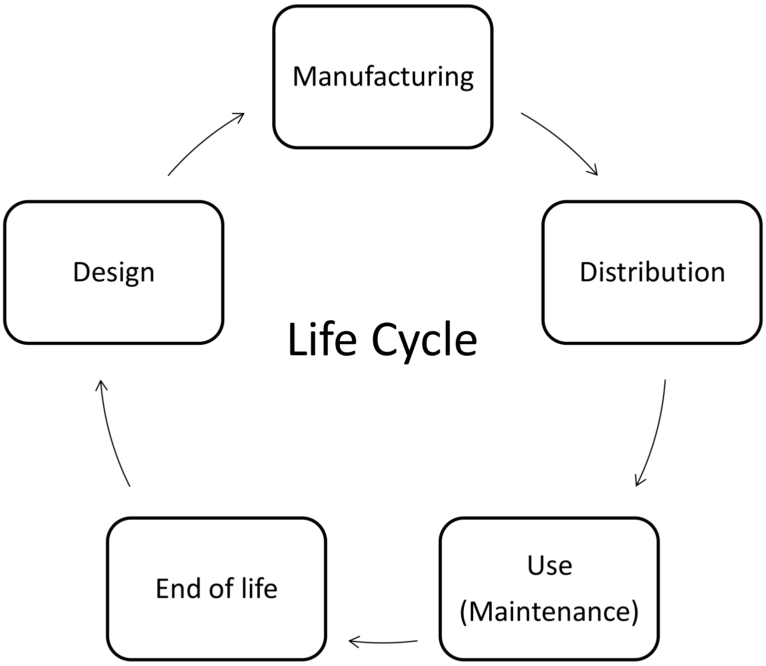

Figure 2.1: Life cycle of a product. (Brissaud et al., 2006).

To offer cost efficient reliable services and maintenance products, the maintainability aspects should be considered as early as possible in the development of a product (Peng et al., 2012). By performing the maintainability analysis as a parallel activity and concurrent engineering could design issues be detected already in the design phase. As shown in 2.2 below does the cost of change in the design increase with the development of a product, while during the same time the flexibility to change the design decreases. If a maintainability issue is found during the use phase will the cost be high to change the design (Peng et al., 2012).

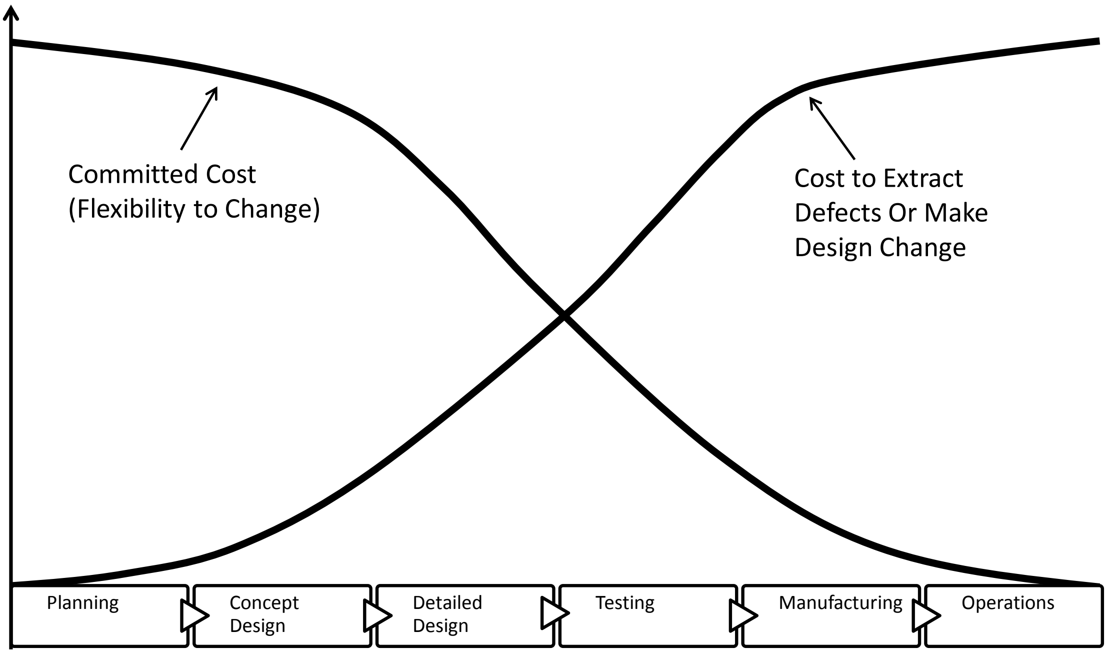

Figure 2.2: Committed life cycle cost against time (Henriques et al., 2014).

2.3 Virtual Reality

Virtual Reality (VR) is a tool that can be used to visualize CAD data in order to be able to perform maintainability analyses (Zimmermann, 2008). In this section will theory connected to the VR area be presented to understand its possibilities and limitations. This include the definition of VR, a brief history and the current application areas, technologies and its effect on human perception and communication.

2.3.1 Definition

Sherman et al. (2003) points out that virtual is defined as “being in essence or effect, but not in fact” and reality as “the state or quality of being real. Something that exists independently of ideas concerning it”. The website merriam-webster.com (Merriam-Webster, 2017) has defined Virtual Reality as “an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one’s actions partially determine what happens in the environment, also: the technology used to create or access a virtual reality”. Virtual Reality is a medium that is composed of interactive computer simulations that can calculate the position of the participant and actions made by the participant and replace the feedback to one or more senses, giving the feeling to the user of being mentally immersed or present in the simulation (Sherman et al., 2003).

2.3.2 Brief history

1961 was the first head mounted display (HMD) built by engineers at Philco Corporation which had a working tracking system, presented in Figure 2.3 below. When the user moved the head, a camera also moved which was placed in a different room so the user could see as standing in the other location (Jerald, 2016).

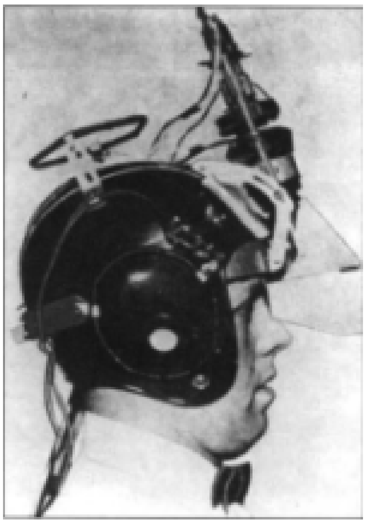

Figure 2.3: The Philco Headsight from 1961. (Comeau et al., 1961).

One year later IBM built the first glove input device designed as an alternative to the keyboard input device. A sensor for each finger recognized multiple finger positions and this technique became a common input device in the 1990s (Jerald, 2016).

The air force saw possibilities with the technology and started developing HMD for pilots in 1965. In 1982 was the Atari Research lead by the computer scientist Alan Kay to explore the future of entertainment. This research lead to new ways of interacting with computers and also designed technologies which soon would be essential for commercializing the VR system (Jerald, 2016). In 1985 NASA developed the first commercially viable HMD. Commercial HMDs, gloves and software was built in 1985 by researchers from Atari. VR exploded during the 1990s when various companies focusing on the professional research market and location-based entertainment. Wired Magazine wrote in 1993 that in five years will more than one of ten wear a HMD while travelling on a bus (Negroponte, 1993). The VR did though peak in 1996 and started to contract and going out of business in 1998 (Jerald, 2016). In 1997 were more virtual studios built in automotive and aerospace industry with an attempt to productize the applications. The studios existed of a powerwall where the graphics are projected on a wall and a system to track the user. During this attempt it was concluded that just having the technology is not enough, data management and change of process became important factors (Zimmermann, 2008). During 2000-2012 was just a little attention from mainstream media given to VR but the research still continued in depth at governments, in academia and military research laboratories (Zimmermann, 2008). During the years between 2000

- 2015 has advancement been done in the technology in both computers and cell phones within 3D capabilities. Around 2012 was Oculus VR formed by John Carmack which did that the new era of VR was born (Jerald, 2016). Recently has also a “do it yourself- kit” of a VR-headset been released by Google which is designed to be used with a smart-phone. Complete VR rigs have during 2016 been released from Oculus, HTC and Sony which have made it possible for the wide audience to use VR and enter the virtual environment in their own living room.

2.3.3 Technology

There is a various range of VR technologies that are available today. The ordinary desktop in combination with a mouse, keyboard and a screen is widely used to visualize the virtual environment. In Figure 2.4 below is an example of a desktop Virtual Reality visualized. Simulations can be performed in the desktop software with a manikin as visualization of the operator performing the operation.

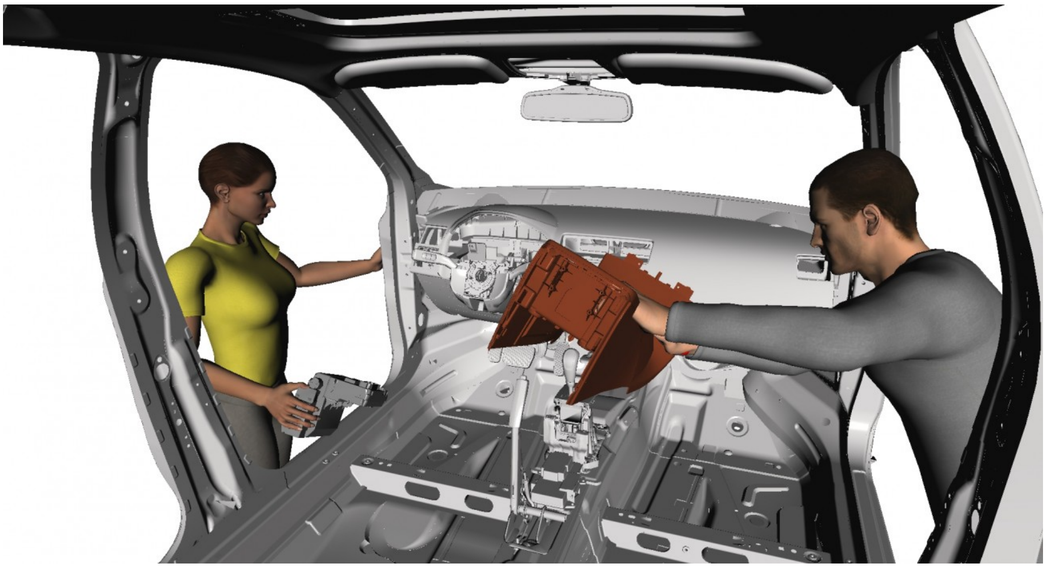

Figure 2.4: An image showing the Desktop Virtual Reality (FCC, 2017).

Head-mounted display (HMD) is another technology which consists of a helmet that usually is designed with a display for each eye that displays the graphics which let the user experience the spatial information in 3D, a HMD is visualized in Figure 2.5 below. The HMD is connected to a computer which renders the graphics and a software on the computer is used to drive environmental actions depending on the users’ activities with the input devices. The HMD cost is around 900 euros (Inet, 2017) and needed computer around 1700 euros (HP, 2017). The field of view in a HMD can be up to 142 degrees (Blach, 2008). A tracking sensor is built into the helmet to tell the computer system where the participant is positioned and looking. The participant is able to look around in a computer-generated environment by moving the head in the world which is similar to the real world (within the limits of technology) and generates a natural intuitive interface. Other tools can be included in the system to let the participant be able to see parts of the own body in the designed VR environment.

Figure 2.5: An image showing the Head-Mounted Display (HMD).

There are technologies that allow the user to use the own hands as input controller in the virtual environment, shown in Figure 2.6. Leap is a motion sensor provided by Leap Motion which is possible to attach to the HMD. Its technology allows detection and tracking of both hands and fingers with optical sensors and infrared light. The device reports the positions, motions and gestures. The controller field of view is an inverted pyramid centered on the device. The effective range is about 25 - 600 mm from the device in the field of 150x150 degrees (Guna et al., 2014). The controller is accessed and programmed through APIs with support for different programming languages. The Leap motion costs around 80 euros (Leapmotion, 2017). The Leap Motion technology is visualized in Figure 2.6 below.

Figure 2.6: Left, the Leap Motion sensor is attached on a HMD. Right, an image showing the hand generated by the Leap motion device.

Another type of VR technology is the CAVE system which consists of a five-channel VR simulation environment where the graphics are projected on three or four walls, the floor and ceiling, shown in Figure 2.7.

Figure 2.7: An image showing the CAVE system (Nvidia, 2011).

The graphics are projected by several projectors connected to computers, an advanced setup costs around 5 million euros (Blach, 2008). The user in the CAVE is possible to interact with the virtual world by using various devices and installed infrared cameras captures the observer's gestures (Qi, 2013). The user wears 3D glasses to look around and experience the environment generated in the CAVE in 3D. The field of view can be from 180 to 360 degrees depending on how many walls the graphics are projected at. The user is not totally immersed since the room from the real world is still experienced.

A powerwall is a visualization tool where the graphics are projected on one single wall which makes it less immersive than the HMD and CAVE systems, the powerwall is shown in Figure 2.8. The user is able to experience the spatial information in 3D by wearing glasses that are tracked by the system and navigate by using physically controls. The system allows several people to attend at a review of the material, but only one user is able to experience the environment in 3D since the system only tracks one user and generates the graphics according to its position.

Figure 2.8: An image showing the powerwall system (Techviz, 2017).

2.3.4 Application fields

The market for VR has become more mature with a wide range of technologies as CAVE-systems, powerwalls, HMDs and haptic devices and speech recognition systems to interact with the technology. During the time when the technical systems have improved has the price of commercial versions decreased which has done that the industrial sector has gained more interest in the area (Zimmermann, 2008). Even if the potentials with VR is shown for a variety of industrial fields is the usage still not completely visible (Thielemann, 2011). Computer Aided tools on the market has improved and been diversified and are today covering practically the whole product life cycle applications (Zimmermann, 2008). Generally is the interaction between the software and user by a LCD screen and mouse which are just 2D controllers. This technology has not changed since the 80s even though the geometric data is in 3D. Virtual Reality may be the next generation of man-machine interface and there are various possible solutions for projects (Zimmermann, 2008).

The different industries have been using VR during different periods where the automotive industry was early introduced to the area. The industries also contribute to mapping the needs and possible barriers to change and also the drivers for the implementation (Zimmermann, 2008). VR is widely used in automotive industry and shall bring profits for the companies which already has been recognized (Jiang, 2011). In the technical and styling department is visual workstations a must-have to enhance ideas and solutions sharing with non-specialized deciding personnel (Zimmermann, 2008). The time in the development process and costs could be diminished and post-processed results from simulations of fluids or crash analysis is also possible to visualize. The need of physical mock-ups decreases in early production by using VR (Zimmermann, 2008). VR is able to partially replace the traditional physical prototypes as it is a very helpful tool to accelerate the development and reduces costs (Jiang, 2011). As a result VR applications were established in the phases that required visual representations for technicians or decisors which gave that almost all department in automotive are equipped with powerwalls or HMDs and the R&D installed CAVE systems where for example ergonomics analyses are performed (Zimmermann, 2008) and (Jiang, 2011). Training is also present in various different areas such as in complex maintenance tasks, procedure executions, specific facility or equipment and training of operators. VR can then be a powerful tool since it can facilitate the process to improve the operator's skills, knowledge, competence, preparedness, awareness and safety behavior (Zimmermann, 2008). VR can allow valuable personnel to replay experiences and experiment where different choices can give different outcomes (Seidel et al., 1997).

2.3.5 Barriers and drivers

The technology in terms of software and hardware is still not mature and too complex and unfriendly for the not savvy user. There is also a lack of bandwidth for simulating the human sensory system (Zimmermann, 2008). The introduction of the technology is also a module that have to be supported by the existing business processes in order to reach a wide usage area (Thielemann, 2011). Designers still tend to embrace their own comfort zone, this affects the development and uptake of new IT-tools related to the social phenomenon associated with this since technologies are inseparable from the social and cultural settings where they are found. IT design support have a valuable role to promote the new technology and its intentions and possibilities to let the comfort zone be expanded (Goulding et al., 2007). To facilitate the implementation of new technologies is there need to understand the interaction concepts. The user interface has to be designed according to the cognitive limitations of humans. The barriers associated with the cultural and social settings have a negative effect on new technology absorption capability (Goulding et al., 2007). To integrate VR in the present process there is a need for interoperability in CAD software where there has to be a standardized methodology. If this is not considered there will be a large amount of own data produced to desired models that not will be reusable (Zimmermann, 2008).

The automotive industry requires VR for activities as prototyping and engineering with the expectation that there will be great benefits from the early phases until almost the end of the process. The game industry helps to set trends in software and hardware technology and visual realism. Many type of industries have available CAD data where the use of VR could benefit the present process (Jiang, 2011). VR may open up new possibilities to use the available data. The information is also getting more complex which requires new technologies in the standard way of work (Karaseitanidis et al., 2008). How to build up the whole virtual capability is crucial for the automotive industry since it is still under development, there is need to understand in what areas it is possible to make use of the new technology (Jiang, 2011). The major industrial areas that drive the development of new VR technologies and give data for development are the automotive, aerospace, engineering and design, energy and construction, entertainment and culture (Karaseitanidis et al., 2008). The interface which comes with VR is known for the next generation of computer users since it is used in the daily life with cellphones and game consoles today (Karaseitanidis et al., 2008). This does that the awareness of interfaces and multiple interaction raising the demand on the development within the area. The drivers for VR encourage to invest into the research area since they relate to the ability to extend the virtual approach to the whole product life cycle management, increase the coverage of performance with simulation and interactive experiences of users and engineers during the development phase (Karaseitanidis et al., 2008). There is also the possibility to react to the process agility with collaboration opportunities among engineers, decision makers and users (Jiang, 2011).

Software architecture for real-time product simulation have to be developed in parallel with that a plug-and-play design for multi-domain simulations have to be considered to design standardized architectures for VR interfaces (Karaseitanidis et al., 2008). The data integration in the external system have to be automatically prepared and adapted to the requirements imposed by the VR technology and the existing process. The physical behavior and haptic realism of objects have to be improved in order to describe realistic environments, there are today no generalized solutions especially not for large data sets (Zimmermann, 2008). The human factor is an important role in the human-machine interface (Goulding et al., 2007). Research in this area will benefit the design towards a more human-centered realization and application of the technology. Presence, perception and cognitive research is then very important within the area (Karaseitanidis et al., 2008).

2.4 Virtual Reality effect on human interaction and cognitive perception

Since VR is used to visualize a real world situation is there need to understand how different type of visualization technologies will affect the user. VR experience can be seen as a summation of the different elements in the user interface, virtual world and life experience. This is explained by Sherman et al. (2003) where the user interface is the hardware and software that is used to experience and control actions in the virtual world like body tracking, sound recognition, physical controllers, visual displays, aural display and haptic feedback.

Software systems are how the system represents the virtual world to the user and how the user interact with the virtual world by navigating, manipulate and share the experience. The virtual world cover objects, physics, venue, immersion and the point of view for the user inside the VR environment. Life experience is the user's individual memory, ability, past experience and the emotional state. These factors together affect how the user experience the virtual world.

In real world situations are multiple of sensory and directly information available which typically provide redundant information to the user (Steinicke et al., 2013). Users in a virtual environment (VE) does often not have access to all the sensory sources of information, it is then important to consider the consequences of their absence or degradement (Steinicke et al., 2013).

The use of desktop VE is superior to the HMD and CAVE on many non-spatial dimensions including availability to a wider audience by cost and convenience. When the simulation is a single virtual object or a small number of objects it may be more intuitive to present it on the desktop and discuss as done if there were a physical product on the table. If the orientation in the VE is not specific important in the environment, a virtual environment in the desktop may be the best used tool for the task (Steinicke et al., 2013). The user is seated in front of the desktop and usually navigates by pressing buttons and using a mouse. The simulation is presented at some kind of screen with accurate position and possible audial feedback which does not match with the senses of the user. The sense tells the user that the positioning is seating and that the movement is still even though the information on the screen simulates the movement. Also to generate intended movement there is need to transfer these intentions to the designed interface in the program by the user. There is a sensory conflict and the sensory-motor feedback that is useful for accurate path integration is removed (Chance, 1998). Accordingly to Prinz (1997) is actions planned and controlled in terms of their effects, the spatial perception between the controls and the outcome action can facilitate the users' behavior (Shin et al., 2010). The action will then preferable be logic to perform in order to get the expected event. For simulations where navigation is crucial and accurate spatial perception is a desktop VE a poor choice of tool, this type of simulation would be best implemented in a system where the users are able to physically move, look around, crouch and remain aware of the position and heading (Steinicke et al., 2013).

The CAVE system offers the ability of motion in a limited range and is a visually more immersive type of virtual environment (Steinicke et al., 2013). The user enters the simulated space by moving the body into it. This engages sensory systems since it is possible to look left by turning the head instead of pushing a button. Since the field of view is not restricted, as in the desktop VE, does the user have control over the spatial information of objects in the environment (Patterson et al., 2006). According to Toet et al. (2007) may the required analysis of spatial details as object recognition be acceptable with a small as 40 degrees field of view but analyses of spatial relations and control over manoeuvring will any field of view lower than the unrestricted affect the performance accuracy. A CAVE has a possible field of view over 180 degrees and can present a complete optic flow to inform the user of its movements (Steinicke et al., 2013). The user may still need to wear glasses that in some degree limits the field of view. A CAVE is the ideal in situations where the user do not have to take more than a few steps or when details in the surrounding vision is crucial like in a vehicle simulator where the user sits in a cockpit and uses realistic controls to operate (Steinicke et al., 2013).

HMDs are compared to desktops and CAVE systems flexible to allow the user to move around in a larger area. This is excellent to provide simulating sensory information about the space accurate to the user (Steinicke et al., 2013). The user can naturalistic navigate in space by walking around and turn the head and body to look around. The strong feeling of immersion gives the impression that the virtual world truly surrounds the user. There are though constraints with the size of the environment where the virtual environment is simulated and that current technology require cables between the components and also have limited tracking distance for the motion tracking equipment. HMD-based systems may be the most appropriate when the navigation in means of natural ambulation like familiarizing with a large scale environment. HMDs are also able to exclude the users view of the surrounding environment to remove visual distraction and increase the sense of immersion (Steinicke et al., 2013). With HMD it is not possible to see the own body without adding external equipment. The HMD field of view require the user to perform more head movement than in a CAVE in order to see all surrounding. From the perspective when the sensory information about space is important is HMDs an excellent way to simulate the spatial information accurately. A comparison between mentioned items among the different technologies is presented in Table 2.1 below.

Table 2.1: Comparison between diffrent VR technologies

Item	**Cave**	**Desktop**	**HMD**
Spatial perception	Good	Low	Good
Vision of body	Very good	External manikin	With devices
Include body in analysis	With devices	External manikin	With devices
Level of Immersion	Good	Low	Very good
Possible physical movement	Good	Low	Very good

2.5 Virtual Reality in communication

Working together in a virtual environment can be an important possibility, many different approaches allow a Virtual Reality experience to be shared. If the purpose of sharing the experience is by working together to solve a problem it is a collaborative experience. This kind of communication requires that the virtual world is possible to share (Sherman et al., 2003). Shared and collaborative are though not synonymous since it is possible to share non-collaborative experiences with audiences that are viewing the immersed participants when there is interaction in the virtual environment or see captured and replayed data or sees the data via some other kind of medium. There are concerns with shared experiences since there has to be a method chosen of how the collaborative interaction is to be handled, like who has the control over manipulation of the environment or communication (Sherman et al., 2003). VR as other communication mediums allow experiences to be shared among recipients.

There are a few common types of shared viewpoints to perform communication. The first possibility is to have one immersed participant with onlookers where one person is wearing a HMD and external monitors provide the audience what is happening. Another type is if two or more participants experiences the same world using HMD or CAVE system or one powerwall projection which allow multiple people to view the same screen where one of the participants' position is being tracked and fully immersed. The different kind of methods allow different communication possibilities among all the involved. With the open display can the user still see the other participants and easy share thoughts and express aspects of the world. Multipresence is clearly important when using Virtual Reality for collaborative work where for example two engineers are located far apart but can come together in the same virtual environment and share the experience and communicate (Sherman et al., 2003).

2.6 Unity3D

To implement a virtual environment there is a need for a software. Unity3D is a multiplatform game development environment. It is designed to facilitate the process of game development for the user by focusing on content center development with scripting in C#.NET, JavaScript or immediate mode graphical user interface. Unity has a large community where developers from all around the world posts ideas and solutions on all type of problems. Through Unity3D is an asset server available where developers can put their codes which can be bought or downloaded for free in order to implement them in the own project. An asset is a finished model, for example a specific object, sound or texture that easily can be imported into Unity3D after download. Unity3D with a support of SteamVR allow implementation of the HMD system. An asset from asset store provides with basic functions regarding the HMD. Leap motion is possible to be used in Unity3D with support from assets from the manufacturer's web page.

3
Research Methodology

The methodology is separated into three parts to keep a chronological structure of the thesis. In this chapter is the research methodology presented where literature review and an empirical case study are the main parts.

3.1 Literature review

The purpose of a literature review was to understand what knowledge existed connected to the research topic of Virtual Reality and virtual maintainability. The research should build on existing knowledge and demonstrate how the research topic relates to previous research in the area (Denscombe, 2013). Another purpose with the literature review was to understand the current knowledge in the field to not reinvent the wheel (Denscombe, 2013). The literature for the review was gathered at internet databases such as Scopus, Google Scholar, Sciencedirect and Chalmers library. The following keywords were used:

- Virtual Reality
- Virtual maintainability
- Virtual Prototyping
- Virtual manufacturing
- CAD visualization
- Communication

3.2 Empirical study

The empirical study is a research method that is used to relate real-time data with observations and theories (Malhotra, 2016). In this thesis was the empirical study used as a systematic approach to get reliable results. There are quantitative and qualitative approaches in an empirical study. The quantitative approach is used to test a hypothesis and get statistically reliable results that are possible to generalize. Compared to the objective quantitative approach is the qualitative approach subjective and used to study human behavior and qualitative methods are typical observations, interviews or group discussions (Malhotra, 2016).

3.2.1 Case study

A case study is one of the several ways of doing social science research. Other available approaches include experiments, surveys, histories, economic/epidemiologic research. There are advantages and disadvantages for each method depending upon three conditions; research question, the control an investigator has over actual behavioral events and focus on contemporary as opposed to historical phenomena (Yin, 2009). The case study is an empirical inquiry and a preferred method when "how and why" questions are being posed, the investigator has little control over events and when the focus is on a contemporary phenomenon within a real-life context (Yin, 2009). A distinctive characteristic of the case study is that there are many more variables of interest than data points to be analyzed, a statistical analysis is then difficult since there will not be any variance within the measured data (Yin, 1992). The case study adds the possibility to perform direct observation and interview of the persons involved compared to other methods such as a historical study. The case study is also able to deal with a variety of evidence like documents, interviews and observations beyond a conventional historical study (Yin, 2009). The use of multiple sources of evidence is essential in the case study since it allows a more comprehensive investigation and that the validity for the research can be enhanced (O´Gorman & MacIntosh, 2015). According to Schramm (1971) is the essence of a case study that it tries to illuminate why some decisions were taken and how they were implemented and what the outcome was.

While multiple case researchers are often preferred, there are occasions where it can be appropriate to adopt a single case study. A single case study is acceptable when the research focuses on a unique case (Hartley, 2004). If the research design is based on a sample of a single case there is a need for some background research on the organization in focus in areas that are relevant for the research (O´Gorman & MacIntosh, 2015). Publicly available data from the company reports or similar material is a useful first step to familiarize with the research settings where data will be gathered in the case study. It is important to take into account the time to analyze and write up the findings since this can be equally or even more time-consuming and demanding than the data gathering (O´Gorman & MacIntosh, 2015).

3.3 Research design

To be able to answer the research questions was an empirical case study at Volvo GTT AMT performed. A triangulation approach was used in the study to evaluate the research questions since the use of multiple data sources indicates a higher validity of the study (Bryman & Bell, 2015). The data was in this study collected mainly by a literature review, observations and interviews.

The literature review was conducted to gain needed knowledge in the areas related to the thesis and also to gather data to the design of the empirical study. The collected information regarding the focus areas from the literature review resulted in Chapter 2 Theory.

The design of the empirical study is based on the main steps according to Malhotra (2016) in order to get a systematic approach. A qualitative approach was used in this thesis as a case study. The case study approach gave the possibility to focus on a specific situation in order to investigate the current process challenges and possibilities with VR at the Volvo GTT AMT.

The main steps with complementary sub-methods of the empirical study are presented in Figure 3.1.

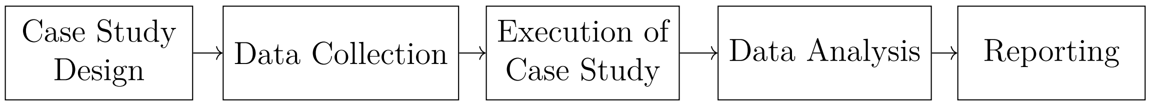

Figure 3.1: Methodology for the Case Study

4

Current State Analysis Methodology

In this chapter are the used methods and procedure for the Current State Analysis presented, the results from this section are presented in the next Chapter 5 Results Current State Analysis.

4.1 Data collection

Below are the used methods and the procedure to collect data during the project described. Several methods are used since each method have advantages and disadvantages and together they are able to support each other.

4.1.1 Interviews

Interviews are used when there is a need to serve the research with material for a deeper insight into the topic with information provided by fewer informants (Denscombe, 2003). The decision to conduct interviews gives a deep rather than breadth information within the project. It is then important to consider if it is necessary to require the kind of detailed information that the interviews supply and also if it is reasonable to rely on the information that is gathered from the informants (Denscombe, 2003). Interview data is a supplement to other methods where data also is gathered in order to give a deeper analysis.

There are three types of qualitative interviews, structured, semi-structured and unstructured. The type of interview depends on the purpose of the research, its research questions and what type of research that already is conducted in the area (Hennink et al., 2011).

A semi-structured interview is more flexible than a structured interview, the order the topics are presented during the interview is flexible and the semi-structured approach also let the interviewee to share ideas and speak more freely about the raised issue (Denscombe, 2003). Questions which are not included in the original questionnaire can be added if there is an interesting topic raised during the interview. Unstructured interviews let the interviewee to extent the thoughts and the researcher's role is to be as uninstructive as possible by mention a theme or topic and let the interviewee develop the ideas (Denscombe, 2003). This type of interview is similar to an ordinary conversation and can be described as a conversation with a purpose (Hennink et al., 2011). The most common form of unstructured and semi-structured interviews is face to face and involves just the interviewer and the informant. One advantage of this set-up is that it is relative easy to arrange when there is only two individuals that have to find a common meeting time (Denscombe, 2003).

Performed Interviews in industry

In the Current State Analysis were interviews conducted with companies related to virtual work. The purpose for the interviews at the companies was to investigate how companies use and work with VR today and which kind of software and technology they use. Three companies in the automotive, aircraft and robotics industry were contacted and a meeting was booked where a visit to the company or a Skype meeting was conducted. The meetings was held with managers and technical specialist from the companies. During the meetings were semi-structured interviews held to get a discussion and find out how they work with and use VR today.

Interviews for benchmark of software

Interviews were also conducted with two CAD-software companies and one game development company. The interviews were conducted with the managers and technical specialists. The purpose was to benchmark the current available software to use VR and where the limitations in the technology are. During the meetings were semi-structured interviews held to get a discussion and find what possibilities they see and how they plan to work with VR in the future.

Current State Interviews at Volvo GTT AMT

Interviews were also held at Volvo GTT AMT to establish an overview of the current process and be able to identify challenges related to virtual work. The engineers were contacted in order to find a time slot for an interview which was held at their department. In total were five interviews conducted with engineers from Volvo GTT AMT. The participants were two service engineers and two requirement engineers with a lot of experience within their area of work. Among the participants were the process responsible engineers for both the Service Engineers and the Requirement Engineers. There was also a participant from Product Development who work as a project owner. The project owner is responsible for balancing the requirements from different stakeholders at Volvo GTT. The interviews were performed in a semi-structured way to be able to catch and extend the participants thoughts. The participants are presented in table 4.1 below.

Table 4.1: Participants from Volvo GTT

Interview participants
Service Engineer 1
Service Engineer 2 / Process developer
Requirement Engineer 1
Requirement Engineer 2 / Process developer
Project owner from Product Development

The interviews were mainly focused to find out information in three areas:
- How the participants work in the current process,
- how the different work roles relates to each other and
- which kind of challenges they are facing in their work.

4.1.2 Observations

Observation gives the researcher a distinct way of collecting data (Denscombe, 2003). Unlike other methods does observation not include any verbal communication, it instead involves recording the behavioral patterns of the respondents without any interruption by the observer (Mohapatra et al., 2014). The observation can be performed by asking, listening, watching and recording people and their reactions in combination with the environment. Observation is a suitable method to use when the topic of research is new and it can provide contextual understanding when it is used in combination with other methods (Hennink et al., 2011).

By performing a literature review can certain things be clear to be prioritized by the researcher during the observation. This is important since the time is limited and also the most significant and relevant areas should be included (Denscombe, 2003). As a participant observer a group is informed about the presence of the researcher and the intentions but it does not involve any participation in the activities. The presence of a researcher can though create some discomfort in the group, the actual observation can be an influencing factor in itself (Hennink et al., 2011). The compatibility of observation and interviewing makes this method highly flexible, interesting observations may be clarified during a highly unstructured interview with participants to let the researcher understand its significance (Mohapatra et al., 2014).

The observations was performed in the Contextual Inquiry described in next section.

4.1.3 Contextual Inquiry

Contextual Inquiry (CI) is a method used to understand how people perform their work. By the use of interviews and observations, the goal is to find out how people structure and perform their work. The focus is to determine the people's work process, what their goal is, and how they try to accomplish it (Beyer, Morgan & Claypool, 2010). When performing a CI on office work, the procedure is to sit down with the worker and observe how they perform the work, and which systems and papers that are used. The observer should further look after notes and sheets that the worker uses to perform the work. The observer will perform an interview simultaneously and ask about the working procedure in order to understand the whole work practice which is the goal of a CI (Beyer, Morgan & Claypool, 2010). An interpretation session is then performed to conclude the CI. The interview notes are often unstructured and need to be clarified. If the CI is performed by a team, the other team members could read the interviews and capture keywords which could be used for conclusion or as foundation for an affinity diagram (Beyer, Morgan & Claypool, 2010).

Performed Cognitive Inquires

Cognitive Inquiries were performed with Service Engineer 1 and Requirement Engineer 1. The engineers were observed while performing work in the current process. An unstructured interview was held during the observation to clarify certain steps in the work process. Which tool they used and which challenges they encountered were documented.

4.1.4 Secondary Data gathering

To gather information was internal documents from Volvo GTT studied. The documents studied were available documents describing the roles of interest in this study. The documents were studied based on the results from the interviews and CI to sort out information and details. The tasks performed by the different work roles were connected to phases in the process to find out where possible challenges could appear and where VR could be used as a supportive tool.

4.1.5 Work shop

Using a focus group share features with a less structured interview, but it does not only gives an opportunity to gather information from many participants at the same time, it also gives a discussion among the participants (Chadwick, 2008). A focus group is often used in combination with quantitative and qualitative methods and gives then a complementary view in the research (Linell et al., 2007). The focus group is meant to generate information and give a rich understanding to the researcher of the participants' beliefs and experiences within the area. A focus group can be used in different methods such as a stand-alone or multi-method design for research related to explore a topic, clarify or extend collected data through other methods (Chadwick, 2008). A focus group usually involves 4-12 persons and is set up depending on the purpose of the research (Linell et al., 2007), (Chadwick, 2008). A pre-existing group may be easier to recruit and to generate a comfort and familiarity which facilitate the discussions ability to challenge the group members (Chadwick, 2008).

4.1.6 Affinity diagram

An affinity diagram is a method for analyzing and organizing large amount of qualitative data. One areas of use of the method is to identify and structure issues which could be based on complex information (Drouet & Bernhaupt, 2016). The affinity diagram is conducted in a team based on different work roles which creates a holistic solution and facilitates argumentation (Drouet & Bernhaupt, 2016). When conducting an affinity diagram could the procedure be divided into eight steps (Spool, 2004). These steps are:

1. Determine a focus question
2. Organize the group
3. Put opinions onto sticky notes
4. Put sticky notes on a wall
5. Group similar notes
6. Naming each group
7. Voting for the most important groups
8. Ranking the most important groups

The focus question is determined in line with the issue or obstacle that will be analyzed, the question is written on a wall, e.g. a whiteboard. The group size should be between six and eight people, preferably from different work roles to get a more holistic perspective. The gathered group will perform a warm-up session for five minutes to discuss the focus question. The members of the group write opinions on sticky notes and put them on the wall. The goal is to generate 19 - 24 sticky notes in total in the group. A group leader is chosen which will read the sticky notes to clarify the meaning and make sure that all members understand the notes. If needed will complementary information be added to clarify the notes. The next step is to group the sticky notes together based on similar meaning and connections. The participants in the group will group the notes according to their own beliefs. This will continue until the group is satisfied with the grouping. The group size of the sticky notes should be two to three in each group, there could also be notes left alone if it does not fit into a group. The next step is to name each group, the heading should express the meaning of the sticky notes under it. The new groups could then be grouped further and new headings could be written. The group members will then vote and rank the most important groups (Alänge, 2009).

Performed workshop

A workshop was held at Volvo GTT AMT to collect additional data beyond the findings in the conducted Interviews and Contextual Inquiry. The Affinity Diagram method was used during the workshop session. A focus group was created by inviting different work roles of interest and plan a time slot where everyone could participate.

The Affinity Diagram method was used to collect qualitative data during the workshop session. The focus was to identify what kind of problems the employees faces in their current work process. In total, six employees participated in the workshop. The participants in the focus group were one group manager, one Service Engineer, two Requirement Engineers and two Virtual Specialists.

Step 1. Determine a focus question

The first step was to determine a focus question. The focus question was formulated to find out what kind of problems that exists in the current process and is connected to the virtual work. The question was formulated as:
- *What problems do you face in your work process?*

Step 2. Organize the group
The next step was to organize the focus group. The participants represented a mixture of different work roles at Volvo GTT AMT. They were contacted in personal and a time slot were decided to let everyone be able to participate. A warm up session during five minutes was held in the beginning of the workshop where the group discussed the focus question. A group leader was chosen to lead the focus group during the workshop.

Step 3. Put opinions onto sticky notes
Each of the participants wrote 4-6 yellow sticky notes with a full sentence related to the focus question.

Step 4. Put sticky notes on the wall
The participants placed the sticky notes at the left side of the whiteboard. Each note was then presented by the group leader to clarify the meaning if needed. When everyone understood the sentence was the sticky note moved to the right side of the whiteboard. This step is shown in Figure 4.1.

Figure 4.1: Content on each sticky note is clarified by the group leader.

Step 5. Group similar items
A first level grouping was performed by grouping the sticky notes in groups of 2-3 sticky notes. The grouping was based on similar subjects and some sticky notes was left alone. The sticky notes was moved around by all participants simultaneously, the grouping stopped when everyone was satisfied.

Step 6. Naming each group
A pink sticky note is put on every group to name the group. The name was a complete sentence that summarizes the meaning of the group. This is shown in Figure 4.2 below.

In the workshop was further a higher level grouping done. The pink sticky notes were grouped together and then summarized with a green sticky note. This follows the procedure as in the first level grouping.

Figure 4.2: Naming of the groups in the workshop

4.2 Analysis of data

In this section are the used methods for analysis of the collected qualitative data described.

4.2.1 Categorizing and Counting

Categorizing and counting is a method that is used to analyze unstructured qualitative data. By identifying categories and keywords in the data it is possible to see the most frequent response. By counting the frequency of the categories and keywords it is possible to present the responses in for example a table (Baxter et al., 2015).

Procedure Categorizing and Counting
To analyze the data from Interviews and Observations was the method Categorizing and Counting used. The data was read through, keywords and categories that appeared frequently were identified.

4.2.2 Verification method

To confirm the validity of results is certain methods able to be used. Triangulation of evidence includes that the researcher uses at least three sources of evidence to collect data like observation, interview and literature research. This helps the researcher to examine a phenomenon from different standpoints. The triangulation helps to limit the bias by the researcher and increases the validity of the findings (O´Gorman & MacIntosh, 2015).

5
Results Current State Analysis

In this section are the findings from the Current State Analysis presented. The data was gathered by using the methods described in section 4.1 and analyses of data were performed by using the methods described in section 4.2. The results about the different work roles of interest in this study and the current process at Volvo GTT AMT are first presented for a better understanding of the results. Further are the results from VR in the industry and used virtual tools at AMT presented. Identified challenges in the current process are presented based on Interviews, Observations and Workshop held at Volvo GTT AMT.

Below in Table 5.1 is the nomenclature presented which is used to define where the information comes from. The information is referred to roles within Volvo GTT in order to retain anonymity.

Table 5.1: Roles included in the study

Role	**Reference**
Product Developer	R1
Service Engineer	R2
Requirement Engineer	R3
Virtual Specialist	R4

5.1 Roles at AMT

In this section are the findings about the work roles at Volvo GTT AMT presented. The results are based on data gathered from available secondary data combined with interviews and contextual inquiry with the employees at Volvo GTT AMT, these methods are described in section 4.1. The results gives an understanding about the commitments the different roles have in the current work process.

Requirement Engineer
The Requirement Engineer (RE) is a unique role at AMT. The activities of RE cover requirement management and technical requirement input within the organization regarding spare parts, service and repair or diagnostics product solutions. The RE supports the process of solution development. The RE has the responsibility to understand all the targets in the project prerequisites document. The responsibility

also includes to verify and validate concepts and solutions and to gather and analyze the project and product knowledge. An important activity is to support the breakdown of the requirements to a component level and aftermarket products. The RE has the responsibility to write requirements to satisfy the aftermarket. The engineer does also have the authority to validate concept selection regarding maintainability and serviceability. The RE has high competence in maintainability knowledge within the area and is an experienced engineer. The RE does also have knowledge about verification methods and tools in the area of expertise. Virtual tools are also used by the RE since visualization is an important part of the daily work to analyze the products.

Service Engineer
The Service Engineer (SE) has the responsibility to develop, write, illustrate and maintain repair information in terms of quality, time and cost regarding methods, standard times and special tools for Volvo GTT's brand dealers. The SE has the responsibility to develop, document, efficient repair information, and product descriptions on the vehicle and component level. The information is created based on CAD data in the first instance and later verified on the physical product. The CAD data is used to prepare text and graphics in order to create repair information. The responsibility also include conducting training for other SE and work packages. The SE will also provide RE and other departments with technical and repair information when needed. The SE has the authority to approve newly created special tools. The engineer has experience and knowledge in various software packages since CAD data analysis and illustrations are important parts in the daily work.

Virtual Specialist
The Virtual Specialist (VS) has the responsibility to prepare CAD data and check its quality before delivery to RE and SE. This includes preparing the content of the CAD data with the different specifications of the complete vehicle. The VS does also perform virtual methods analysis to support the RE in early phases of the project to satisfy the creation of requirements. Virtual verification methodologies and its implementation in projects is also an area of responsibility for the VS. When CAD data is not available is the interaction with vehicle architecture and product development department important to secure 3D content. The VS also develop and perform training to SE and RE in the virtual tools to share the virtual way of working. The competencies are very high regarding CAD tools since this is a basis for the daily work for the VS.

5.2 Current process at AMT

This section describes the findings about the current process at Volvo GTT AMT. Information is collected from Interviews held with employees from the three different roles at AMT, Observations, and Secondary data analysis. These methods are described in section 4.1.

5.2.1 Project management at Volvo GTT AMT

The current process involves different gates where activities have to be performed and information has to be delivered by the different roles to different departments. There are principles set to manage projects from a business point of view at Volvo GTT. This includes different phases which are designed to be cross-functional as visualized in Figure 5.1 below.

Figure 5.1: The product development process

Cross functional communication is very important from the beginning in the development process to make best decisions based on best available knowledge. The RE has the responsibility to perform a pre-study to see if the new design could satisfy the aftermarket top lists of service actions. The VS also supports the RE by providing and analyzing available CAD data. The RE is also responsible to transfer knowledge and findings from the study to the SE and also express the targets and needs for AMT to other departments. A lot of communication is performed by the RE in order to express these prerequisites. This includes regularly meetings with all the involved roles in the project. Available visualization tools are used to transfer the findings.

During the process it is important that all knowledge gaps are closed among the involved to have the prerequisites for making robust concept decisions. The SE will participate to build valuable knowledge in order to be able to design method descriptions.

The RE and SE are working close to each other to discuss content and plan further activities to verify that the requirements are met in the current design. The SE perform virtual method studies and identifies if there is a need for special tools with the current design. RE and SE identifies if there is a need for a physical product to verify the requirements fulfillment and also to verify the created methods.

5.3 Virtual Reality in industry

This section presents the results from the interviews in industry and benchmark interviews described in section 4.1.1 Interviews. The results is used to understand how VR is used today in the industry and how they see the future in the area.

VR is a tool used to visualize the products for customers but also to perform analysis of details in the design and ergonomics. Live rendering of pictures is done to get a real perception of properties with shadows and materials which is prioritized before the ability to interact with the parts. VR is also used to visualize the product in the customer's own environment to guarantee that the product will be able to implement and fit in the environment. VR is used to improve communication and collaboration between different departments. To perform communication inside an organization is a powerwall used but other techniques are considered. To be able to have a high quality in the virtual simulation is orderliness of the data critical to be able to get the needed meta data with details about its properties. VR is also used to document important knowledge from experts that will be reproduced by automatic machines. Support for HMD is implemented in the own software since they see an applicable area and need of this technique in the future. There are companies that have developed VR software which can handle critical functions such as apply collision control on parts while analyzing an accessibility situation and support for import of different types of data with HMD, CAVE or a powerwall as visualization and interaction tool. There is though not any available software that includes the technician hands or body parts while performing the analysis. This is though considered and under development among the companies. The current software supports the use of manikins to perform these kinds of analyses but not the user itself. There are also some software developers that have not considered the use of any kind of VR except the ordinary desktop version in the software. After discussion they see the use of it in the future but in order to implement the technology in the software there is need to have a support from the industry to know what specific functions are needed. All the companies see that a new way of presenting the virtual environment by stepping into the virtual world will have a breakthrough in the near future.

5.4 Virtual tools in the current process at AMT

This section will present the virtual tools that are used in the current process at AMT.

The engineers uses various tools to perform their daily work. All engineers are mainly working with analysis of CAD data in desktop software where it is possible to manipulate the CAD parts with constraints, to save different manipulated scenes, hide and show parts, create cutting planes, and to export the data to different formats. The VS performs special analyses when there is need to check accessibility, visibility and the possibility to disassemble parts. To perform these analyses are special programs used which the other engineers does not have enough knowledge in to use. In these programs is the VS able to import the CAD-data that will be analyzed with properties enabled such as collision detection to let the program calculate if it is possible to eject the part without collision with the surrounding. The planned path created in the software is able to be used in another program which includes manikins to evaluate the ergonomic aspect, some accessibility, and visibility of the planned path. The VS also generates information regarding requirements that will be communicated to the product development department by the RE. Sweep volumes are created where CAD data and tools are included to visualize the needed space in the design to satisfy the aftermarket needs. This information is possible to be used by the engineers in the communication process.

5.5 Challenges in the current process at AMT

This section describes the findings about challenges in the current process at Volvo GTT AMT. The data is based on Interviews, and Contextual Inquiries held at AMT. The methods and procedures are described in section 4.1. The findings are divided into three sections based on analysis of the results with the method Categorizing and Counting described in section 4.2.1.

5.5.1 Communication

Communication is one major part during the project process, overall is the information that has to be delivered from AMT complex and there is generally problems to be sure that the information is interpreted correctly by the receiver (R1, R2, R3). One of the interviewees stated -“The reason that the requirement is screened out could be that it is hard to understand it” (R3). A common opinion was that it is important to consider that the people with other backgrounds have to understand quite complex information (R3, R2, R1). It is not easy to build a complete method without previous experience and a lot of knowledge in the functional area (R2, R3). There is today not many geometric visualizations of requirements set by AMT, which could be used to facilitate the communication process (R1). There is need to send better data than the created from the current software, one of the interviewees stated -“In order to make sure that the information is interpreted correctly we have to find new ways to send the information” (R2). Another interviewee said -“Even if we spend a lot of time designing information is the outcome sometimes difficult to visualize and explain in the way so that the information is correct interpreted by the receiver” (R2). The current communication is often based on information in Excel or pictures and texts presented in PowerPoint which gives a limited possibility to add other necessary information (R2, R1, R3). The lack of feedback to all involved after a situation where requirements have been screened out and an aftermarket solution have to be implemented may affect how the requirements are prioritized during other projects (R1). The expertise from AMT is very important during the early phases in the product development, but the ability to transfer the knowledge is difficult with the support of currently available software, as stated by one interviewee “It is possible that the designer thinks that the requirement is correctly interpreted but the intention may be totally different from the AMT” (R1). There are situations where you want to explain how special tools are used in context and why the design of the product is important which is not possible without a physical prototype today (R3).

5.5.2 Tools for virtual analysis

There is today a lack of virtual trust since it is not possible to perform virtual analyses of all types of situation and get reliable data since all factors cannot be included (R3). There is a need to understand how the situation in the analysis looks like in reality, in its context, to know if it is possible to enter with tools or hands to perform the activity. The current software does not give the ability to perform the analysis and there is a need to order a physical mock-up of the area (R1, R2, R3). The ergonomic aspects is also an important part since the operator have to be positioned in a posture while performing the activity, if it is a harmful position there is need to redesign the created information (R2).

5.5.3 Analysis of CAD data

All interviewees work with CAD data in their daily work and do meet limitations while performing the work. Problems are today found when the designed methods are verified on the physical products. The verification is performed to ensure that it corresponds to the expectations in order to be sure that no problems will occur when the production is set (R2). During discussion while performing CAD data analyses is a software used where the data is presented on a desktop screen without the possibility to let the recipient of the information know about the products real size, in its context, if this is not experienced on a physical prototype (R1, R3). The available CAD data does not always satisfy the work that will be performed, some parts or details may be missing or misplaced which could affect the outcome of the analysis and it is not always easy to find the incorrect data while analyzing on the desktop (R2). While designing information is also the time it takes to perform a specific operation assumed. As said by one of the interviewees “It is hard to include all needed steps with the current way of work since you have to for example eject parts and put them in a specific spot and reach for tools in reality” (R2).

5.5.4 Workshop

The conducted Workshop procedure is described in section 4.1.5. The Workshop resulted in five main groups that answered the focus question:
- *What problems do you face in your work process?*

The explaining text below each of the headings is a conclusion of the underlying groups from the Affinity Diagram.

Lack of standardization in the organization
It is today not possible to have a common platform and pipeline related to CAD data to satisfy the aftermarket needs. There is a need for a common platform for knowledge, meta data and process data. Several systems are used and the level of knowledge is different in the systems among the employees.

Not sufficient tools to work 100 % virtually
There is today a lack of quality in the CAD data, available meta data, and knowledge in simulation software. It is hard to get a perception of for example small components and cable routing when using currently available tools. It is today not possible to simulate situations where all important factors are considered, such as flexible material, needed tools in combination with hands, to analyze accessibility and visibility.

Not enough preparation for Global Work Package (GWP)
There are not sufficient tools to communicate information with the GWP. The created content is based on expert opinions and knowledge which is hard to transfer to others within the GWP. There is a need for other technology to present the content.

Global and internal communication is a problem
Product Development department is not organized to handle the information communicated by the AMT. There is also a need to ensure correct updated CAD models. The current process and communication tools do not support the needed information transfer.

Maintainability and AMT business needs more attention
There is a lack of understanding in technical solutions, there is a need for more efficient tools to visualize requirements set from the AMT to guarantee correct interpretation by the recipient.

6

Methodology Design and Evaluation of VR at AMT

In this chapter will the used methods and procedure for the evaluation of the designed Virtual Reality environment be presented. This methodology is based on the results from the Current State Analysis presented in Chapter 5. The procedure for this methodology is presented in Figure 6.1 below.

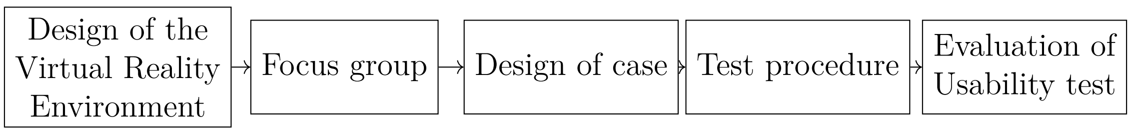

Figure 6.1: Usability test procedure

6.1 Usability test

An usability test is a structured interview which is focusing on a specific feature in an interface prototype (Kuniavsky, 2012). It is also a systematic observation of an end user attempting to complete a specific set of tasks in the designed product. Individuals participate in sessions where the interaction with the interface is performed (Baxter et al., 2015). The usability test can immediately show the development team if the assumption about how people will understand and use the design. The researchers evaluate the data which could have been gathered by recordings and notations done during the test to find opinions, possible mistakes, and misunderstandings done by the evaluator. After a number of tests, the researchers can compare the observations and collect the most common information highlighted during the tests (Kuniavsky, 2012). The type of testing depends on what types of features that will be examined and how. Even though the usability testing is the recommended usability engineering practice are there several usable methods that could and should be used to gather important supplementary data. This is observation, interviewing, using focus groups, logging the actual use and think aloud protocol (Nielsen, 1993). Think aloud protocol is a process where the participants speak out what they are thinking of while they performing the task, this will help the understanding about why certain actions were performed (Baxter et al., 2015). The choice of method gives both advantages and disadvantages, and by combining them it is possible to cover the important factors (Kuniavsky, 2012).

6.2 Usability test procedure

Usability tests were designed and conducted in the VR environment to evaluate if VR could support the challenges described in section 5.5. This section describes the procedure of the design of the virtual environment and the usability tests.

6.2.1 Design of Virtual Reality Environment

Based on the findings in the current state analysis and previous research in VR at AMT was a VR environment implemented in the software Unity3D. Knowledge was gathered about the program and the results from section 5.3, Virtual Reality in industry, was used to design the environment.

The technology chosen was the HTC vive as HMD since the results in 5.3 indicates that this technology will be used in the future. The previous study also indicates the need to include body parts in the virtual environment, especially hands, since the operations are mainly based on activities performed by hand. The Leap motion was chosen to let the users be able to use their hands to interact with the designed VR environment. The designed software in Unity3D supports the import of CAD data from Volvo GTT and includes different functions such as manipulation of objects with constraints, highlighting of parts, taking measurement, collision detection between parts, taking screen shots and record the session, and performing collaboration in the environment over the internet.

6.2.2 Focus group

To conduct the planned usability tests were nine experts working in the area contacted to create a focus group. The focus group composition was four Service Engineers, three Requirement Engineers, one Project Owner and one Virtual Specialist. These roles were chosen since they were investigated in the Current State Analysis and also were familiar with the challenges.

6.2.3 Design of case

To cover different situations where the identified challenges in the Current State Analyses appears, were four different virtual environment designed in Unity3D. These scenarios are from projects which members in the focus group were working with at the moment.

The first scenario covers the process where a SE will design a draft method, the virtual environment is shown in Figure 6.2. This scenario covers the challenges where the SE meet a new product and has to understand its properties and function in context to create material for a method. The SE was also able to verify that the method was possible to perform with hands and that needed tools were possible to fit in the environment. The method that will be created is about a removal of a pump from a gearbox. In this designed scenario was the SE able to manipulate individual CAD parts into different positions and during the process save media in forms of pictures and movies. All needed steps in the method will be included to perform the activity. This is ordinarily done in a desktop software and if there are some issues then also analyzed on a physical prototype. In the VR environment will the SE be able to perform the activity with similar functions as used in the desktop software and the needed CAD data was imported into the scene. The manipulation of parts was performed by using the hands and it was possible to constrain the parts with a menu defined on the physical controller. Functions were also added on parts to let them have collision detection enabled in order to help the engineer to design the method correctly and analyze if the tools can be used, and then not to oversee any possible problems like accessibility issues.

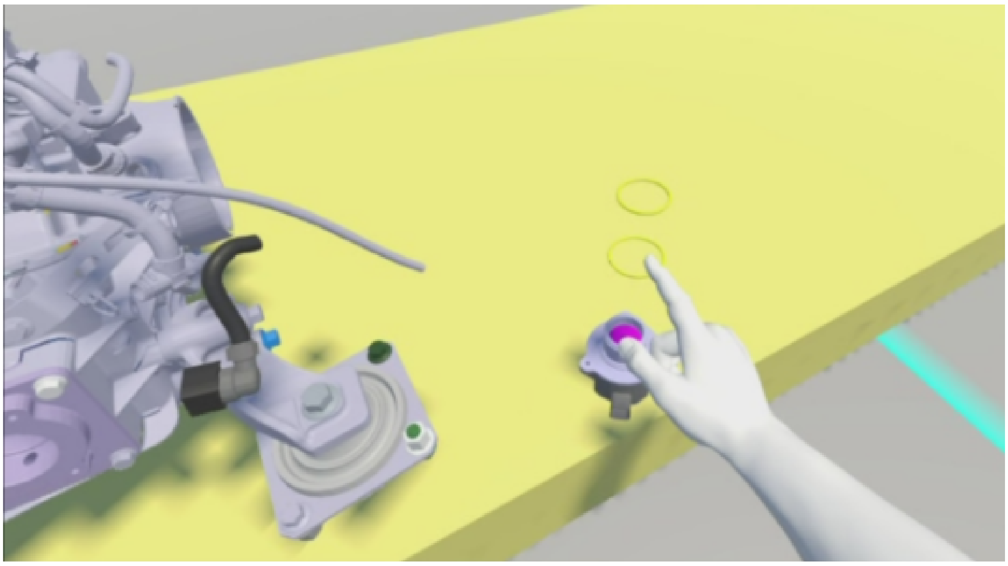

Figure 6.2: Scenario where the Service Engineer is able to design a method in the VR software.

In the second scenario was a situation designed where the RE will create information to give feedback to the product developer regarding a part. The product development department want to redesign a part to make it easier to produce. The RE want to show why the product have to be designed in this specific way to let its design satisfy the aftermarket requirements. This test covers the problems stated in the current state analysis when communication and explanation are performed with other departments. Needed CAD data and special tools was imported in the environment in order to let the engineer show how the activity is performed, the situation is shown in Figure 6.3. The used hydraulic press which is used in the operation is visualized in the environment by using the Unity3D library, where it is possible to design parts out of standard geometrical shapes. The press was designed to correspond to the one used in the workshop. The imported and created objects was possible to manipulate with physical behavior and collision detection enabled to let the engineer evaluate how parts react when they get in contact with each other. The physical controllers were used as interaction tools and the RE was able to take pictures in the environment.

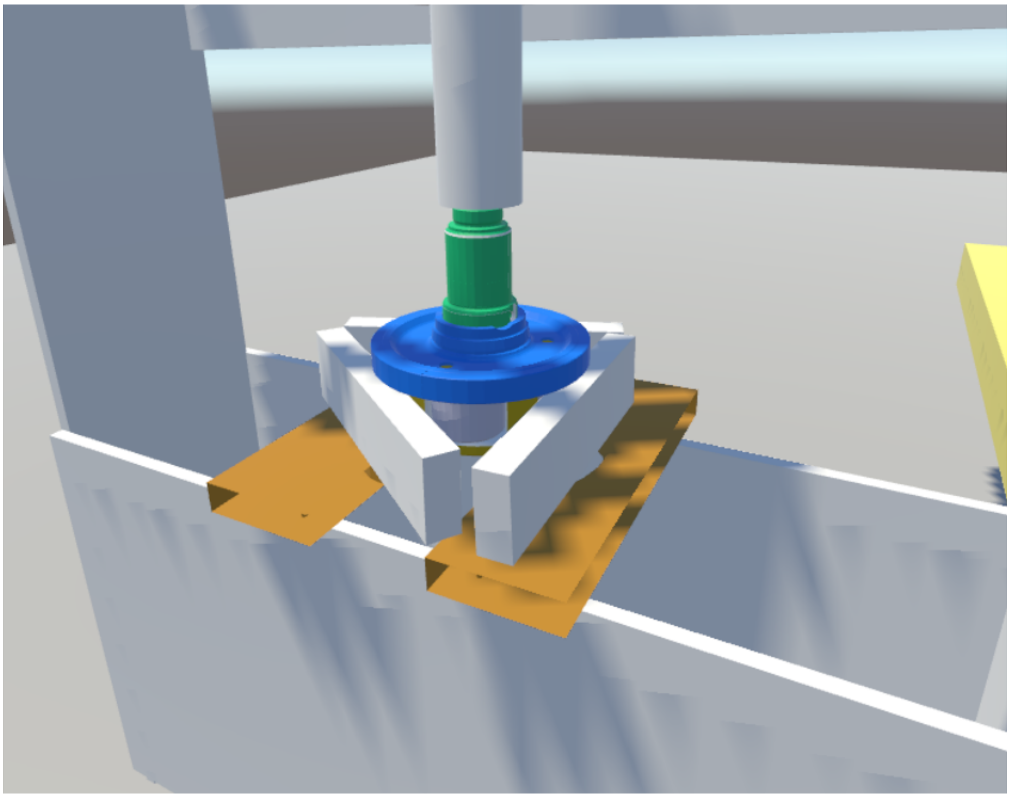

Figure 6.3: Scenario where the Requirement Engineer is able to perform an activity in the designed environment.

The third scenario covered the process of when the RE performs an analysis if it is possible to access a narrow area with needed tools and hands in order to perform a method, the situation is shown in Figure 6.4. The results will be used in communication with the product development department. Needed CAD data and tools were imported into the scene with collision detection enabled. Leap motion was used to let the RE evaluate if it was possible to access the area with the combination of tool and hand. In the environment it was possible to manipulate the tool into wanted position while collision detection is enabled to the environment. This feature let the RE to know what tool that could be used and if there was a collision between the tool and surrounding. Found problems and solutions was able to be documented by taking pictures with the menu on the controller.

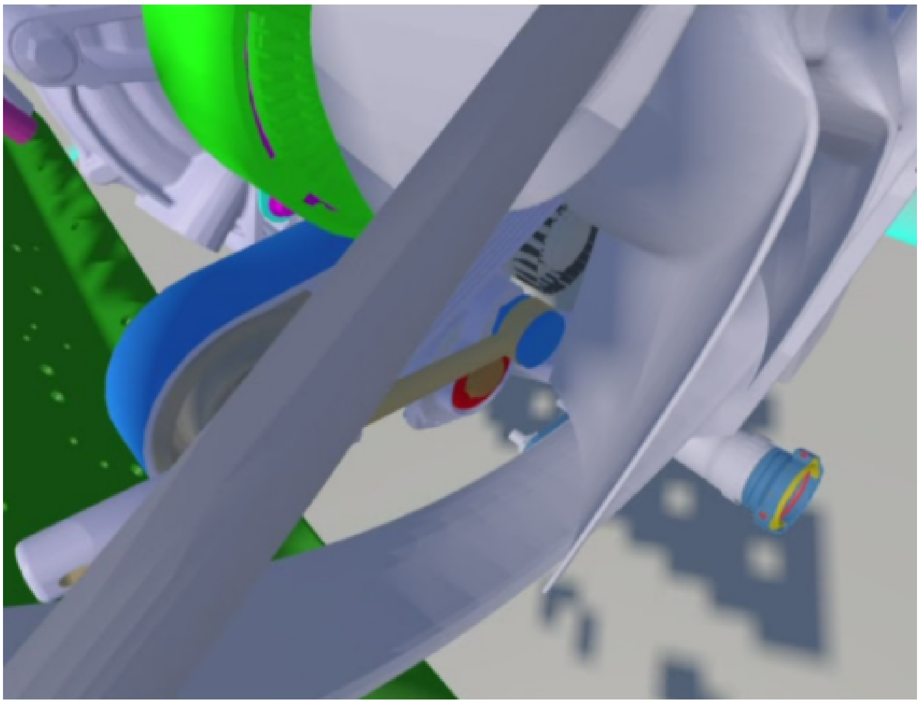

Figure 6.4: Scenario where the Requirement Engineer is able to perform an accessibility analysis in a narrow area with a tool in the VR software.

The fourth scenario was designed to cover the challenges met in the analysis of CAD data while evaluating limitations regarding visibility and accessibility when trying to perform an activity with the hands, the situation is shown in Figure 6.5. The requirement engineer was able to perform the analysis in the VR environment with needed imported CAD data and tools with collision detection enabled. The hands were visible in the environment by the support of Leap motion. The RE was able to move around in the virtual environment and evaluate different postures in terms of the visibility opportunities. During the analysis it was possible for the RE to analyze the parts in the environment to see if other variants could affect the accessibility. Found problems were possible to be documented by taking pictures with the menu on the controller.

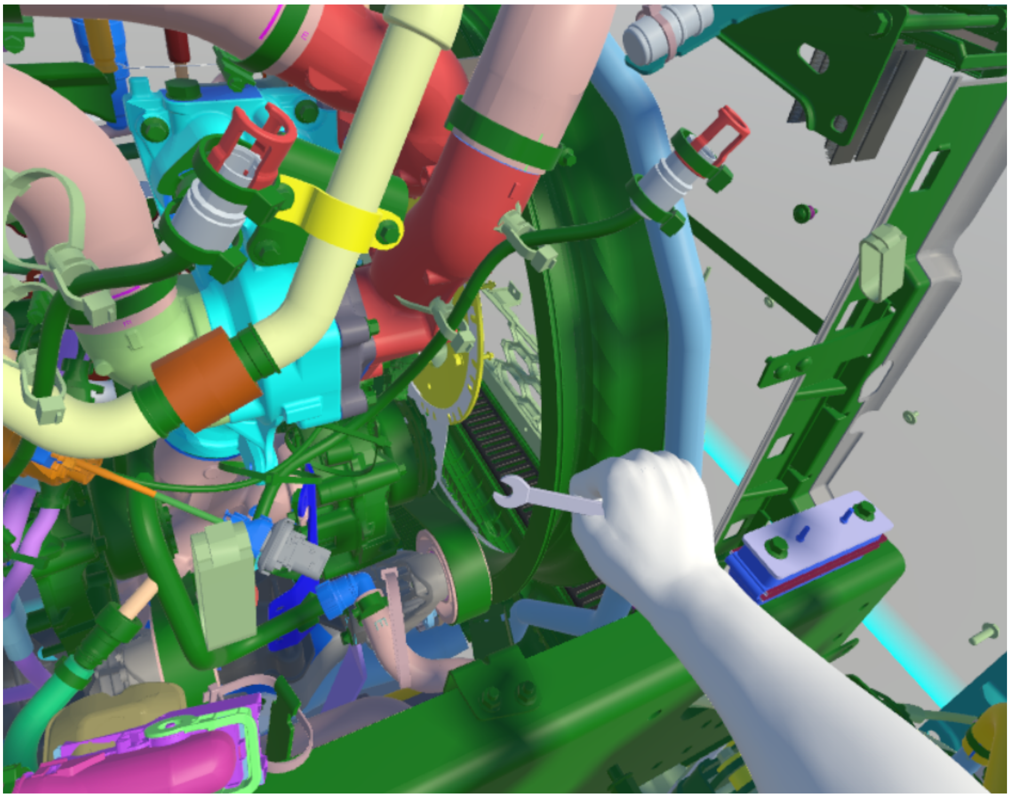

Figure 6.5: Scenario where the Requirement Engineer is performing an accessibility analysis with hand and tool in the VR software.

6.2.4 Test procedure

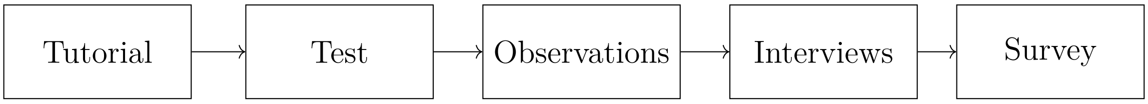

Figure 6.6: Test procedure

The members of the focus group were invited to perform a test of a scenario in the software in one-by-one session planned in 90 minutes. The test procedure is shown in Figure 6.6. The time was planned to cover a tutorial with instruction about the test, time for questions by the user, the usability test and interview and survey. The tests were set up and conducted at Volvo GTT AMT in Arendal where the engineers and VS are positioned.

The session started with a brief introduction of the program and instructions about the used technology such as the HMD and Leap motion. The user was instructed about the activities to be performed in the environment and had some time to familiarize with the environment and functions. When the user felt secure about the interface and functions was the session started where the user performed the analysis. The user performed the analysis with the available tools and had the possibility to decide how to perform the analysis (within the limitations of the designed environment and its functions).

6.3 Evaluation of Usability test

According to the standard ISO 9241-210 is the user experience defined as “a person’s perception and the responses resulting from the use or anticipated use of a product, system or service”. The user’s experience needs to be evaluated by the use of qualitative or quantitative data in order to document the experience and be able to improve it in the future (Drouet & Bernhaupt, 2016).

6.3.1 Evaluation of Usability test procedure

During the Usability tests in the VR environment was the user’s experience collected. It was collected by conducting Observations, Interviews and a survey. The collected data was analyzed to conclude the results of the usability tests.

The session was recorded to be able to analyze the collect data later, the user was told to speak aloud during the test. After the test session was a semi-structured interview held with the participant. Further was also a survey conducted by the participant where VR was compared with desktop software and physical product. All gathered data was analyzed by using categorizing and counting.

7

Results Usability test in the designed Virtual Reality environment

This chapter presents the findings from the Design and Evaluation of VR at AMT, described in Chapter 6.

7.1 Result from Usability tests

The experts from the four different roles who participated in the Usability tests, described in section 5, Usability test procedure, are presented in Table 7.1. A reference initial is connected to each role. The subsections are based on the structure of findings in section 5.5, Challenges in the current process at AMT.

Table 7.1: The different roles participating in the usability test

Role	Reference
Product Developer	R1
Service Engineer	R2
Requirement Engineer	R3
Virtual Specialist	R4

7.1.1 Communication possibilities with VR

Overall, the participants see possibilities to improve the communication process with VR. As stated by a participant -“This kind of visualization could be used at meetings in order to let the others to understand what is meant with the requirement set by AMT” (R3). By letting the other involved in the process enter the environment and perform the activity, this could give the extra information needed to understand what have to be adjusted to satisfy requirement set by AMT. This could also be used to assure that the requirement is correct interpreted (R1, R3). One participant stated -“The possibility to create a vision of how an operation could be performed and let the other involved parts like suppliers or designers experience the situation by themselves, or send data in form of video and pictures of the designed situation is very valuable” (R3). The transfer of knowledge among the involved and experts could be improved with the support of VR, as said by one interviewee -"It is easy to explain what is seen since you can behave as in real life by point at parts with the hands and at the same time put the head in an otherwise impossible position to clear show what the discussion is about" (R3), this situation is shown in Figure 7.1. One of the participants said -"It is hard to explain when there are no physically products available, but with the VR environment you can transfer an understanding about the situation since it is possible to perform the activity with all parts and tools in context with important physical constraints and behavior added" (R3). It is easy to discuss the design and methods in VR, even if just one is immersed, compared with using desktop software, pictures or text (R2). The communication of information worldwide could be improved, as said by one participant -"It would increase the understanding of the methods in the work packages if it was possible to show the method in VR to them, since it is like performing it in reality, VR could then be a complement to the standard hand over documents" (R2). The tool could also add important information to the data, as said by one of the interviewees -"It is possible to use the gathered information from the Virtual Reality environment to create simple methods and at the same time include further information as the positioning of hands and required tools" (R2).

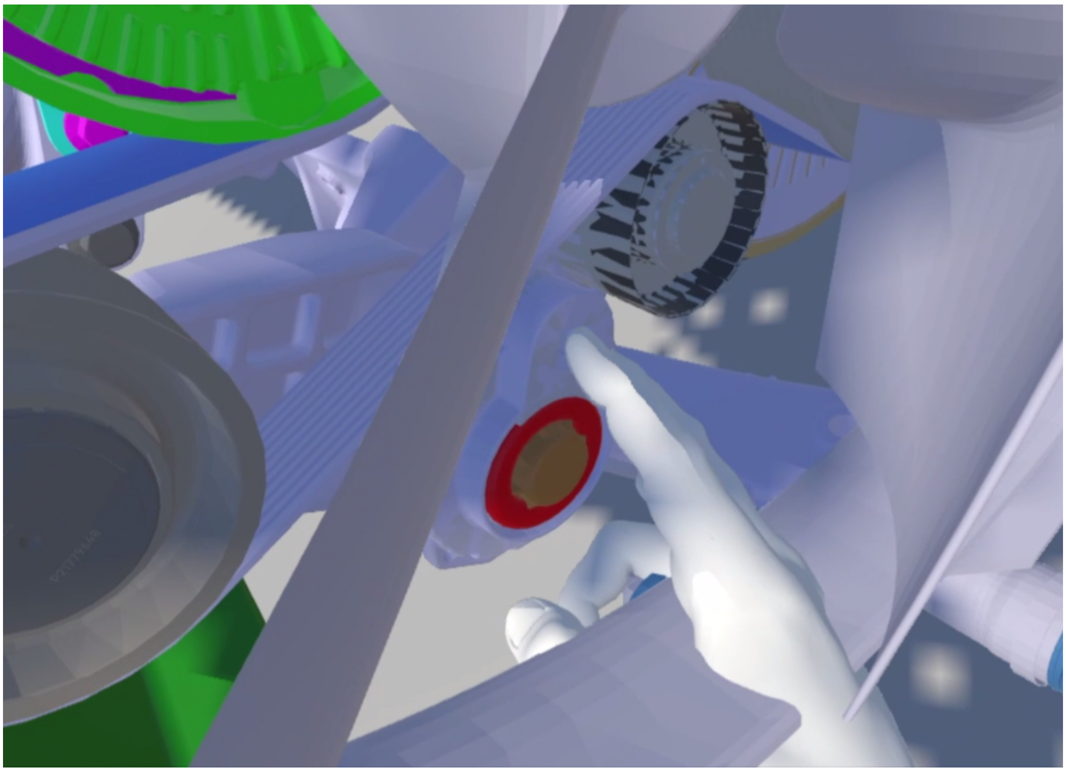

Figure 7.1: Scenario where the Requirement Engineer points on an area of interest in the VR software

7.1.2 VR as tool for Accessibility analysis

A common comment from the participants is that since it is possible to see the hands in the environment, it is easier to get an understanding about the real size of the parts but also if it is possible to reach and access the area with the hands (R2, R3, R4). As said by one of the participants -”When looking at the parts in this environment it is easy to determine if there is a need for a tool or support to eject it” (R2). Another comment stated by the participants is that the ability to perform accessibility analyses with the natural intuition gives possibilities to see a new way of performing the operation (R2). The ability to include tools in the environment and manipulate them into wanted position, as shown in Figure 7.2, does that it is possible to analyze the accessibility as done on a physical product. As one of the participants stated -“Performing the analysis is like performing it in reality, it is possible to conduct similar result in this environment as in reality” (R2). The participants say that the collision detection between the tool and environment in combination with the ability to look close gives good information to decide if it is possible to enter the area and where the problems are (R1, R3). The quality of the collision handling in this software is not enough to conduct critical analyses (R3). While creating information it is possible to see the size of parts and the surrounding which could improve the ability to create content that is correct the first time, -“Since the service engineer is dressed as the manikin it is possible to determine if it is possible to perform the activity while designing it” (R2). The ordinary way of work includes the virtual creation and then a physical verification, -“By using this it is possible to combine creation and analysis activities and then earlier meet possible problems than today, it is experienced as performing the activity in reality” (R2).

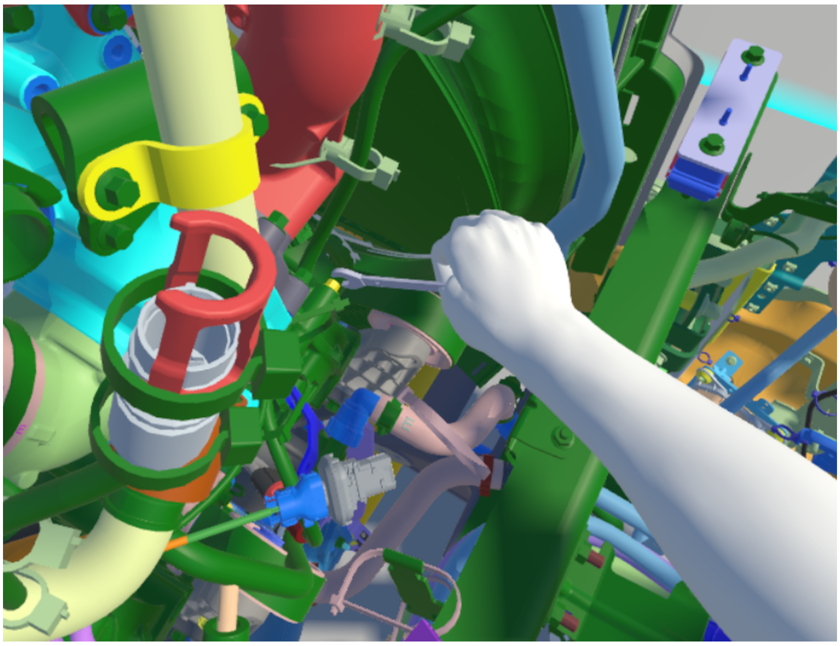

Figure 7.2: The Requirement Engineer performing an accessibility test with hand and a tool

7.1.3 Possibilities in analysis of CAD data in VR

A general opinion was that when entering the virtual world you get a whole new perception of the parts you are working with, especially when it is possible to see the hands as shown in Figure 7.3. "There is a totally different spatial perception in VR than in the desktop software" (R2). When using the CAD data in the work there is not always need for the use of VR, -“Some geometrical analyses and simulations may be more efficient to perform in the current desktop software and then later analyze the results in a virtual environment for a deeper understanding” (R4, R3). Because of the expertise of the user in combination with the perception of the CAD data in the virtual environment it is easier to notice if there are parts missing or misplaced. One participant stated that -“It was possible to immediately see that there were some parts missing which were important to include in the analysis” (R2). If there is a situation where the engineer does not have earlier experience could VR support to understand what type of problems that may occur in order to set the correct requirements to PD (R3). There are new possibilities to assume standard times with the support of VR since it is possible to understand and include all supportive tasks that have to be performed during the operation (R2, R3).

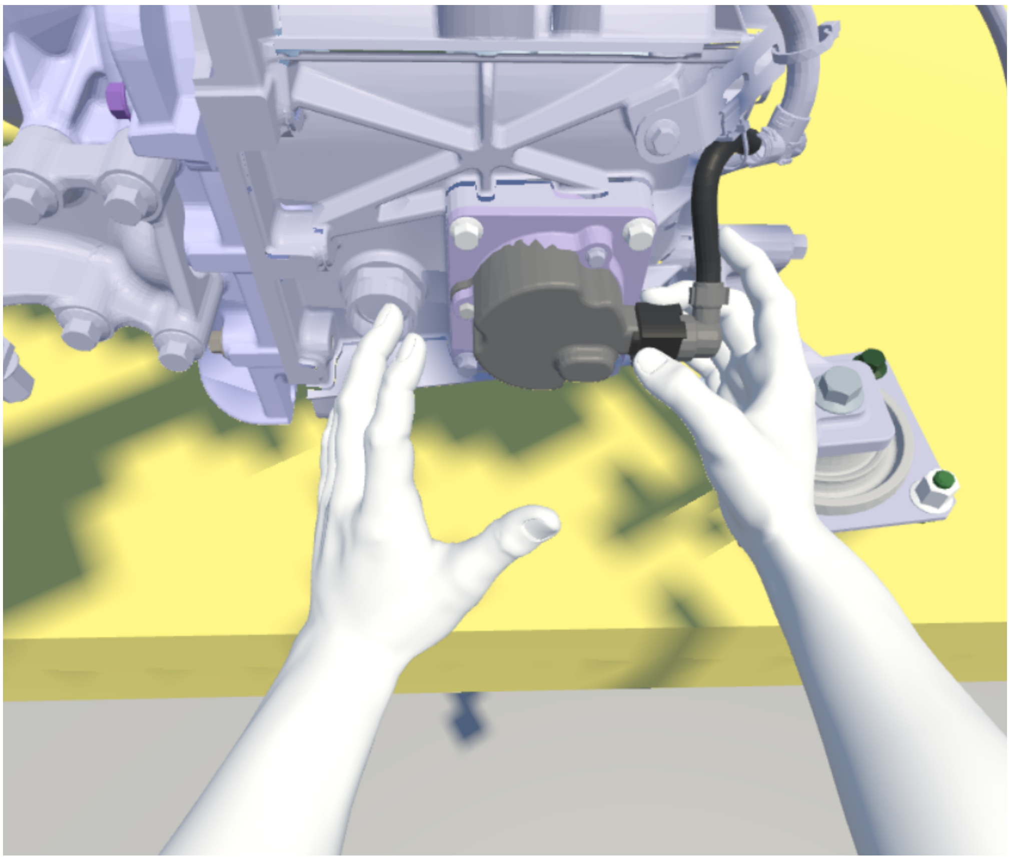

Figure 7.3: The Service Engineer performing and analyzing a method creation

7.2 Survey ratings

Below in Table 7.2 are the results from the survey presented where the comparison between the used tools within the areas in focus are rated by the participants from the Usability test. The items are rated between one to five where one is a poor tool and five is an excellent tool.

Table 7.2: Results from survey conducted with the participants in the Usability test

Item	**Virtual Reality**	**Desktop software**	**Physical product**
Realism of situation (surrounding awareness)	4.0	2.8	5
Understanding of product properties (size, function in context etc.)	3.9	2.6	4.7
Ability understand the variants effects on information creation	3.8	2.9	3.8
Perform ergonomic analyses	3.3	2.3	4.9
Perform requirement analysis	3.7	2.6	4.9
The trust of the findings in the performed analysis	3.6	2.9	4.7
Communicate information between roles and departments	4.1	3.3	4.2
Test and verify solutions	3.2	2.3	4.8
Ability to identify errors	3.8	2.9	4.7

8
Discussion

This chapter covers a discussion about the used methods and how they have been adapted to the study. The overall results are analyzed and discussed in relation to the theoretical framework. Recommendation for future work and a validity evaluation of the thesis is also presented.

8.1 Choice of methodology

The used methods in the empirical study are combined to cover the possible drawbacks of each method. Further does the triangulation approach used in the study provide a higher reliability and validity of the findings (Bryman & Bell, 2015). Methods are used to have multiple data sources such as interviews, observations and a literature review on earlier studies and theory.

8.1.1 Interviews

The interviewees were able to express their opinions since their anonymity and sensitive information would not be published or able to be traced to them. The interviews were used to capture sufficient experience and knowledge covering the possible problems in the work process. The choice of interviewees was important since different roles would yield different problems in the current work process. To not limit the scope to early were semi-structured interviews held to discuss the themes brought up by the interviewees to enrich the discussion around the questions (Denscombe, 2003).

8.1.2 Workshop

The purpose with the workshop was to let the employees together try to identify challenges in the current process and try to find the root cause of it. The candidates in the focus group work together on a regular basis which enhanced the level of participation among the involved since there is then a comfort and familiarity within the group (Chadwick, 2008). Another factor that needs to be considered is that the sticky notes used are not completely anonymous. This could have affected the stated information on the notes since there could be a risk that the opinions are more generalized because of the other participants presence. The collected data from the workshop was interpreted by using categorizing and counting. There is a risk that the collected data in some extent are subjectively interpreted. To consider this was the data analyzed with an open mind and triangulation used for data gathering to limit the bias in the interpretation (O´Gorman & MacIntosh, 2015). Step 7 and 8 was not performed in the affinity diagram since the identified challenges where all able to fit in the previous defined areas.

8.1.3 Group constellation

Interviews at AMT
The selected interviewees for the current state analysis were selected because of their knowledge and experience within the area. They shared information about their individual process of work during the interview. Since the number of held interviews is low it is not possible to generalize the findings because it is possible that the interviewees' way of work is a bit different compared to the coworkers. Volvo GTT has a standardized way of work but the engineers may have changed some activities in the process during their time in the company. By performing further interviews with more engineers it would have been possible to identify modifications in the current process. It would probably also be possible to identify other areas with challenges which could be of interest for the study. There is only one interview performed with a participant from PD to consider their view of the work with AMT. There are no further investigations within the department and the results are only based on this interviewee. In this case it is also possible that the process deviates from the standardized way of work within the department. Further interviews could have helped to evaluate the current process and may have given other results.

Workshop
The focus group in the held Workshop was selected to cover the different work roles of interest in the study. The focus group did not include all of the employees from the respective role which could have affected the collected data. The group was designed with participants which had worked together earlier to enhanced the productivity during the workshop.

Usability test
In the study are experts from four different knowledge areas included in the usability test. The participants were chosen because of their expertise about the information that has to be generated during analyses. They also know the current process with its current challenges. The experts are then the ones that can contribute with the most valuable information during the usability test. The engineers chosen for the test are the ones that will use the technology in the future, to let them evaluate the technologies opportunities to meet their requirements is then of high interest.

8.1.4 Usability tests in the designed virtual reality environment

The participants in the test had tried a VR solution earlier and then probably already had a picture of the possibilities and limitations with the used technology in their area. This may have affected the outcome of the performed the usability tests.

An advantage of this is that the interviewees could discuss their thoughts based on another program. A disadvantage could be that they already had a vision of the applicable areas with VR and did not highlight other important areas during the usability test.

As said by Goulding et al. (2007) is the comfort zone still embraced by the designer that is used to perform the work in an established way, this also applies to the engineers, they maybe do not want to change the current way of work. Goulding et al. (2007) also said that the cultural and social settings have a negative effect on the implementation of new technology. Changes within a large organization may take a long time and the engineers may not see the possibilities to implement such new technology in a near future even if it is needed. Because of this, the engineers may have been critically set to the technology from the start which may have affected the results during the tests. The users may also be afraid to lose the access to the currently used tools and the physical products if the management finds that this new technology could replace the physical prototypes. This situation probably is because of that the engineers, as shown in the results from the workshop, does not have enough virtual trust with the current virtual tools. The previous experiences in the virtual analysis area among the engineers may have affected how they see possibilities with the VR technology. The engineers probably have preconceived thoughts about that the technology is not enough mature yet to give enough information to generate decisions based on the same robust information as done when analyses are performed on the physical prototypes.

The tests were conducted at the facility where the RE, SE and VS are stationed. This did that it was easy to find a time slot to perform the usability test. During the development, there was a close contact with the engineers who helped to test different solutions designed in the software during the development of the environment. This may have contributed to a positive view on the technology since they have contributed to the functions in the program and have seen that some of their thoughts are able to be designed in the VR environment.

Four different scenarios have been designed and evaluated in the usability test. These four scenes were designed with current ongoing projects to make it possible for the engineer to compare the test environment with the ordinary way of work where desktop software and prototypes are used. This could probably generate better data from the engineers than predetermined situations would have done, which the engineers could not relate to. There are many different analyses being performed by the engineers with different complexity. It was not possible to manage all different situations during the test to cover all situations the engineers meet in their work. This made that the engineers had to visualize about the possibilities to use the technology in other and more complex situations instead of try it out.

To let the users experience the VR environment was the HMD used. According to Steinicke et al. (2013) does the HMD give a strong feeling of immersion which could give the user the impression that the environment encloses. In maintenance can activities such as go to a workbench and get a tool be included which is easier performed in the HMD compared to the CAVE since their rooms are not constrained in the same way. The CAVE is though the currently available technology that gives the user the best field of view during the session in the VR environment. As said by Toet et al. (2007) is only 40 degrees field of view enough to analyze smaller parts and this in combination with the spatial experience which the HMD gives (Steinicke et al., 2013) to the user it is superior the CAVE in terms of the immersion, easy to set up, costs and navigation possibilities. The currently available software also indicates that the HMD technology will be used in the future. It is possible that the test could have given other results if another system was chosen.

Unity3D was chosen as the VR development environment because of the worldwide usage which generates a lot of information about the software which is available at communities and designed assets at the asset store. After benchmark with other available software was Unity3D seen as the development environment that could be used to easiest design similar functions used in the current desktop software at AMT. Some solutions implemented in Unity3D was inspired by other software. It was not possible to implement all identified functions since many are based on complex mathematical algorithms, the possibility of such functions was though described to the user during the test. With more knowledge in Unity3D and available assets could probably more complex environments have been created for the usability tests.

The designed environment used in the usability test is not of the high quality that is required by the aftermarket. As said by Zimmermann (2008) is the disassembly an important factor in maintenance which require basic behavior like collision handling. Collision handling is implemented in the software but not with the level of precision as needed by the engineers. As Purschke et al. (1998) and the usability test result indicates is there a need for functions to let the technician body to be included in the analysis where collision handling and feedback are important factors. The implementation of the hands gave much value to the engineer, but having better precision of the hands and implementing the whole body is required to let the engineers perform the analyses with confidence.

The results from the usability test indicate that the VR technology can be used in many areas to support the process but not replace the physical products, not with the currently available technology and software that is used in this master's thesis. There is a need for better systems that can handle larger models and calculate collision handling while including the operator's body with precision in the analysis.

8.1.5 Survey rating

The items chosen to be rated in the survey is based on the findings in the current state analysis, but it is possible that these could be interpreted differently by the engineers. To try to avoid such bias was the survey conducted face to face with a deeper explanation about the items. The users in the test have different backgrounds and they also perform different tasks in their daily work, they also analyzed different scenarios during the Usability test which could affect how they rated the items in the survey. A more comprehensive survey could also have been conducted to cover more different items and then see if new opportunities are seen with the VR.

8.2 VR in maintainability

As explained in section 2.3 have technologies for Virtual Reality been present since the 1960s but it was not until the 1990s the area exploded and different companies joined the research area. Industries as automotive and engineering have early adopted technologies such as CAVEs and powerwalls. During the 2010s has the VR technology been more mature and available for a larger community with less expensive systems. The availability to a wide community may accelerate the development of the technology, the used VR software in this master's thesis has been based on functions provided by the community. If functions keep being developed further it is possible that the aftermarket is able to use these as a solution in their VR software. As stated by Thielemann (2011) and Amditis et al. (2008) has the possibilities with VR been applied and verified in several industrial fields but not yet within all areas. The maintainability area has not yet been fully applicable with VR because of its complex needs in analysis (Zimmermann, 2008). The results also indicate that there is a need for complex functions and further development before it could replace the physical product and be used as a tool in the current work process. Also as stated by Jiang (2011) has VR the possibility to partially replace the traditional physical product which is an important factor to accelerate the development process and reduce the costs. As stated in section 5.3 is VR used by the interviewed companies to perform visualization where the quality of the visualized material is in focus and not the ability to interact with the parts. There is software available at the market that aim more to the maintainability area but it is not mature to meet the needs that are set by the area. By evaluating the technology within the maintainability area will the limitations be identified and then possible to hand over to software developers to let them develop the needed functions.

The implementation of new technology requires more changes in the way of work than to just implement a new module in the process. As said by Zimmermann (2008) is the software and hardware still not mature for the not savvy user which require organizational learning and research in the area to be able to adopt the technology. Another major barrier for the implementation of the technology is that it has to be compatible with the current used tools and way of work. There are though many possibilities with VR, Jiang (2011) mention the possibilities with collaboration opportunities and as stated by Karaseitanidis et al. (2008) is the information getting more complex which forces the organizations to find new way of presenting the data. The process to implement new technology may be challenging but there is a need for an organizational change, as said by Peng et al. (2012) does the level of competitiveness that exist on the global market today forcing companies to develop new strategies and think different. As stated by Peng et al. (2011) has further research to be concentrated on the relationship between physical-based modeling methods and virtual human in the environment.

8.3 Findings at Volvo GTT AMT

The results of the empirical study shows that there are challenges in the current way of work. These have been identified by using various methods as described in the empirical study procedure in section 3.2. The found challenges are:

- *Communication of knowledge and requirements*
- *To use the current tools to perform virtual analyses*
- *Analysis of CAD data and to have a virtual trust*

These challenges and their areas are discussed below and how VR could support in the current process.

8.3.1 Communication

The results of the case study indicate that the communication is a very important part in the process. It is challenges to make sure that the requirements and information are correctly interpreted by the receiver. This challenge is also stated in the previous research performed by Andersson & Ericson (2013). In the thesis is it also stated that one source of the challenge is that the designers are put on small areas and do not know what happens outside it because of the lack of knowledge and low level of received information. This lead to lower prioritization regarding the aftermarket requirements in the design process. During the case study did one of the interviewees said -“Even if we spend a lot of time designing information is the outcome sometimes difficult to visualize and explain in the way so that the information is correct interpreted by the receiver” (R2). Both AMT and PD experiences the limitations in the current communication process. The usability test shows that both departments see possibilities to facilitate the communication process between AMT and PD by using the VR technology. Since the input from the engineers from the AMT is very important, the implementation of new technology could help to develop the communication process in the early phases. This implementation could help to add information to the data during the design phases in a way to facilitate further communication and spread a better understanding among the involved. As said by Thielemann (2011) is the introduction of new technology only a module that has to be supported by the existing process. To implement the new technology there is a need for a new way of work and standardization (Amditis et al., 2008) and this requires that more departments than the AMT adopt and evaluate the way of work with VR.

In the survey rating in section 7.2 is the VR tool rated higher than the current desktop software in all items within the communication area such as realism of situation, understanding or properties and communication of information. Much data is created and available to use in VR today but the created information and data have to be possible to provide further in the communication process to build up the virtual capability, which is a crucial part to be able to use virtual technology (Jiang, 2011).

8.3.2 Tools for virtual analysis

The challenges to understand a new situation when the physical prototype is not available affects the ability to set requirements and perform accessibility analyses or design methods at the AMT. The available desktop software is a good tool to use when small individual parts are analyzed or discussed (Steinicke et al., 2013) and when there are no physical products available. As seen in the results from the survey rating in section 7.2 is the physical product rated highest in all items. A reason for this could be that when the VR environment is entered and actions are performed are not all human sensors stimulated as in a real-world situation which gives the engineer all needed robust information when performing the analysis. According to Steinicke et al. (2013) is it important to consider the consequences of the absence of the sensory stimuli. To consider this when the user entered the Virtual Reality environment in the HMD has Leap motion and menus on controllers been implemented. Since the perception between controls and action can facilitate the users' behavior (Shin et al., 2010) is Leap motion implemented to let the user see and use their own hands in the environment. The comments stated from the interviewees does also show that Leap motion gave much value, as said by one of the users -"It is easy to explain what is seen since you can behave as in real life by point at parts with the hands and at the same time put the head in an otherwise impossible position to clear show what the discussion is about" (R3) and "Since the Service Engineer is dressed as the manikin it is possible to determine if it is possible to perform the activity while designing it" (R2). As also shown in the survey from the users is the VR preferred compared to the desktop software which today has to be used if there are no physical products available.

8.3.3 Analysis of CAD data

The analyses performed on smaller products are optimal to perform in a desktop software when a spatial dimension is not needed (Steinicke et al., 2013). In the engineers work are individual parts and parts in context analyzed which indicates that VR in HMD is not appropriate for all types of analysis. The results also indicates that the spatial perception given by the HMD gives a better understanding of the situation when the aftermarket complex information have to be analyzed and communicated. The survey ratings also show that the engineers prefer the VR to the desktop software when performing the analyses. The HMD system in combination with a software that can provide needed functionality requested from the maintainability area to perceive the properties of the product could give the users better information to understand the situation. A more mature solution would probably give the users the confidence to make a decision in the VR environment as done on a physical prototype.

8.4 Validity of results

The results in this study are mainly based on qualitative data. Therefore, the results from this study are not possible to generalize in the area. Although, the qualitative data is based on employees which have a lot of experience and that can be seen as experts in their work role. This could be a factor that indicates a certain degree of validity of the results even if the results in some degree are based on subjective data. A factor that makes the results more reliable is that the results are possible to relate to earlier studies and theory in the field of Virtual Reality and maintainability. The triangulation approach with multiple data sources used in the project is also a factor that gives the results a higher reliability and validity (Bryman & Bell, 2015).

That the results are based on a case study conducted at one department in one company is also something that have to be considered. How the results would look in another company or field is something that has to be investigated further. The aim and limitations of this study do not include this. The conducted study is though performed at a big enterprise where a lot of knowledge and expertise exists.

8.5 Sustainability

With respect to sustainability could Virtual Reality support social, economic and environmental aspects. By reducing e.g. physical prototypes is the consumption of material reduced. Zachmann et al. (1999) state that Virtual Reality is a tool which can be used to obtain quick answers already in the concept phase of a product. This gives the possibility to avoid unnecessary design cycles which are expensive (Zhou et al., 2011). By implementing the VR technologies will the ergonomics for the workers be better since it is considered earlier in the development process. It is also possible to analyze situations in VR before the operator is exposed for possible dangerous environment which will contribute to a safer work environment.

8.6 Future work

The results indicate that the technology could be used to support the current challenges in the work process at Volvo GTT AMT. There are though a number of points that are of high interest for future research within Virtual Reality in maintainability.

To be able to generalize the results within the aftermarket technology should further tests be performed within Volvo GTT and other companies.

The technology develop fast and other possibilities with Virtual Reality should be evaluated to see what the best solution is for the maintainability area, such as visualization systems and external equipment to include the body in the analysis.

The maintainability field is wide and there is need to investigate other situations which were not possible to cover in this study.

There is a need to further evaluate where the application areas of Virtual Reality are within the daily work of the engineers within the maintainability area, to identify what should be done in the desktop software and in Virtual Reality.

The need from the maintainability area should be communicated to software developers to let them design and implement functions in the software to give Volvo GTT AMT the possibility to have virtual trust when performing analyses.

The identified challenges in the current process and the possibilities to support with VR could be used to perform a more in depth research within Volvo GTT to specify more detailed challenges. Other departments within Volvo GTT should also be included in the further research to find possible applicable areas of Virtual Reality since there is a need for an organizational change and standardization when implementing new technology.

9 Conclusion

The purpose of this master's thesis was to investigate the possibilities to use Virtual Reality as a tool in the aftermarket technology at Volvo GTT to support identified challenges in the current process. This has been done by using several methods in an empirical study procedure.

Volvo GTT is offering service solutions and up-time as a complementary product to the truck. This is a lucrative business which has high demands on maintainability in the design to be able to offer competitive service solutions at the right cost. The maintainability analyses needs to be performed as concurrent activities early in the development process. At the same time is the number of physical prototypes used during the development process to perform analyses decreased by the company to lower the cost. Virtual maintainability and VR is a complement tool which is able to be used in the current process to manage this situation.

- How is the Virtual Reality technology used in the industry today?

There are several areas where the VR technology is used today. The main area where VR is used is in the visualization of products and marketing of solutions. The field of maintainability has not yet been able to apply the technology in all areas because of its current limitations. Further research and development is needed within the technology in order to let the maintainability industry apply the technologies in their process.

- Which are the main challenges connected to virtual work in the work process at AMT?

The process at AMT was investigated and the results indicate that there are challenges in the current process. The main challenges are:
- Performing communication of complex information created at AMT to other departments in the organization.
- Performing virtual analyses with the currently available tools when a physical product is not available.
- To analyze CAD data with current tools and understand the situation when no earlier experience from physical products are available.

- How could Virtual Reality support the challenges in current work process at AMT?

VR could support the communication process with its possibility to let the user to perceive the information as in reality. It is possible to visualize complex situations with more information included which could facilitate the understanding among the involved.

Different types of analyses could be performed in VR, such as accessibility and visibility analyses, to design and verify requirements and methods early in the process when physical products are not available.

The analysis of CAD data could be conducted in an earlier phase and also give important spatial and physical information as an analysis performed on a physical prototype. It is possible to recognize design and method issues earlier in the development process with the support of VR.

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