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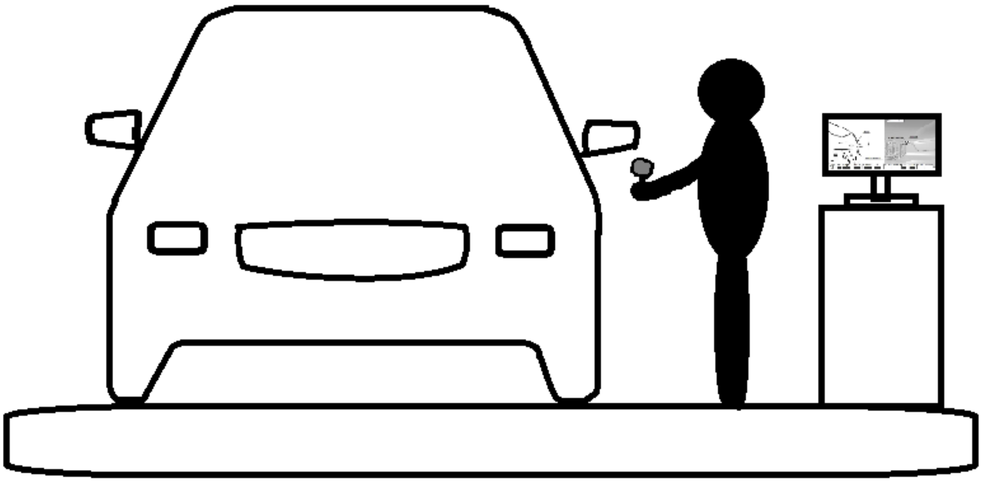

Digital Visualization of Quality Data in Final Demands Station

Master's thesis in Production Enigeering

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Master's thesis2020

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Abstract

To have better customer satisfaction, high quality of the product is necessary to compete on the market. Many automotive industries use perceived quality to maintain their global market value. With ever-increasing competition on the market, industries tend to move towards mass customization which involves digitization, better visualization and automation too in their process. This thesis discusses the process of arranging standardized specifications data to an evaluated visualization device which will support the current process, by creating better circumstances for the operators from a cognitive ergonomics point of view and finally stating that having the visualization aid in the process helps the inexperienced operators and other parts of the work task.

The research begins with a basic literature study followed by a structured work procedure to meet the objectives and demands set for the thesis, which was done by answering framed research questions. After the literature study, the research is followed by the screening process consisting of a current state analysis and an identification of limitations with observations and interviews with operators working in the observed work station. Some evaluation methods were used to select a suitable visualization aid with regards to the identified information. The next phase is the testing phase, which involves the evaluation and testing of the newly developed solution.

Finally, the implementation of the developed program with the visualization device was introduced to the process. These obtained results were compared with the older results to finalize the main objective of the thesis and point out the differences per the operator's feedback which was obtained. These results pointing out that their is an requirement of cognitive support in the process and it having it does improve the process and also possible recommendations in the future.

Keywords: Perceived Quality, Digitalization, Visualization, Cognitive Ergonomics, Final Demands Station, Implementation.

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Kevin Billskog Johansson and Madhusudhan Chowda Shetty, Gothenburg, June 2020

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1
Introduction

The introduction chapter consists of the background to the thesis from suitable literature. It also explains the aim and delimitations of the thesis. The introduction ends with formulating research questions that need to be answered and a description of the case.

1.1 Background

In all manufacturing industries, there are variations within their internal manufacturing processes [Jiang, 2015]. These variations within different parts can cause the final product to have too large variations affecting its performance or appearance [Sarangi et al., 2008]. This results in defective products, that need to be scrapped or altered. To ensure that these kinds of products are found and taken care of before they reach the customers, different quality controls are necessary. Most of the industries prefer a digital representation of the quality data for their designed products due to the ease of sharing it with their fellow workers, which makes it easier to manufacture and compete on the global market because, more precise quality results in customer satisfaction and also increase in demand of their product [Yang et al., 2006]. The quality control and quality assurance in the industries are done by having certain specification demands that are set by tests conducted by companies themselves, and one useful and effective way of conveying that specification information to the operators is through a visual system or other informative platform [Cepeda and Lopes, 2019]. The mass customization refers to the automated manufacturing of the products and involves the combination of digital manufacturing and the smart factory [Kull, 2015]. Mass customization or Industry 4.0 defines the similar things of the increased use of information and communication technologies in the production process [Kull, 2015].

For the automotive industries, it's not enough to fulfill the quality demands if they want to be an attractive manufacturer due to the high competition [Stylidis et al., 2015b]. Therefore some automotive companies, will take the perceived quality of the car into consideration. Perceived quality means that the customer is placed at the center and the specification demands are based upon how they affect the quality perceived by the customer [Stylidis et al., 2015b]. By placing the customer at the center, the perceived quality will change depending on the industry. Therefore it can also be defined as a dispersed, convergent and usually exclusive to the automotive industry [Stylidis et al., 2015b]. One of the important aspects to have a good perceived quality is the appearance of the car and to accomplish this, the car manufacturers measure the fitting and alignment between components and surfaces of the car.

This is done by measuring the gap and flush between the different components [Stylidis et al., 2015b]. In a large scale industry like automotive industry, there are many different parts and components, this results in thousands of measurement points to measure in a car to ensure that the perceived quality is up to the mark. The mass customization within the automotive industry further increases the complexity of measuring due to the changes in the measuring points caused by the large amount of car variants [Michalos et al., 2010].

By having thousands of measurement points with variations in their measurement location, it's hard for operators to remember their complete work routine. Therefore instructions on where to measure is required. To support the operators the instructions needs to be visualized in a good and comfortable way. This could be done by adapting some of the logistical aid in the workstation which makes the operator's work more easier and increases the cognitive ergonomics [Mattsson et al., 2018].

1.2 Aim

The main aim of the research is to create better circumstances for the operators while performing measurements of the gap and flush of the car. This type of cognitive support will mainly be done by providing better visualization of their work task while performing the work.

1.3 Delimitations

To make sure that the project focuses on answering the aim, some limitations were decided upon and a few other delimitations were added from the company's demands. The delimitations are presented below:

- No changes will be looked into with regards to the measuring equipment currently being used in the measurement station.
- The data that is presented to the operators will not be altered as it is a standard specification demands set by the organization.
- The systems surrounding that the developed solution can't be changed as to not disturb the normal work process at the company.
- Any technical solutions used needs to be readily available on the market for the company to purchase.

1.4 Research Questions

Based on the aim of this thesis, three research questions were formulated. The questions are answered under certain chapters of the report by covering aspects related to the research questions stated below.

- How could the available information be better visualized to help operators when conducting measurements?

- Which technical possibilities are there to share and assimilate information about measurements with the operators?

- How do the operators perceive our technical solution? And how can the solution be further improved to encourage operators to use it in their work?

1.5 Case Description

Volvo Cars Torslanda (VCT) is designing, manufacturing and selling cars to the public market at present. They are currently producing cars with a lead time of one minute. The final assembly occurs in the TC factory, from there, completed cars are sent to the 'Final quality inspection' station for a final inspection. Three final inspection operators are working simultaneously with two cars. It takes around one to two days to finish measuring everything for one car. This thesis is concentrated on this final inspection or demands station.

They are measuring the gap and flush between different car surfaces to ensure that the perceived quality of the car is upheld. In the Torslanda plant, the operators measures the features manually and obtain results using gauges, which is a traditional way of measuring. The information is shown to the operators on a computer screen using a called software (CM4D) to visualize the specification demands and to document the measured tolerances data. This is checked based on the color codes present in the software, which are Green (Within the nominal value) and Red (outside the nominal value). If the measured data is not within the nominal tolerance value, an error is alerted with a pop-up on the screen.

The company wants to implement a visualization aid, to support the operators when measuring and when comparing the results with the specification demands during their work routine. The visualizing aid that is being introduced must be capable of having notifications or alarm functions like the Andon or ATACQ systems in which the measuring results are synced to the new visualizing aid. The visualization aid needs to be portable, so the operator can easily access the data on all locations around the car. There hasn't been any attempts previously to visualize the specification demands of the quality inspection using visual aids other than from the computers. This thesis is focused on introducing a cognitive support to the operators in the final quality check or station. The logistical aid which is being introduced should help the operators to visualize the specification demands data of the company during the quality inspection which makes the work process more simpler and faster.

2
Frame of reference

This chapter consists of the theories which are applied to this thesis. A literature study was conducted, and important aspects are presented in this Frame of Reference. Various sections and sub-sections explain the different areas which creates the basic foundation for this thesis.

For any research, survey or study of various topics is used to provide complete details about areas that is required to investigate by performing this empirical research [Berlin and Adams, 2017]. According to the background and thesis case description, decision was taken to break it down into different areas to mainly focus and dive deep into those areas. Some of the main topics investigated were the types of measurements and tools used to measure gap and flush in the automotive industry, the digitalization, visualization, information related to Industry 4.0 and also various displaying devices or visualization aids which can be used in modern-day industries.

2.1 Quality

The quality of a product from the perspective of production can be defined by how well it fulfils the customer and specification demands. There are two ways to achieve better quality. The first is to reduce the amount of existing deficiency's. The alternative is to improve upon existing features which meets the customer demands, resulting in a product with higher customer satisfaction. While improving existing features usually increase the running cost, reducing inefficiencies tends to decrease the running expenses. In some competitive industries such as the automotive industry, it's not enough to only deliver products with no defects. They also need to work on improving the customer's satisfaction to stay competitive on the market [Stylidis et al., 2015b].

2.1.1 Perceived Quality

To ensure that customer satisfaction is always one of the main priority, when it comes to quality, some automotive companies place importance on the perceived quality of the car. Which means that the focus is always on the customer and what the customer expects is of high quality that signifies [Stylidis et al., 2015b].

Since a company usually has many different customers that all have a different opinion about what customer satisfaction implies. Perceived quality has a subjective definition that changes between different companies, even in the same industry [Garvin and Quality, 1984]. The automotive company Volvo Cars, for example, have defined perceived quality into several different categories such as performance, drivability, design and manufacturing elements such as split lines, fit, finish and level of NVH (noise, vibration, harshness) [Stylidis et al., 2015a]. To ensure that the specifications set on the quality and perceived quality are upheld, there is a need to verify the quality.

2.1.2 Quality Assurance

Quality assurance compares the actual quality with the specifications and stimulates corrective actions if necessary [Juran and Godfrey, 1999]. The purpose of quality assurance is to verify that the quality is up to standards before the product is sold to the customer. Every product's quality is inspected thoroughly after the manufacturing is done and try to improve further than before.

2.2 Cognitive Support

In any kind of manufacturing industries, there is an requirement of human operators in some of the stations like assemblies and quality inspections mainly because of the ability to respond to the variations and specific instructions provided in the production process [Berlin and Adams, 2017]. Ergonomics is one aspect which must be taken into consideration, to not only take care of the operator's safety and increase productivity but also to provide support in the operator's work tasks [McCauley-Bush, 2011]. Cognition is a type of ergonomics, which refers to the complete process of handling information. It also involves sensory stimulation combination, memory interpretation and leading to the decision making and response [Berlin and Adams, 2017]. It's also necessary to give attention to what kind of supportive equipment that is provided to the operators, which will affect the cognitive strain or load during their work [Kalakoski et al., 2020]. There are many ways to provide cognitive support which originate mainly from the desire to optimize the performance of systems depending on the working environment and no single solution is obtained as the standard practice, it is dependent on various aspects and situations [Berlin and Adams, 2017].

Table 2.1: Table for the different levels of cognitive automation [Frohm et al., 2008]

Cognitive automation level	Description	Example
1. totally manual	The user creates their own understanding of the situation and develops their own course of action based on their knowledge and experience.	Users earlier experience and knowledge
2. Decision giving	The user gets information on what to do, or a proposal on how the task can be completed.	Work order
3. Teaching	The user gets instructions for how the task can be archieved.	Checklists, manuals
4. Questioning	The technology questions the execution, if it deviates from what the technology considers suitable.	Verificatrion before action
5. Supervision	The technology calls for the users' attention, and direct it to the current task.	Alarms
6. Intervene	The technology takes over and corrects the action, if the executions deviate from what the technology considers being suitable.	Thermostat
7 Totally automatic	All information and control is handled by the technology. The user is never involved.	Autonomous systems

2.2.1 Andon systems

Andon systems are used to control the indicating systems in the production stations, with flashing lights or sounds to help the operators during their work [Fieldbook, 2004]. This could be done by the operator or the authority of controlling the Andon systems is given to operators in their work routine [Fieldbook, 2004]. By the implementation of Andon systems in the production process, the problems are visible and could be detected and fixed for better quality maintenance [Li and Blumenfeld, 2006]. These type of principles are evidently used throughout the production systems of Toyota [Fieldbook, 2004].

2.3 Industry 4.0 - Digitalization

According to the thesis case description, the main focus is towards the digitization and visualization in the production process. Companies try to transform their production and operations into Industry 4.0 due to its creation of change in the business and value proposition citeustundag2017industry. In order to introduce technological advancement which results in increased productivity, it is also important to consider a transformation to use a digital platform [Ustundag and Cevikcan, 2017]. This transformation could be a strategic move and should be considered a long-term plan for any organization. Working in a similar fashion is the next transformation from digitization to visualization. This thesis is concentrated on improving digitalization and also improving the visualization.

2.4 Presenting digital information

Usually, information nowadays is stored in a digital platform. To view the information, some kind of digital device is necessary. One of the most common ways to present information is by using a computer screen. The downside with computer screens is that they usually are hard to move around. So a person needs to move to the screen if they want to see any information or go to that particular location where the computer is situated. By using a digital devices in the process, it allows for portability and a better access to the desired information for working operators [Shafiq et al., 2019]. This step of implementing the digital connectivity is considered as one of the major step under the components of Industry 4.0 and this benefits in having a better data analysis, processes, resources support, flexibility and efficient production rate [Shafiq et al., 2019].

2.4.1 Portable display devices

There are other smaller, compact devices available to present information that are portable [McTear et al., 2016]. They can therefore, carry with a person and show them the information wherever they are required. But they usually have a lower capability in comparison to the stationary solutions, since the device needs to be small enough for a person to carry it with them.

2.4.1.1 Smart Glasses

Smart glasses are glasses with mountable equipment added to them, such as video cameras and microphones. They can also include holographic technology, which makes it possible to superpose information on the users' normal vision [McTear et al., 2016]. They usually use a wireless connection which makes it possible to communicate with devices around them, such as smartphones. Most of the currently available smart glasses are larger and heavier than normal glasses [McTear et al., 2016]. Some also tend to cause eyestrain and discomfort if they are used for a longer time. This problem is caused by the placement of the holographic screen that overlays information into the eye [McTear et al., 2016]. The screen can also cause issues with safety, as a user might be reading the information displayed in the glasses and be distracted from the environment around them [McTear et al., 2016]. The glasses are used in industry to help with picking material in warehouses [UBiMAX, 2019]. Another way to use them is for remote assistance where the worker calls an expert through the glasses enabling the expert to see what the operator sees by using the glasses camera, while also presenting information to the operator in the glasses screen [UBiMAX, 2019].

2.4.1.2 Smart Phones

Smartphones are multi-purpose mobile computing devices. Their hardware capabilities are strong enough that they can be used for a variety of purposes. They have a touchscreen covering one entire side of the phone that is used for interaction. On the touchscreen buttons or a keyboard can appear to interact with any software on the smartphone [Samsung, 2019]. Smartphones can also connect to the internet making it possible to interact with other applications [McTear et al., 2016]. Smartphones also include a camera, speaker and a microphone that could be used by any application running on the smartphone [Samsung, 2019][Zuehlke, 2008]. The industry smartphones can be used to remotely monitor a system [Zuehlke, 2010][Görlich et al., 2007], so if an error occurs an alert can be sent to the phone remotely. The phones could also be used to send pictures of the problem area if any external help is necessary [Zuehlke, 2010][Zuehlke, 2008]. A smartphone can be seen in 2.1 below.

Figure 2.1: Picture of a Smartphone

2.4.1.3 Augmented Reality

Augmented reality is an interactive experience where the digital information enhances the real-world experience. The most common way is to use a headset placed on the head. The headset has a see-through glass on the front covering the entire vision that can directly overlay digital information to the user [Microsoft, 2020]. The overlay is used in combination with sensors to accurately position the information presented to the user with regards to their environment. AR uses a powerful processor to handle this information, making it possible to visualize information quickly [Microsoft, 2020]. Two examples of AR applications are to provide work instructions to the operators in the form of pictures and videos shown in the AR

[Niedersteiner et al., 2015]. The second example is using AR to train operators, by using hand tracking sensors and guide the operator through the step if they make anything wrong [Fast-Berglund et al., 2014].

3

Methodology

This chapter explains about the methods which were being used to proceed in our project. It also includes the knowledge and information data used to approach the answers for the research questions.

3.1 Research Approach

To begin the research and fulfill the set of objectives, using and following systematic methods are essential. A variety of methods were used in our research which gave some of the important and basic foundations for obtaining satisfying results and achieve the required targets. In some of the areas, we used both of the positivist and the interpretivist models to answer our main research questions [Denscombe, 2014]. Both required qualitative and quantitative data, which were acquired to evaluate the process and a complete overview of the content [Denscombe, 2014]. Some basic methods of observations and interviews were conducted to gain in-depth knowledge of the process to provide an efficient solution [Denscombe, 2014].

The main plan with performing the research according to the methodology was to have a well-structured flow and following it one phase after another. Our two main phases with regards to the aim were, Analysis Phase and the Evaluation Phase leading into a final evaluation of the results. It is important to have a good research strategy and research tools in order to proceed with the project [Denscombe, 2014].

The workflow or sequence for the complete thesis was sketched and its shown in figure *3.1.* Once the necessary research questions were framed based on the project description and the project demands, a basic literature survey was conducted to gain in-depth knowledge about topics important to the thesis and to get a complete overview about various aspects which is categorized under this duration of initial stages of thesis. The next phase was the analysis phase where the complete screening of the current process was performed, including a current state analysis and a identification of possible limitations, drawbacks and information needed to export to various systems. Tools like observations, interviews and questionnaires were used in this stage. In the evaluation phase, an evaluation of the generated solutions was carried out. The final chosen solution was developed further and implemented with a final comparison with the older method.

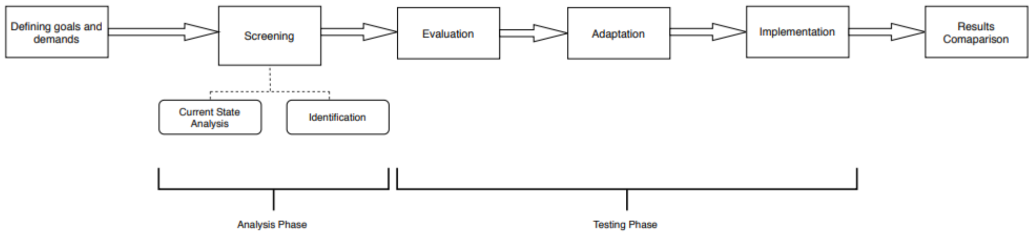

Figure 3.1: Methodology sequence

The information required for the topics like measurements and digitization were studied with the help of published journals and papers which were available in Chalmers Library and Google Scholar. In addition to the literature review, the analysis phase was done in parallel. This phase includes a current state analysis as well as framing the research questions depending on the demands identified.

3.2 Analysis Phase - Getting to know the Current Process

The Analysis Phase involves studying of the process currently used at Volvo. This was done in two stages which includes analysing the current state process at Volvo, followed by identifying drawbacks and limitations of that process. The qualitative and quantitative data were collected through observations and interviews conducted during the process [Denscombe, 2014].

3.2.1 Current State Analysis

The Analysis Phase consists mainly of a current state analysis that is used to obtain knowledge of how the actual process functions, which is required for later stages in the project such as what kind of visualization aid that could be used. The data were mainly acquired through observations at the workstation, that was complemented with questions to better understand the important parts in their work. A few short interviews were also held afterwards as a compliment to catch information that could not be observed or answered by quick answers.

3.2.1.1 Observations Of The Current Work Procedure

To begin with the current state analysis of the process, a systematic observation was planned and executed mainly to acquire qualitative data which could be used to help to identify the best visualization aid that is applicable for new solution [Denscombe, 2014]. This was done by having a checklist where notes were taken down, as to how the process was carried out, the main equipment and tools used. The through analysis of the process was done in detail to understand the drawbacks with the current process, improvement potentials, which was mainly done with cognitive ergonomics point of view.

The main objective of the observation was to observe the exact routine, the operators are following in that station. As the thesis is based on improving the visualization of digital data, understanding their work procedure is important since it points out what information is important to show to the operators. Which will affect, what kind of visualizing aids that could be implemented into the process.

The observations were conducted three times for four hours each time on different days. At the station, there are three operators in total and a maximum of two operators are working simultaneously at a time. But two operators work routine was observed by two of us separately. One of them works there full-time with around 20 years of experience with this type of work. The other two switch in between each other. Both operators have at least a couple of years of experience with this process. This makes it simpler, that the feed-backs we receive during the measurement process might differ compared to if we asked operators those were not as experienced. Due to there only being experienced operators working, more inexperienced operators could not be observed. Instead, the interview part includes questions about their experiences when they just started working at the station, to attempt mitigating this shortcoming.
To get as much information from the observations as possible, the observation were made separately with both the operators being observed simultaneously. After each observation, different experiences were summarized and then discussed to find the common points and differences, which was used when creating new questions for the next observation. The observation of the process was done for one complete product. One of the operators observed was quite experienced and other one was moderately experienced and both had their ways of working. An opportunity was provided to test using the tools and measure ourselves which helped with better understanding how the information required might change if the operator is experienced or not.

3.2.1.2 Interviews

The interviews were done, mainly to clarify some questions that could not be answered through observations and to get to know the operator's opinion regarding the measurement process. The type of interview which was conducted was designed in a semi-structured way. These interviews were conducted to the same operators those were being observed previously. It had a clear list of issues which was discussed about the process as well as an open-ended conversation [Denscombe, 2014]. To facilitate a comfortable conversation during the interview, some parts were also done in their native language, which also gave way to build a good relationship between participant and researcher [Glegg, 2019]. The interviews included some of the aspects like their roles, experiences and opinions.

Some of the basic interview methods were used like, thematisation, preparation, execution and summarizing [Glegg, 2019]. The first stage involving, the main objective of the interview was defined and prioritizing the main areas where we need to focus on as per our project aim. Preparing certain types of questions like technical, ergonomical and non-technical aspects. Once the preparation was done, we planned and conducted the interviews during working hours when they had time for us to disturb them as little as possible and therefore have as long interviews as required. Afterwards, the thoughts on the interviews were summarized.

Once self-introduction to the operators was done, an complete explaining of why we were present and what our role was, they started explaining their work routine and complete information about their work. Their work routine was completely observed and some of the doubts and questions were clarified during the process itself. The answers given during the interview was noted down as notes. The interviews session were conducted around fifteen to twenty minutes apart from the work routine observation.

The interview questions were mainly focused on the main areas working time, displaying system, software usage during the process, type of specification data used and types of measurement tools. The questions were framed with regards to these aspects, some of these questions are listed below *in figure 3.1*, the rest could be found in B;

Table 3.1: Questions asked to operators

NO	Questions
1	How many cars are being measured in a day?
2	For how many hours are you working with measurements each day?
3	What kind of specification data do you think is important to be displayed during the process?
4	We have found some of these devices, are these devices suitable to work during your work routine?

The first interview consisted of basic questions related to the measurement process, in addition, some questions were roused during the observation of the measurement process, which related to the various types of tools used and measuring units which were documented. The main goal with having these questionnaires was to analyze certain aspects and noting the identified information [Denscombe, 2014]. To be able to obtain even more clearer answers, one of us had taken the opportunity of performing the interview in their native language which some of the operators were a bit more comfortable with. At the final stages, it was made sure that all the points were covered and areas which were required for the documentation and also took the contacts of the operators for further clarification of doubts or questions and also for getting appointments for future visits. This was necessary due to knowing that when the project progresses further, some of the decisions that is taken, could require the opinions or perspective of the operators.

3.2.2 Identification - Process Limitations and Drawbacks

This stage was the second part of the screening process, where the extent of the current state analysis was done. The identification of the limitations or drawbacks was performed based on the observations and interviews conducted previously. A few of the potential limitations were noticeable during the observation process and others were identified later with regards to information acquired correlated with the solution applied.

3.2.2.1 Limitations and Drawbacks

For the given process, there were some of the potential improvement areas which were noticeable during observations. But as per our thesis objective and limitations, we needed to restrict ourselves in a cognitive ergonomics point of view and improve the information display assistance for the operators. Our identification of limitations and drawbacks of the process is listed in form of particular points covering some of the areas like measurement, process and ergonomics which could be seen in further chapters. This was diagnosed in the form of a process study, which involved some of the major elements that was followed during the project to recognise those limitations or drawbacks present in the process. For analyzing a case, the elements we followed to diagnose were [Ellet, 2018]:

- Definition of the problem
- Causal diagnosis of the case
- Overall diagnosis
- Recommendation and actions

As the definition of the problem was done in the earlier stages, we concentrated more on the causal and overall diagnosis of the process. The main purpose of this identification of limitations or drawbacks of the process was to provide a solution that makes the overall process better while keeping the thesis demand into consideration [Ellet, 2018]. But the recommendation actions were taken into consideration in later stages of the project.

According to the observations and input from the interviews, the causal analysis of the process was carried on. In this process, we focused on the number of total measurements to be made per day using the number of various types of tools and gauges, which were used to measure. Additional to this, the variations in the car models (Product variation) and it's surfaces were taken into consideration. The next sector that we noticed was the specification demand data being displayed on the computer screen involving at what distance it was placed, could it be movable, how often an operator required to see the data while measuring, what kind of Andon systems [Li and Blumenfeld, 2006] were available to the operator and also, does having more experience in this measuring process affects for the operators. Some of the other factors like the measuring points on the car, documentation being done, the transmission of data from the gauges to the software (CM4D) appearing on the system monitor was also analysed. In the final analysis, the areas such as what kind of cognitive ergonomics was provided to the operators and to what extent, the manual work involved, the amount of re-work or remeasuring which could be done due to some reasons to achieve the precision set by company was taken into consideration and important points were identified and listed accordingly.

3.2.2.2 Required Important Information

Once the identification of the limitations of the process was analysed, the listing or mapping of the necessary information that is required for operators while measuring the gaps and flushes were done. The information that was considered as the specification demands, set by the company standards and the required 'quality data' that needed to be documented and exported to the company's software (CM4D) was essential to know so that the solution that was going to be created had that important information while being presented on the visualization aid that is going to be implemented.

According to the quality assurance fundamentals maintained in the automotive industries, the necessary standards for the quality specification will vary from one company to other [Stylidis et al., 2015b]. In this case, based on current state analysis the main information that has to be exported and specification demands which has to appear on the device or the visualization aid that has to be implemented in the process are, the measuring points, type of tools to be used at the respective points, tools placement during measuring, the drafted picture of the car measuring points, distancing dimensions and final verification.

3.3 Evaluation Phase - Testing and Choosing Solutions

The Evaluation, Adaptation and Implementation part was the processes being carried out after the process analysis, and this was performed under the Evaluation phase. This phase includes the listing of possible solutions available and suitable for the analysed process with testing, evaluating and developing a better solution. Some of the discussions and recommendation actions were made with the core team authority inside the company to have their opinion and inputs resulting in proceeding on the final decision made based on those discussions. This phase also includes the final implementation of the newly developed solution to the process and then summarizing with a comparison of these new results with respect to the older solution.

3.3.1 Evaluation

3.3.1.1 Listing of Possible solutions

Once the analysis phase was completed, the next progress was to propose a new solution and proceed on to finding answers to the research questions. To begin with the evaluation, it was necessary to investigate and list out the possible technologies available and also solutions which is suitable for visualization of data. The devices that were considered had better interface, user friendly and flexible operation. The visualization devices which were shortlisted (Listing of all the devices one by one which was investigated) was compared and analysed if that device was suitable to the current process.

As far as the displaying devices are concerned, which are used in the manufacturing industries to ease the process, there are various types of devices with their own respective features and specifications. The investigation that was done had a main objective of finding a device having a capability of good visibility or resolution, better battery, user friendly and easy connectivity. The devices that were being searched, had an operator's point of view or opinion which was taken into consideration, as to make sure the features work together as a bundle of affordances which provides better benefits [Glegg, 2019]. And that makes the strategy realization for the workers hence understand the plan which improves the process of an organization [Glegg, 2019].

The investigation which was being done, constitutes of various type of displaying or visualization devices and most of them were categorized under the smart devices [McTear et al., 2016]. The another platform apart from the smart devices category, was looking for the AR(Augmented Reality) solution [Microsoft, 2020]. The searched devices were classified according to their respective platforms and the listing was done on basis of their advantages and disadvantages of some of the features involving display resolution, type of connectivity, programming, user interface, flexibility when working with it, battery, and price. These different visualization devices identified were tested and the operator's opinion for each device were taken into consideration for the evaluation.

3.3.1.2 Testing and Evaluation

As the devices were shortlisted according to their respective features for main purpose of coming up with a good visualization aid for the operators which suited the analysed process, this required a physical testing of available devices around us and also have the operator's opinions on each of them. Various companies pertaining with this special smart devices especially built for industrial applications were searched and contacted [Denscombe, 2014]. The main core group or committee in organization, wanted to discuss with the proposed inputs and recommendations regarding this thesis hence, the shortlisted devices were matrix evaluated to get the better reasoning and results by rating each of the essential criteria.

Some of the shortlisted devices were available with us and some of them in Chalmers laboratory which was borrowed for testing purposes and AR(Augmented Reality) related devices were tested personally. The smart devices which were available at the laboratory was considered to be an older version or the basic version, when the manufacturing company of those smart devices were being searched. But eventhough the testing was carried out to explain the operators of how the devices would look like and also it's interface. In additional to this, based on the feedback from the operators and some of the smart devices had an issue of image resolution hence, further focus was given to look into alternative companies making the same smart devices. Different smart devices companies (Vuzix, UBiMAX) had several version and types of the smart devices used of different applications in the industries with respect to their own specifications and costs [UBiMAX, 2019]. These were tabulated according to their features and considered their delivery times and possible alternatives under AR(Augmented Reality).

In order to decide and propose a better device among our shortlisted devices as an recommendation action, a matrix evaluation (Pugh matrix) was performed to make an accurate evaluation in between the different visualization aids. This matrix was evaluated and weighed on some of the important criteria like, usability, battery, display, successful implementation and potentiality. These criteria were selected according to the project demands and rated based on the analysis carried out previously with having operator's opinions taken into consideration. The main priority was given to the display, as it was the main aspect which mattered the most in this process. Along with this priorities, some of the possible risks that may rise in the middle of the project were also mentioned based on the research. This results of matrix were rated to the smart device, which was suitable for this process and finally the better rated smart device was proposed.

3.3.1.3 Recommendations and Final Decision

The evaluation of different devices provided the results of a suitable device for this process and that was considered as the recommendation. This recommendation action was presented and discussed with the TPC group (Core Geometric Assurance Committee) at Volvo in order to obtain feedback and inputs from the group. This decision was helpful in the final confirmation of the type of visualization device that would be carried on working with that device in further stages of this thesis.

The presentation to the TPC group, involved the various devices that could be used as an visualization device based on their respective features and specifications. And some companies that develop solutions for the identified solutions were also included. To present the preferred device, the matrix evaluation was presented, which conveyed the results of the listed devices based on the preset criteria. At the end of this presentation, the TPC group were convinced and agreed to proceed on to the recommended device as an visualization aid for the gap and flush measurements of the assembled cars at the final demands station. This discussion with the core authority of the company was a major checkpoint and turning point in this project. With this discussion it was possible to get the confirmation about the device that will be experimented on, in the further stages of thesis. And from here, the progress was made on to the adaptation phase and creating new solution, which was a major step in this thesis objective.

3.3.2 Adaptation

Once the solution was decided, the adaptation phase was started. This phase starts with first developing the solution chosen into a test version that can be evaluated with the operators. Afterwards, their feedback was taken into consideration during the rest of the development.

3.3.2.1 Developing the Solution

The solution chosen needed to be developed before it could be implemented at the workstation. But before the development began, the exact specification of what to include in the solution needed to be decided. Depending on the solution chosen the size of the actual display for information will vary when wearing the gadget, from a size similar to how they currently see information on the screen reduces to sizes as small as one-tenth of their current display for information. This results in that there might be a need to exclude some of the information which was less important or to not show all the information at the same time. How to control the solution was also decided in this step and if the solution will have any way to interact directly with the 'final demands' software that they currently use. A drawback with the alternative solutions are that they use different programming software's, this was discovered in the earlier stages of the project, but since the solution was chosen in later stages there was no option of beginning learning/programming the solution beforehand.

When all the specifications had been decided upon it was presented to the operators for opinions with regards to the information shown, the display size and controlling the solution. From their feedback the solution was adapted to better fit their demands. Then a demo version was developed to test that the solution is fulfilling their demands, by testing how well they can navigate the solution, see the information presented and how well they can use the solution when working. From the tests, the final solution was changed to try to improve upon the worst part which was identified during the testing.

3.3.2.2 Implementation

After developing the complete solution, a small test or demo was done before finally demonstrating the solution to the operators. This was done to ensure that the connectivity of our solution was working with the company's system, servers and to identify necessary minor adjustments. The testing was also performed to ensure that there were no disturbances during the usage of the program during the operator's work procedure. In this implementation stage, it was possible to present the new solution to the operators to make them understand exactly how the solution works, while also explaining how it could be used in their process.

The solution was tested primarily and made sure that it was working without any disturbances in the middle of the process and made some adjustments accordingly. Once this was done, the newly developed solution was presented to the operators for a final test. Their feedback was noted down as potential improvements for the solution. And the new solution was compared with their old work procedure to see how the new process affects the ongoing process [Denscombe, 2014]. Then the final solution was presented to the other members of interest in the company, by providing them with the exact specifications of our program, our work sequence the final result.

3.4 Final Results Comparison

The newly developed solution was implemented and the necessary information of the solution was provided to the company and in this final results comparison process, the obtained results was compared and analysed with respect to the older method. And also at the final stage, having some of the questionnaires to the operators regarding the new solution was also conducted for thesis purposes.

In order to compare the obtained results from the new solution implemented to the process, it was planned to consider having a record of the time reference in between normal work process and the work process with the new visualization device. The total time to measure the gap and flush of one segment of a car was taken. This was done with and without the visualization device and later was analysed. In addition to the time reference, the feedback of operators using the new visualization aid was documented with some sort of questionnaires.The necessary pictures and videos of the new process were taken for better presentation to the company. These results helped to analyse and get some of the concluding statements for the thesis. These final results along with previous stages of methods, helped to answer the research questions which was created at the beginning.

4
Results

This chapter explains about the results obtained form the previous methods performed in the progress of this project. The results which are presented here provides important information for answering the research questions.

4.1 Analysis Phase - Getting to know the Current Process

The results of process analysis are carried out in two stages such as Current state analysis and Identification process which consists of respective qualitative and quantitative data.

4.1.1 Current State Analysis

The results of the current state analysis were acquired mainly through observations at the workstation, that was complemented with questions to better understand the important parts in their work.

4.1.1.1 Observations of The Current Work Procedure

The operators work is divided into work sessions and each work session includes all measurement points for a specific area of the car. On average there were around 3000 measurement points for the newer car models and around 1000-1500 measurement points for older models. This large amount of measurement points makes it time consuming, hence it might take up to one and a half-day to completely measure a car.

When the operator starts measuring they begin by loading up a session. Then they acquire the information about where to measure, type of tool to be used and the specified tolerances in the program that is visible on the computer screen. Afterwards, they look at the placement of they are supposed to measure and move the mobile table with the computer on it around the car to where they want to measure. Before starting to measure with the gauges that they call 'clocks', they first mark the measurement points with a marker. This is done because they measure the gap and flush on each measurement point, which is done with different gauges meaning that they have to measure two times on each point. To make sure that they measure on the correct location, they start by measuring with measuring tape, the distance provided from a reference point to the point that have to be measured and then they mark that point with a marker. And for some more standardised parts of the car, they have magnetic strips which are placed on the car that is already marked beforehand. Although this only works if the frame in the car is magnetic, which is not always the case.

After all the points have been marked it's time to start measuring, due to the difference in shape on the surface of the car, the gauges used needs to be changed frequently to ensure that a stable measurement is taken. On average they switch gauges after two to six measurement points. The gauges they use is connected to a transmitter each time they use it, so the values measured can directly be transferred into the program on the computer at the click of a button. This also makes the program update to a new measurement point which is shown on the screen, so the operators don't need to go to the computer and manually switch measurement points. For some measurement points, the clock tools can't be used to measure the gap. Instead 'feeler gauge' are used. They are a type of plastic stick with a specified width that is inserted into the gap to measure the tolerances. To measure the exact gap you might need to change feeler gauge until it fills the gap perfectly.

When all points in a session have been measured the operator verifies if the measurements are within the specified tolerances, if they are they will be colour coded green otherwise, they will indicated red in colour. If a value is colored red, that measurement has to be retaken to verify whether the actual value is outside it's specified tolerance or if it's a measurement that was done incorrectly. When all the values have been verified they submit the measurements to the main database, cleans the car from pen marks and eventual magnetic strips. Then they start a new measurement session.

4.1.1.2 Interviews

To complement the observation, an interview was conducted to answer questions not answered through observations. All of the questions could be found in *Appendix B*. Some of the most relevant questions asked are listed below with their respective answers in figure 4.1.

Table 4.1: Interview questions asked to get a better overview of their work-procedure.

NO	Questions	Feedback
1	Are there any differences between car models when measuring?	*Yes, each and every car has different dimensions and has to be inspected thoroughly*
2	What happens when a measurement taken is outside the specification demands?	*There are some alerts which is popped on the screen, which is red in colour with the nominal values that the measurement has to lie within.*
3	What is the most important information for you to see on the computer screen? And in what stages during the measurement process is this information necessary?	*The tool placement, type of tool to be used, gauge number are the important information and during some of the tricky curved surfaces, we have to look at the screen.*
4	Which parts of your work procedure do you think is the hardest to perform and which parts were the hardest for you to learn when you just started working with measurements at the station?	*It's working with the gap pins as well as learning how to place the gauges when measuring to get a stable measurement. The second hardest thing was to learn exactly where to measure since the pictures are not always that good.*

4.1.2 Identification - Process Limitations and Drawbacks

The results of identification involves the recognition of limitations and drawbacks of the process form the observation and interviews done under current state analysis.

4.1.2.1 Limitations and Drawbacks

The identification was diagnosed in the form of process analysis, which involved some of the major elements such as casual and overall diagnosis of the process. The potential limitations and drawbacks which were analysed were:

- The measuring gauges which are being used in the current process, doesn't work for all the car surfaces. There are many types of surfaces in the finally assembled car which requires different sets of tools. Hence, the tools need to be changed after a few measurement points.

- In the process, there is only one transmitter available to each operator while measuring, and this transmitter is shared between all the gauges for the documentation of the measured values into the software being used.

- This limitation is regarding the use of the transmitter while measuring. During the measurement the transmitter gets in the way of measuring, if the operator is not used to holding it in one hand, then the transmitter could fall off if it is not being held properly due to the transmitter being not completely fixed on to the gauge. This depends on the experience of the operator too.

- As far as the visualisation of the specification demands is concerned, currently the information is presented to the operator and it is being displayed on to one monitor screen. The monitor could be moved around as the table on which the monitor is placed up to some extent due to the space around the work station, but the operator still have to travel away from the screen to the measuring or working area to see the information on the screen. This specification information is to both visualize the measurements that has to fall within the tolerances or nominal values set and also which measurement point has to be measured next.

- This type of process is beneficial for the experienced operators. But according to the observation and self-experience, this type of measurement process requires an operator to be experienced to some extent for more precise measurements, accurate quality check and a faster working capability.

- The measuring points placement is very importance in this case. Before the measurement is taken, the operator needs to clearly find the spot to measure on the car and that is done by measuring from a reference points on the car.

- An alert or Andon system is provided to the operator during the measurement. While measuring, if the reading or an alert indicates in red colour on the screen, the operator has to move to the computer to change and back to that measurement and has to re-measure.

- There are different sets of measuring tools, which could be called as 'feeler gauge' available along with the gauge clocks. When measuring with 'feeler gauge', the operators have to manually insert the measurements to the system since a transmitter could not be used in this case as this type of measurement is purely analog.

During this observation, it was evident that the company preferred the manual way of inspecting the final quality check and it has been in practice for very long time. It was complex to identify or point the limitations or disadvantages of the process, instead there were some of the potential areas like in measurement, tools usage and ergonomics wise, which could be improved from the analysis.

4.1.2.2 Required Important Information

Apart from the identification of limitations from the case analysis, the necessary information which is required during the measurement and for the documentation, is listed in point-wise .
Some of the necessary information that has to be presented for the operators during the gap and flush measurements are:

- The drafted image of the cars portraying of the various dimensions of measurement points and reference distances.

- Information about which tools to be used for respective surfaces.

- How to place the tool for measuring (On what side of the gap and which part has to be used as the base for the flush).

- Measurement distances that has to be measured before the marking of points.

- Final verification of the exact measurements which is taken and documented. (Colour indicators such as green/red).

In additional to this the important information that needs to be exported to the systems were, transmitting the measurements taken into the system through transmitter instantly and uploading the measurements to the system, once the complete measurements points have been measured.

4.2 Evaluation Phase - Testing and Choosing Solutions

The testing phase results is classified into Evaluation, Adaptation and Implementation with their respective sub-tasks. This phase being one of the important phase answers most of the framed research questions according to the case description.

4.2.1 Evaluation

4.2.1.1 Listing of Possible solutions

In the evaluation stage, it was necessary to investigate and list out the possible technologies available and also solutions which is suitable for visualization of data. The devices that was considered were evaluated based on their interfaces, user friendliness and flexibility to operate. The visualization devices were compared and analysed to see which device that is the most suitable to the current process. The results were categorized in the form of advantages and disadvantages with respect to their features which could be useful for the observed process.

The most important devices that were shortlisted are;

SMART GLASSES

Advantages

- Hand free experience (Portability).

- Visibility of the data required to measure.

- Easy connectivity with the phones or the computers used at the measuring area.

- Android based programming. (easier to program)
- Voice commands ability due to availability of mic.
- Connectivity via Bluetooth or WiFi.

Disadvantages

- Low battery time (varies up to four to eight hours).
- Reduced peripheral vision in the upper right quadrant eye due to the camera and electronics blocking out a part of the vision field.
- Small screen, limiting the amount of information that can be shown at the same time.
- Voice commands don't work well in noisy environments.
- Low internal calculations capacity (computerization).

SMART PHONES

Advantages.

- Big screen to show information.
- Only need to look at screen when you want, without blocking view while measuring.
- Long battery time.
- Interaction through touch, alternative voice if wished for.
- Various information/applications/guides to help programming with desired application.

Disadvantages.

- Risk of not being able to see phone when measuring due to angle of arm.
- Risk of damaging the car due to the phone being attached to the arm that will be in close contact with the car.

- Could only be used at the final demands station but not in the production line.

AR (Augmented Reality)

Advantages.

- Have the capability to do real time computing, might be able to point at measuring points where to measure, that is removing the step where you mark the points.

- Large screen compared to other options.

- Only option with a direct overlay on reality.

Disadvantages.

- Expensive when compared to other devices.

- Slightly heavier (Front part).

- Harder to program, (if you want the better features the AR can give compared to the phone or smart glasses).

- Lower flexibility.

These were few of the displaying devices which could be found in modern day manufacturing industries which is in use currently or about to be implement in the future. According to the research, some of the devices which were looked into either had a better displaying features but were more expensive or had a lower cost with lesser displaying abilities. Some of the other smart devices were found, but had a very small displaying ability, and as the visualization data was given more importance, the device having better displaying feature which was taken into consideration.

4.2.1.2 Testing and Evaluation

After the selection of few visualization devices which were suitable for the process, they were tested and evaluated to obtain the most optimal device. Some of the devices which were available, were tested personally and also took the feedback from the operators which helped in making the decision. From these tests, the devices were tabulated in the tables 4.3 4.4 4.5 according to their important features and their technical specifications. These results were complimented with the operator's opinion regarding to the devices up for implementation in the process.

SMART GLASSES

Operator's Opinion :-

Table 4.2: Advantages & disadvantages of the possible solutions

VISUALIZATION DEVICES	ADVANTAGES	DISADVANTAGES
SMART GLASSES	• Hand free experience, with the help of voice commands. • Visibility of the data required to measure. • Easy connectivity with the phones or the computers used at the measuring area. • Android based programming. (Will probably be easy to find information/help) • Voice commands ability due to availability of mic. • Connectivity via Bluetooth or WiFi.	• Low battery time (some have up to 8 hours though). • Reduced peripheral vision in the upper right quadrant due to the camera and electronics blocking out a part of the vision field. • Small screen, limiting the amount of information that can be shown at the same time. • Voice commands don't work well in noisy environments. • Low internal calculations capacity (computer).
SMART PHONES	• Big screen to show information. • Only need to look at screen when you want, without blocking view when you work. • Long battery time. • Interaction through touch, alternative voice if wished for. • Various information/apps/guides to help programming your own app. • Option to run several apps in the background if wanted.	• Risk of not being able to see phone when measuring due to angle of arm. • Risk of damaging the car due to the phone being attached to the arm that will be in close contact with the car. • Could only be used at the final demands station but not in the production line.
AR (Augmented Reality)	• Have the capability to do some computing, might be able to point at measuring points where to measure, that is removing the step where you mark the points. • Large screen compared to other options. • Only option with a direct overlay on reality.	• Expensive when compared to other devices. • Slightly heavier (Front part). • Harder to program, (if you want the better features the AR can give compared to the phone or smart glasses). • Lower flexibility.

- The displaying data or the image resolution is small. As the visibility of data is very essential, larger the specification data image more convenient during measuring.

- The tested device or the smart glasses was a device once worn by a person, the image or it's display interface was projected on to the top right position of the right eye only. This made some of the operators experience an eye strain and headache kind of sensation, which could be considered as an ergonomical strain when the glasses were used for longer duration of time.

In additional to this, some of the other alternative companies which manufactured these smart glasses were investigated and analysed the major differences in their specifications which could be beneficial for the process. The information regarding the alternative smart glasses companies which were looked into could be seen under

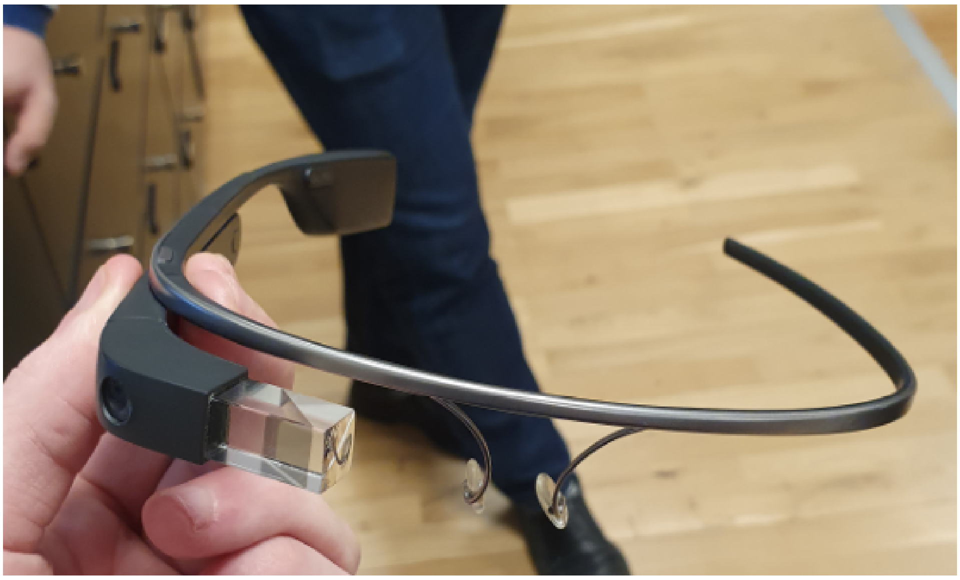

Figure 4.1: Smart Glasses

Table 4.3: Tabulated evaluation for Smart Glasses

Handling	Hands free, Voice commands (mic), touch pad on the side
Display	Small resolution screen displayed in the right eye.
Connectivity	WiFi, Bluetooth.
Battery time	~8 Hours, battery backup.
Price	~1000 $.
Programming	Android based.

C.

SMART PHONES

Operator's Opinion :-

- According to operators, this device would be fine and could be implemented to the process. The phone could be strapped around the arm while measuring. This device had a better display and flexible when compared to smart glasses and other smart devices.

Some of the additional points regarding smart phones was obtained such as;

- The phone holder which could be used to cover the phone and wrapped around the operator's arm while measuring, was approved by the material allowance authority near the cars. And this was restricted only for the final demands station.

Figure 4.2: Picture of the phone holder tested

Table 4.4: Tabulated evaluation for Smartphones

Handling	Phone wrapped around the forearm using a phone holder.
Display	Good resolution, Display screen up to 5 ~ 6 inches.
Connectivity	Wifi & Bluetooth.
Battery time	8h+, battery backup.
Price	~900$.
Programming	Android based.

- By using smart phones, we would be able to use already pre-existing applications in order to design the program to get the specification data and also for other connectivity purposes.

AR (Augmented Reality)

After observing hollow lens (AR) devices, some of the things which was noticeable were;

- The device looks similar to smart glasses on outside but a bit bigger and more heavier.
- It has a capability of computing in real time.
- Possibility to directly overlay the measurement points within the AR for the operators.
- Very high potential in future.

Figure 4.3: Augmented Reality glasses

To decide the best device among the shortlisted ones, a matrix evaluation was performed. This matrix was evaluated and weighed on some of the important criteria like, usability (how the devices could be used,basically their compactness and flexibility), battery (working duration of device), display (image resolution of device), successful implementation (for the process) and potentiality (application in future). These criteria were selected according to the project demands and rated based on the analysis carried out previously. From this matrix evaluation, the Smart glasses and Smart phones had a higher total but smart phones having slightly more rating than smart glasses. The Pugh matrix evaluation of the different devices according to the respective criteria could be seen in 4.6.

The recommendation action was presented and discussed with the TPC group (Core Geometric Assurance Committee) at Volvo in order to obtain feedback and inputs from the group. The recommendations and main reason to choose smart phones and some of the risks involved in it could be seen in the *Appendix C*.

Table 4.5: Tabulated evaluation for AR

Handling	Needs some sort of controller to manipulate.
Display	2K Good resolution, Overlay covers the whole eye.
Connectivity	Wifi & Bluetooth.
Battery time	2-3 hours.
Price	~3500-4500$.
Programming	Microsoft Visual studio, Fewer guides for software being used.

Table 4.6: Pugh matrix evaluation of the devices weighted against each other based on a set of criterias

Criteria	Weight	Smart Glasses	Phones	AR
Usability	5	3	3	3
Battery	3	3	4	1
Display	4	3	3	4
Successful implementation	5	3	3	1
Potential	1	4	4	5
Sum	18	3,1	3,2	2,4

4.2.2 Adaptation

The adaptation phase starts with developing a solution with feedback from the operators. Afterwards, the solution was implemented at the workstation, followed by a final comparison of the solution compared to their previous work procedure.

4.2.2.1 Developing the Solution

The development phase began by designing various layouts for how the complete user interface could look like.They were created in real scale according to the phone used in the testing phase. Three layouts are presented below. The rest are presented in *appendix A*. These layouts were presented to the operators from the feedback and the discussion with the operators, it was decided upon which of the planned features that was important, unnecessary or missing. The result of the discussion is presented in table 4.7 below.
When the features were decided upon it was time for the actual programming of the software. This was done in HTML and Python. A server was hosted locally on the computer in HTML that the smartphones connected to. This allowed the smartphones to see the information presented. If the operator wishes to interact with the software such as switching between measurement points the HTML will run Python scripts at the computer handling the interaction with the final demands

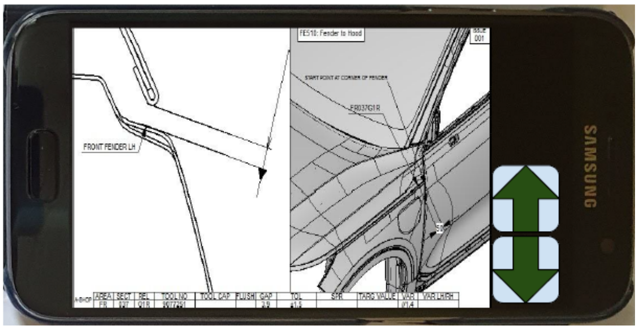

Figure 4.4: Design Layout 1

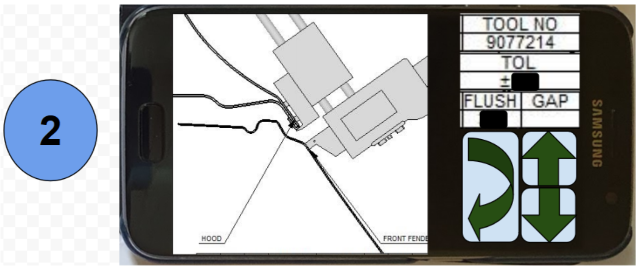

Figure 4.5: Design Layout 2

software used. To synchronize the information shown on the smartphone with the information shown on the computer basic image analysis was done in Python to detect when the measurement point changes and send an updated picture to the server displayed on the smartphone.

4.2.3 Implementation

In the implementation stage, the newly programmed solution to the visualization device was introduced to the process. This consists of the results of the implementation process.
The testing of our newly developed program to the visualization device being used in the actual process was the main agenda of the implementation stage. From this process we were able to make sure that the program created was connected to the Volvo servers without any issues. The required specification data to the operators while measuring was available on the screen of the new visualization device which made it possible to document the measured gaps and flushes data directly from the device by typing the values and submitting. These are some of the pictures which was evident to show the testing was performed with having both the gauges or clocks and 'feeler gauge' used with the visualization aid.

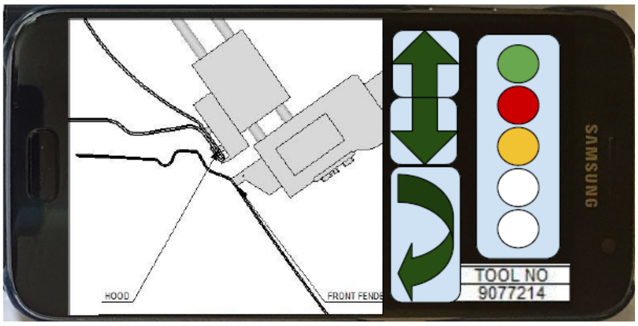

Figure 4.6: Design Layout 3

Table 4.7: Table with design features and their feedback from operators

Function	Description	Feedback	Shown in Layout
View of pictures (where to measure and how)	How will the pictures be shown will they both be shown at the same time or split up?	An overview picture will be shown like in layout 1. If you click on the picture it will zoom in to only show one part as shown in layout 2 & 3.	All
Switch between measurement points	Two buttons for switching between measurement points are these buttons necessary?	The buttons are necessary to be able to follow the desired work procedure where you mark all measurement points before measuring.	2 & 3
See tool number	Is it required to see the tool number at all times or just when switching tools?	It's necessary to see the tool number at all times, so you can verify that the correct tool is used. But only the three last numbers are necessary to determine the correct tool.	2 & 3
Indicator list	Is it desired to have an indicator list that shows if previous values were within or outside the specified demands?	No, this is not necessary since it's easier to verify the results on the computer, where you can see all the measurement points at the same time.	3
Current value	Is it desired to have the option of seeing the current value taken for the measurement when you go back to a previously taken measurement?	No, this is not necessary since it's easier to verify it on the computer where you can see all the measurement points at the same time.	2 & 3
Calculator tool for pins measurement	Would a feature to manually insert measurement values into the system help with measurements where the transmitter can't be used?	Yes, this would help, since it removes the need for using a separate tool when performing this type of measurement. And you this tool can't be carried when measuring, meaning you have to put it down and it can't be placed everywhere without risking damage to the car's surface.	None. The suggestion came from the operators during the discussion.

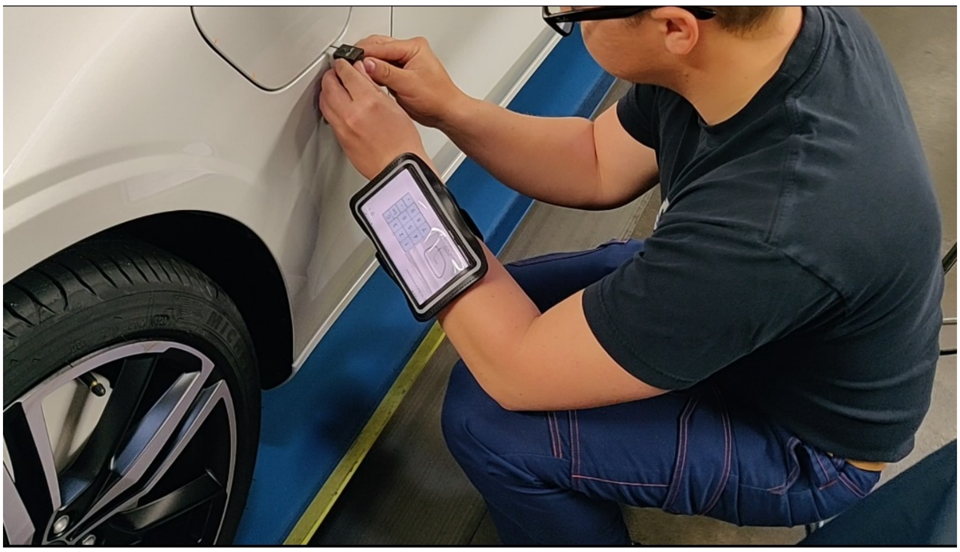

Figure 4.7: Taking a measurement with a gauge

Figure 4.8: Taking a measurement with pins

Figure 4.9: Typing in the measurement value

4.3 Final Results Comparison

The results obtained from testing the solution and comparing it with the older method are presented below.

To obtain the results of testing and analyse the new solution, the time taken to measure four segments of a car using gauge clocks and the developed solution. The same segment was measured two times each, half of them began with using the operators current work procedure and the rest with the developed solution.

The recorded time for both tests had some time difference between each other. When the developed solution was tested before the normal work procedure, it was on average 5% slower compared to their current work procedure. But when the solution was tested after their current work procedure, it only took on average 70% of the time taken for their current work procedure. When the function of manually inserting the values was tested, it was proven to be slower than their current work procedure. The time it took was longer than the time saved by, not having to move to the location, look into the computer screen and to pick up the calculator. The cause for this delay was the phone holder's plastic cover that made the screen less responsive to touch. Some of the observations made by us and the feedback from the operators indicate that having a visualization aid is helpful for the new inexperienced operators and it is also useful while measuring the interiors of the car.

Table 4.8: Final Feedback from the operators about developed solution

NO	Questions	Feedback
1	Did the developed solution improve the work procedure in any way compared to the previous work procedure?	*For the exterior - It's pretty much the same. But for the interior it helps since it's much easier to just bring the phone in with you instead of moving everything else.*
		If I was a more newly trained operator it might have been more useful for the exterior since i know most of the measurement points by heart at this point.
2	Was there anything needs to be improved with the developed solution?	*The size of some of the buttons needs to be a bit larger to make it easier to press the buttons*
		It takes longer than preferrable to click on the phone until the program is updated
		The time it takes to update the pictures when you move inbetween measurement points is a bit too long.

5
Discussion

This chapter includes discussion of Research Overview, Findings that provides answers to the research questions, Important decisions taken during the thesis and Potential aspects in the future.

5.1 Research Overview

Various methods and analysis were performed to achieve the thesis objectives. As per the case described by Volvo, the company wanted to further digitize the visualization of specification data in the final demands station to create better circumstances for the operators while measuring the gasp and flush of finally assembled cars [Stylidis et al., 2015b].

This also results in having better cognitive ergonomics for the operators working in the station. To create this visualization aid, a structured work sequence was planned, which included a current state analysis, listings of various alternative of devices available, evaluating them using a matrix and finally recommending a suitable device for the process to the Geometrical Assurance Group at the company. As far as our solution is concerned, we faced a few limitations during the research such as for the proposed solution device, the protective cover was only given permission for the final demands station but not to the actual production line where more gap and flush are measured.

This was taken into consideration before the final solution was chosen since this project is planned to be the base of several projects with broader perspectives. Some alterations could be possible in future projects to evaluate if the proposed solution could be bought to the main production line.

5.2 Findings

5.2.1 Research question 1

Which technical possibilities are there to share and assimilate information with the operators?
From this research, different technical solutions that could be used to mediate information to the operators, it became apparent that there is no real categorization

for devices was used in sharing information. For example, the devices that were looked into could be categorized into smart devices, phones, smart glasses, projectors and Augmented Reality devices. This lack of a common categorization creates a risk that a device which could work within the project's demands was missed when researching different devices. To reduce the risk of missing any possible solution, data were acquired from several different types of sources. Databases such as google scholar, Chalmers library were used to identify papers using one or several different devices, such as the paper [McTear et al., 2016]. The companies which are into manufacturing visualization aids were also researched such as [UBiMAX, 2019]. Two persons working with these kinds of devices were also interviewed. From all these different sources, a better overview of the kind of different digital alternatives that are available which could be used for sharing and presenting information was obtained.

When over viewing the devices identified, all of them uses vision as their main focus to present information. All the smart devices, phones and glasses, as well as the AR (Augmented Reality), uses screens to display the information. The projectors also use vision to deliver the information, but it's projected upon a surface instead. Most of the devices also have the option of using sounds but from the findings, sounds are mostly used for alerts or short instructions, which could be categorized under Andon systems [Fieldbook, 2004]. The portable devices sometimes also use vibrations in combination with sounds to alert operators. Since all the different visualization devices uses similar solutions for presenting information to the user, the probability of missing the technical solutions that presents information differently is unlikely. Which means that visualization devices mainly presents information by presenting it through vision. This kind of accomplishment can vary between using screens or projections. Sounds are also used to present more straightforward information or as a supplement to the information presented through the users vision. Sounds are also commonly used for alerts in a combination with vibrations in the handheld devices.

From this, it can be concluded that there exist many different devices that could be used for visualization, but they all present information in similar ways. So, the important thing to think about when choosing the type of technical aid to use, is to think about what kind of information that has to be presented, how large information display is necessary, how do the environment limit the size of the screen used, should the information be shown at different locations? If so is it better to have several visualization aids or use a smaller but portable solution? The fact that the operators were the end users of the particular technical solutions made it so a portable solution was chosen. Since the information needs to be presented at the actual work location and the car in itself prevents the use of a stationary solution at these locations. As a conclusion many different visualization aids can be used, but the restrictions surrounding the work area has to be taken into consideration to provide the best possible solution [Glegg, 2019].

5.2.2 Research question 2

How could the available information be better visualized to help operators when conducting measurements? For any kind of manufacturing industry, maintaining their product's quality is very important in customer satisfaction and marketing perspective [Stylidis et al., 2015b]. How to achieve the quality standard set by the organization can vary for each case depending on their respective factors [Stylidis et al., 2015a]. It is essential for any organization to make sure they stick to their set of standards and specifications. Hence during the manufacturing of their products, the company wants to stay inside the specified limits and the operators performing the related work are meant to utilize these specifications accurately to maintain the quality of their work which defines the product's quality. The second research questions answers how to improve the visualization method in a working station.

The research was focused on improving the visualization quality to the operators while performing their work task, which was measuring gap and flush of a completely assembled car. There were various ways to present the data to the operators, but only few of them were considered because of a few restrictions from the available type of possible solutions, for example, if the type of the visualization is incompatible with the solutions due to lesser resolution of the device, or the type of interface the device use. The visualization devices plays a prominent role in presenting the specification data during the work task. Better visualization of information to the operators was performed in a couple of stages by first listing out the possible devices, deciding the device to introduce in the process and the important part of deciding on how the information will appear on the selected device in such a way that the operator is comfortable in using the newly developed application or the program.

The main way to provide accurate information to the operators was to only show the information necessary to do their work while marking, measuring and inserting data. To ensure that the correct data was visualized at the right moment, interviews were conducted to guide us to the essential parts of the specification data which is required during the measurements. After viewing the results and observations, it was noticeable that analysing the current process and choosing the suitable device which helps for a better visualization was a primary thought, followed by conducting interviews and acquiring the essential information and making it appear on the selected device in the correct order creating a better situation for the operators while performing their work tasks.

5.2.3 Research question 3

How do the operators perceive our technical solution? And how can the solution be further improved to encourage operators to use it in their work?

From the tests conducted and the interviews held with the operators testing the new solution, it became apparent that they think the solution has potential. But the solution required modifications, at best it's similar to their current work procedure. Most of the functions designed the work as planned, except for the calculator, which requires some layout adjustments to make the usage easier. Therefore, the size of the information shown and the controlling options implemented works as intended. From the feedback received from the operators, there are no big issues with the layout were brought to light either. This shows that improvement potential does not lie in improving the layout. Instead, from the testing and the feedback, it became apparent that the delay in communication between the devices needs to be fixed. From findings, the delay was caused by three different problems.

The largest issue came from the slow internet connections within the factory where the test was conducted. The delay caused by the network resulted in a delay of several seconds. Therefore a separate local network was created temporarily to be able to continue testing. The solution developed works by communicating through the local network, which is quicker than by going through the internet, but these both devices needs to be connected to the same network for the solution to work. This means that the computer could not communicate properly with Volvo's surrounding systems during the test, which was fine for testing purposes. For the new solution to be viable this problem needs to be solved, either through creating a local network as done during the test or sending the data through a different channel such as Bluetooth. While still having the possibility of communicating with Volvo's surrounding systems properly, since it's necessary for the operators to complete the rest of their work tasks.

The second problem that causes the delay is the phone holder itself. When the operators measured and used the calculator to manually insert the values, the time it took to measure with their normal routine and with our solution was practically the same. This is because the plastic cover covering the screen from the phone holder makes it necessary to delay or decrease in sensitivity of touch on each number that has to type half a second extra for it to register the input. Because of this delay the time they saved by not having to pick up the calculator they normally use, was spent on typing the measurement value. In comparison, when the solution was tested without the phone holder the time it took to type in the values was reduced to one third. The purpose of the holder is to ensure that the phone can't damage the car in any way and with the holder's design, the plastic in front of the screen is not necessary to fulfil this purpose. Therefore, parts of this plastic can be removed to ensure that the buttons can be clicked on, but still keeping some plastic so the phone has no possibility of falling out of the holder.

The third cause for the delay comes from the way solution is programmed. The data shown on the phone is presented in an HTML format to ensure that it can be shown on all types of phones. The downside with HTML is that it can't update the information shown unless the code in the HTML is scripted to ask for it. Which means that it constantly needs to send a message to the server to ask if the data has been updated and to receive it. This will always cause a slight delay, but the delay its very small compared to the delay caused by the other two issues.

If the two first issues were solved then the solution will most likely prove to be a better alternative for measurement points where the calculator is used. Which will work better than their current work procedure.

5.3 Important Decisions

During this research, there were few checkpoints and key decisions which were taken during the progress of the project which helped in obtaining better results, achieve objectives and to obtain answers for the research questions. Apart from the basic literature review and screening process, the stage which involved the evaluation and adaptation had situations where the decision had to be taken and come to a conclusion in order to proceed on to subsequent stages. For instance, during the selection of a visualization device after the shortlisting for the process, even though those devices were evaluated using matrix evaluation, the decision had to be taken to consider an exact device that was planning to be implemented. Some of the inputs and suggestions from the core authority of the company were taken into consideration after presenting the research aim to proceed in the right direction. This could be considered as one of the key decision taken during this research. Then the other checkpoint includes the type of programming platform that was to be used to build an application interface where the essential specification data appearing on to the selected device during the measurement process. These decisions gave rise to obtain some of the important results in this research.

5.4 Potential Aspects

Based on the entire research and its findings, there were few areas where it has a potential for improvement and could be developed further. The areas such as, the measuring equipment which are currently being used required almost manual application, due to the following up of traditional practice, the implementation of the new solution does affecting the surroundings of the work station including the operators work. To support the operators with better cognitive ergonomical solutions, according to the research findings, it was noticeable that much of the digitization in the automotive industry is under the stage of development and the necessary software used are very few and needs upgrades and at present, there are only prototypes available in the market. The research which was performed, could be considered as the beginning of the basic stage of a bigger project, due to the reasons like having the focus on a single quality inspection station which is separate part from the actual production line. The upcoming project could be built to develop digitalization involving real-time applications based on the current research which we have attempted. This could also involve, the idea of presenting the measuring points overlaying directly in real time on the type of digital platform that is being used.

6
Conclusion

The manufacturing industries at present usually possess some sort of digital medium to present the specifications set to the operators. This digital medium is usually situated at one place slightly away from the actual work, this forces the operator to move away from their work to see any requirements or instructions.

This thesis shows that having the required specification data on a device, which is present closer during the measurement results in easier access to the measurement details, reduces travelling time to the main digital screen location and therefore improves the work quality. But the testing shows that the new visualization device takes some time for the operators to get used. It also shows that the new solution is quite helpful for the new or inexperienced operators working on this task and also some the special measurements like, involving interior measurement of the car, since they have easier access to the information compared to previously.

From the results obtained, it can be noted that the thesis has potential areas which can be developed further in the future. For example, a type of digitization involving visualization in the production line.

The implementation of a better visualization situation in the process would increase the cognitive support to the operators. To accomplish the implementation, it is important that the operators are involved in the process, since they are the end users of the solution. To meet the required quality of the product, customization and deliverability, companies needs to need to support operators as it boils down to them using the solution at the end. Using this kind of visualization aids and introducing them into the process is just an initial step of the development, but the operator's opinions and feedback should be of the primary preference to ensure a successful implementation.

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A

Design Layouts

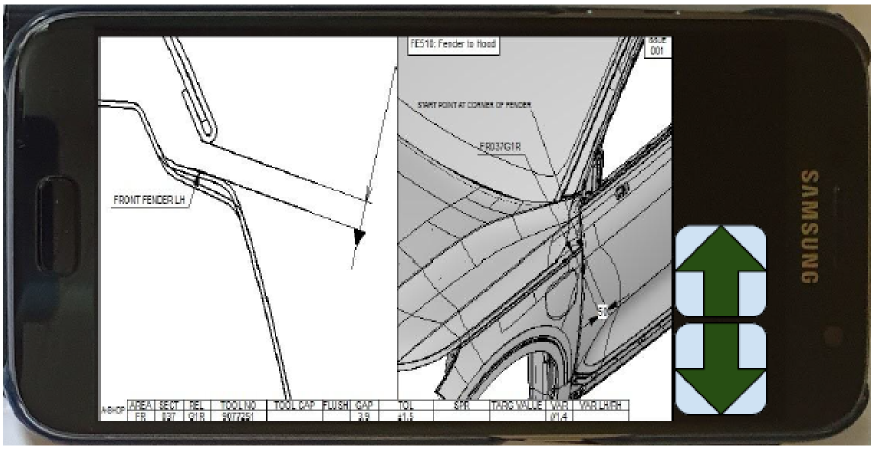

Figure A.1: Design Layout 1

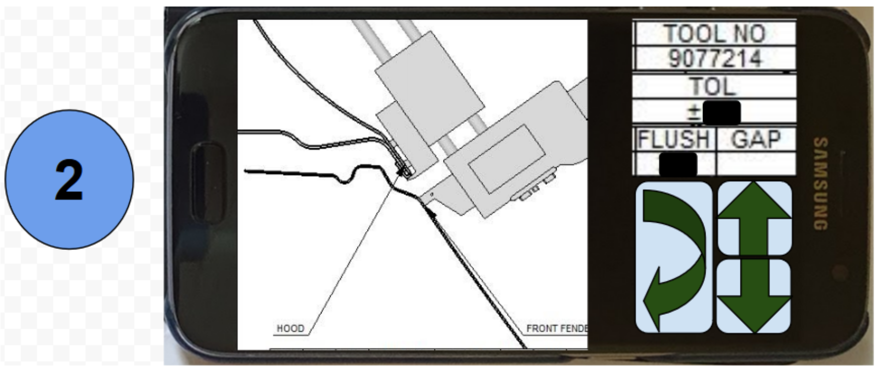

Figure A.2: Design Layout 2

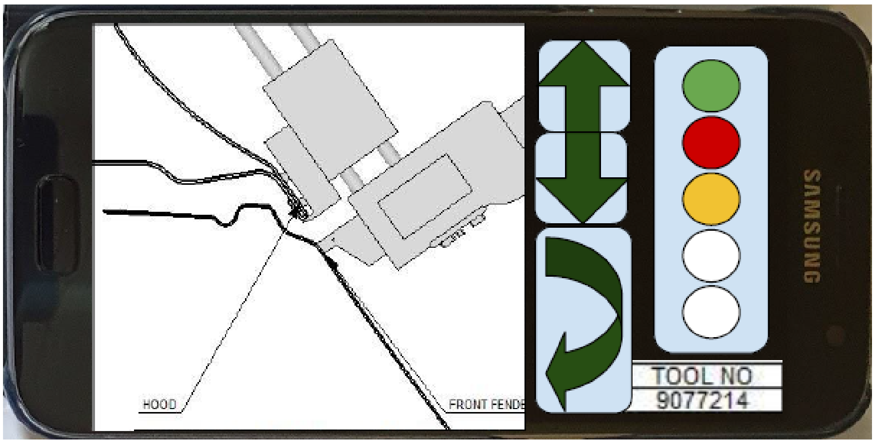

Figure A.3: Design Layout 3

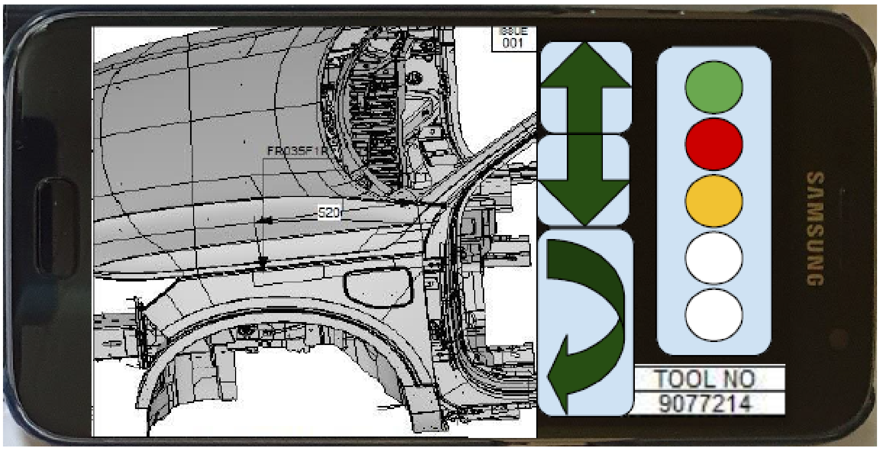

Figure A.4: Design Layout 4

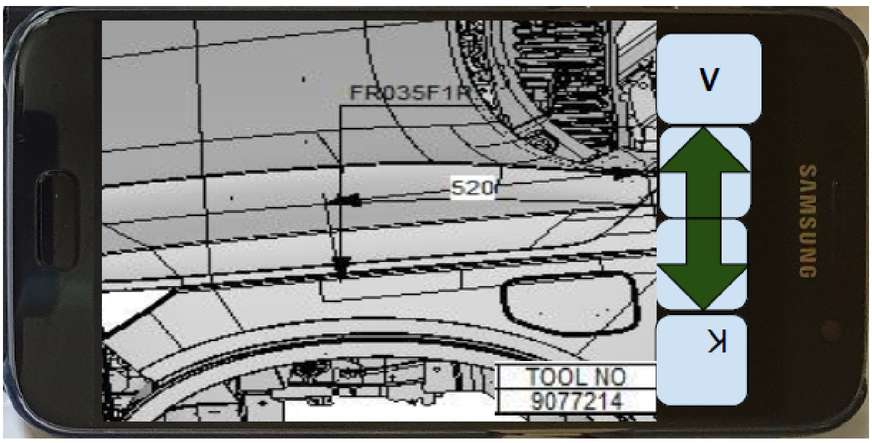

Figure A.5: Design Layout 5

B

Interviews

Introduction

Hello, we two are students from Chalmers, doing our masters in production engineering. We are currently doing our master thesis at Volvo and out aim is to create better circumstances for the operators in the final demands station. So, we want to introduce an visualizing aid to the work task that is currently being carried out and the required specification data will appear on this new device while working which benefits the operator. It would be helpful if you could answer few of our questions related to the process which is performed by you. This interview could take few minutes.

Questions

Question 1
How many operators totally work in this particular this final demands station?
There are currently three operators working in the final demands station.

Question 2
How many hours do you work per day?
The working hours per day is 8 hours including breaks.

Question 3
How many cars do you measure per day?
It depends but usually one car per day sometimes two.

Question 4
Are there any differences between car models when measuring?
Yes, there are differences in each and every cars we measure, no car is same after the final assembly.

Question 5
What types of tools are used to measure gaps and flushes of a car?
There are certain gauges or clocks, 'gap pins' and calculator connected with transmitter with transmits the information to monitor.

Question 6
What happens when a measurement taken is outside the specification demands?
when the measurement is out of the nominal value, there is an alert popping on the

screen of the monitor in red colour. Then the point is remeasured and the value is entered.

Question 7
What is the most important information for you to see on the computer screen?
The whole drafting information of points is important, but the tool placement information and type of tool (clocks) to be used to measure are most important ones.

Question 8
In what stages during the measurement process is this information necessary?
Once the points has been measured and also before to make sure of the placement. And sometimes in middle of measuring.

Question 9
Which parts of your work procedure do you think is the hardest to perform and which parts were the hardest for you to learn when you just started working with measurements at the station?
It's working with the gap pins as well as learning how to place the gauges when measuring to get a stable measurement. The second hardest thing was to learn exactly where to measure since the pictures are not always that good.

C

Alternative Smart Glasses

Some of the other smart glasses companies which we looked upon and their various different features are ;

Vuzix Blade

Figure C.1: Vuzix Blade glasses

Characteristics.

- Projection onto glass.
- Tinted glasses.
- Bulky (90 g).
- Bright screen.
- Better display resolution (480 x 853).
- Replaceable and additional lens (figure).

Glass Enterprise Edition 2 (Google).

Characteristics.

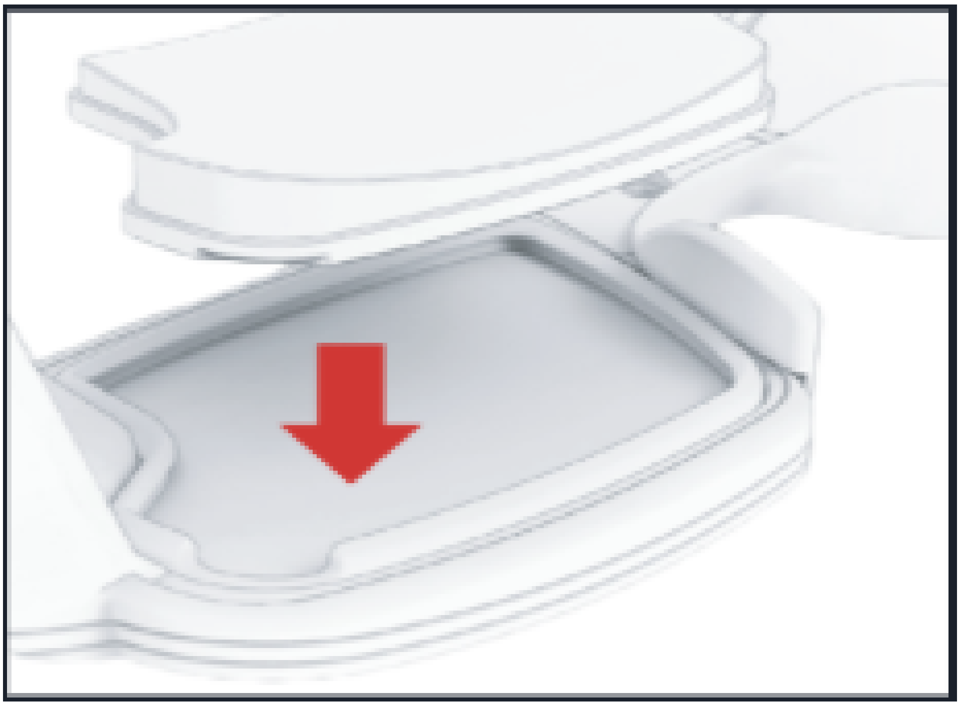

Figure C.2: change of lenses for smart glasses

- Display outside the glass.
- Blocks peripheral vision.
- Weight - 46 g.
- Smaller display (640x360).
- Eyestrain possibility due to usage of long duration.

UBiMAX

Types of UBiMAX Glasses;

- Xpick.
- Xmake.
- Xassist.
- Xinspect.

Figure C.3: Google Glass Enterprise Edition 2

Figure C.4: Glasses sold by Ubimax

Figure C.5: Glasses sold by Ubimax