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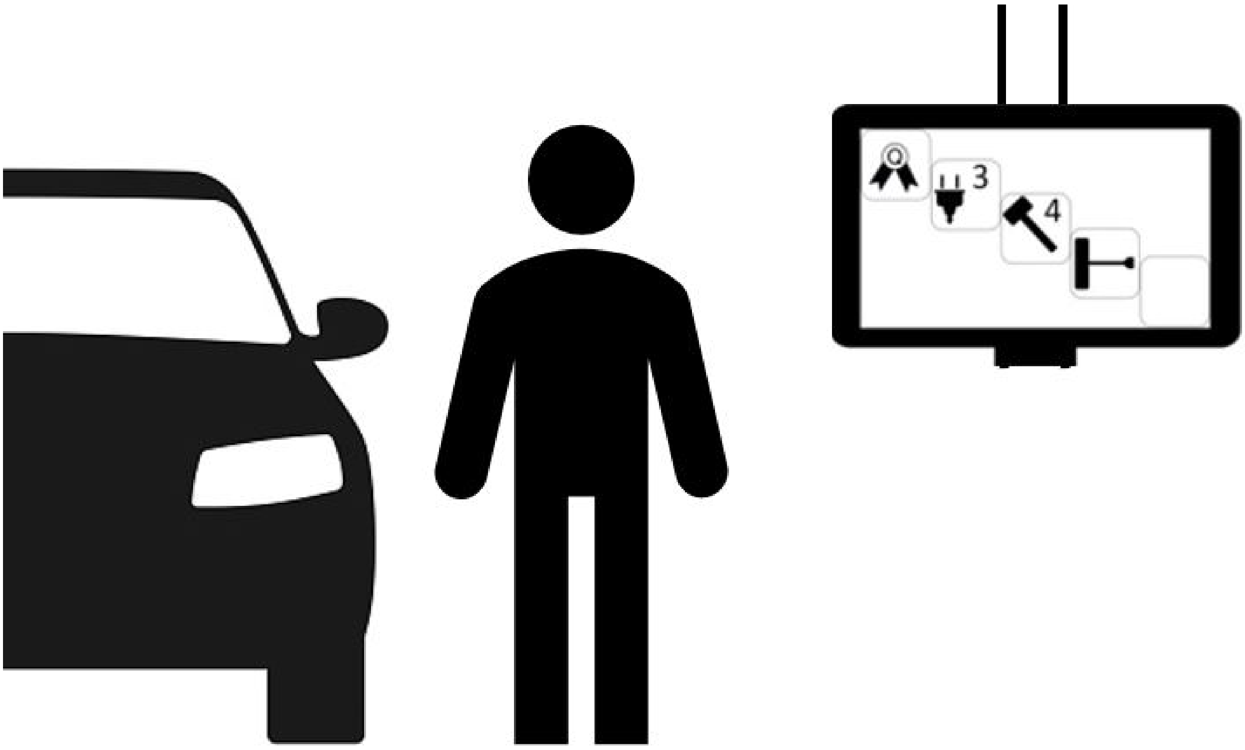

Development and Evaluation of Digital Assembly Instructions

Cognitive Support in Final Assembly

Master's Thesis in Production Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

Master's thesis 2020

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Cover: Operator performing assembly work supported by digital assembly instructions

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Abstract

Customer demands have greatly changed in recent times within the automotive sector. Customers are now demanding highly customizable products. This forces the final assembly to be highly manual in order to be flexible enough to handle the variations in production. The manual assembly combined with highly varied operations leads to increased complexity for operators. This has created the need for a cognitive support for operators in final assembly.

This thesis has developed and evaluated digital assembly instructions for cognitive support of operators in final assembly of the automotive sector. The instructions are focused on highlighting variations and important tasks. The digital assembly instructions were evaluated based on information quality through consulting a set of experts within information handling in production systems.

It was concluded that it is possible to create digital assembly instructions with high information quality as a real-time support for operators in the final assembly. These instructions are able to support operators in their assembly work and reduce complexity. The increased cognitive support reduces the mental load on operators and thus improves cognitive ergonomics. This support is also likely leading to a reduction of the total number of quality errors in production. However, the instructions are likely to have a limited impact on physical ergonomics. This thesis has thus provided industry with a tool that can be used to improve production in terms of quality, cognitive support and work environment sustainability.

Keywords: Digitalization, Instructions, Information Quality, Operator Support, Final Assembly, Quality, Ergonomics, Mass Customization

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We would like to thank all of the participants in the evaluation of the digital assembly instructions. This was a highly important part of our thesis. Lastly, we would like to thank the production leaders, line technicians, team leaders and operators at Volvo Cars for taking part in the project when requested.

Anton Andersson & Wilhelm Trogen, Gothenburg, June 2020

Contents

List of Figures

List of Tables

1
Introduction

This chapter gives a background to the thesis, including the demands from industry and earlier research. The purpose of the thesis is then explained along with the delimitations made. Lastly, the research questions in this thesis are stated.

1.1 Background

The production system is an important part of keeping automotive manufacturers competitive in their market. It has the possibility to reduce costs and increase quality, flexibility and deliverability (Bellgran & Säfsten, 2009). These are considered the most important competitive factors for manufacturing companies (Bellgran & Säfsten, 2009).

The main goal of the production system is to fulfill the customer demands. In recent times, these demands have changed (Chatras, Giard, & Sali, 2016). Customers are now demanding highly personalised products, which have created the need for high product variability (Hu, 2013). This change is referred to as mass customization and it has put increased pressure on production systems (Chatras et al., 2016). In order to fulfill the changes in demand, production systems have been adapted to be able to produce models and variants in a mixed-model approach (Aroui, Alpan, & Frein, 2017). This creates a production system where products and operations are highly varied.

The effect of mass customization in the automotive industry is especially evident in the final assembly part of the production system. Much of the customization is done through the parts assembled here (Chatras et al., 2016). The customization forces the final assembly to be highly manual in order to be flexible enough to handle variations (Mattsson, 2013). At the same time, the increased amount of variation that assembly-operators are subjected to leads to increased complexity (Mattsson, Tarrar, & Fast-Berglund, 2016), (Hu, 2013). Poor cognitive support in such an environment can lead to mental fatigue, which in turn can lead to ill health and mistakes being made (Berlin & Adams, 2017). Increased complexity is also linked to increased process errors and reduced quality (Fast-Berglund, Fässberg, Hellman, Davidsson, & Stahre, 2013). This can have a large impact on the ability of the company to operate successfully, as quality errors can worsen customer relations as well as disrupting the production flow and increasing unit costs (Hossain & Sarker, 2016).

Earlier research points towards benefits of supporting assembly operators, in the automotive industry, using digital assembly instructions (Palmqvist & Vikingsson, 2019). Through instructions presented on screens connected to thin-clients, important variants and tasks can be communicated (Palmqvist & Vikingsson, 2019). In this thesis, supporting operators in the final assembly with digital assembly instructions will be further investigated.

1.2 Purpose

The purpose of this thesis is to improve ergonomics and to reduce quality errors in the final assembly of the automotive sector. This will be done through developing and evaluating digital assembly instructions to increase cognitive support for operators.

1.3 Scope and Delimitations

The development of digital assembly instructions was limited to be performed within team Alpha in the final assembly plant at Volvo Cars Torslanda. This was done as earlier research had been performed in this part of the production system. This research indicated a possible need for digital assembly instructions at this location. The thesis was further limited to choosing two stations to develop instructions for, which was done to limit the work connected to developing instructions and having more time and resources invested in the evaluation of these instead.

The digital assembly instructions to be developed are limited to support the operators in the operative phase. It is assumed that the operators using these instructions have performed their initial training and are able to work independently on the two stations. No testing of the digital assembly instructions in production was performed. Circumstances out of control influenced the production in such a way that an evaluation of a test would not be able to give a result that could be used to draw conclusions based upon.

1.4 Research Questions

The purpose of the thesis can be reached through two research questions. These questions will be answered throughout the thesis by using the presented methodology. These questions are:

- How do digital assembly instructions affect support for operators?
- How do digital assembly instructions affect ergonomics and quality errors?

2
Frame of Reference

This section provides theory and knowledge connected to the thesis. The production system where this thesis was performed is described together with earlier research performed in this system. In addition to this, theory related to both assembly work and instructions is included.

2.1 Volvo Cars

Volvo Car Corporation is an automotive manufacturer based in Gothenburg with plants located around the world. Volvo Cars Torslanda (VCT) manufactures six car models and many variants of each. The final assembly of VCT is performed at the TC-assembly plant, where the final parts are assembled and where the cars are also tested. In this plant, a large number of employees work. The employees are organized into teams which have responsibility for certain stations. The work is split into three shifts; day, evening and night.

In the TC-assembly plant, cars are produced in a one-piece, serial flow approach. The assembly is highly manual in both physical and cognitive aspects. As the cars are highly customizable by customers, the assembly operators have to deal with many product variants. The TC-plant is a fast-paced work environment with cycle times just below one minute.

Team Alpha is working in the trim-part of the final assembly in TC. It consists of one team leader and five operators, for every shift. The team is responsible for five stations: Station Right (Station R), Left (Station L), BV, CH and CV. During production, one operator is located at each station for assembly work, and the operators rotate the stations at which they assembly once every hour.

2.2 Earlier research

Earlier research has investigated effective means of supporting operators in the final assembly. Digital assembly instructions were found to be an effective way of communicating information in a fast-paced assembly environment (Palmqvist & Vikingsson, 2019). These instructions were suggested to be displayed on stationary touch screens connected to thin clients. The best location for the screens was determined to be at the material racks where operators can easily view them while fetching material and tools. The digital assembly instructions focus on highlighting variations and important tasks in the assembly work. It was concluded that these instructions should be presented in the form of up to five symbols presented diagonally, reminding the operator of certain operations, see figure 2.1. In the figure, what can be seen is an example of how the symbols could look like, in this case reminding about connecting a LED contact, assembling two clips as well as using a leather mallet three times. Digital assembly instructions were found to be the best way for the operator to be able to obtain and understand information with short cycle times present. Recommendations in this research were to develop digital assembly instructions specific for a set of stations and to test them in running production.

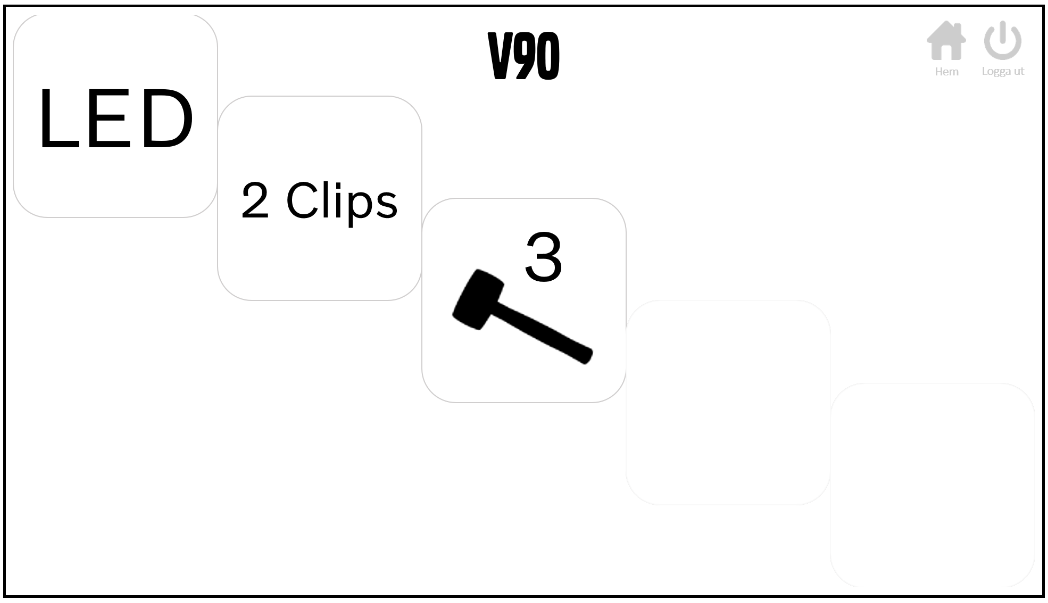

Figure 2.1: Digital assembly instructions (Palmqvist & Vikingsson, 2019).

2.3 Quality in Production

Quality is widely recognised as one of the most important competitive factors for manufacturing companies (Bellgran & Säfsten, 2009). Poor quality products reaching customers can have large impacts on the ability of a company to operate. Product quality is also important in production where quality errors reduce production rate and increase unit costs (Hossain & Sarker, 2016). In a one-piece, serial flow line layout, quality errors have an especially severe impact. Here, quality errors will either have to be resolved once the product has made it through the entire production system (Hossain & Sarker, 2016). Then, the error can be resolved on an off-line rework station, which can include major work such as removing components in order to reach and fix the error. Another possibility is to fix the error while still on the line which will likely lead to the line having to be stopped and thus stopping several stations (Hossain & Sarker, 2016). No matter how the quality error is solved, it leads to extra work which can be classified as waste.

There is a significant connection between the production system and the product quality (J. Li, Blumenfeld, & Marin, 2006). A production system that is designed in the right way can significantly improve the production quality (Inman, Blumenfeld, Huang, & Li, 2003).

2.4 Ergonomics in production

Ergonomics is a widely used term, and includes everything from physical activities; how the body is aligned when performing a work task, *physical ergonomics*, to mental activities; how the mind understands instructions, *cognitive ergonomics* (Berlin & Adams, 2017). When investigating ergonomic effects in a workplace, it therefore means that both physical and cognitive loads must be considered.

2.4.1 Physical ergonomics

There are several components involved in physical ergonomics. These include posture, force, and time (Berlin & Adams, 2017). Posture means how the body is aligned when doing activities. Indications of good posture are that there are symmetrical distributions of forces on different parts of the body. Posture is connected to time and force in the sense that the total physical load is dependent on all these three factors. Good posture ensures that forces do not cause great physical load, however if a certain posture is held for a long time there might still be a critical physical load. Likewise, if a poor posture is held, resulting in great forces on some parts of the body, this might not be critical if it is only held for a short period of time. All factors are thus important to consider when striving for good ergonomics in a production system.

2.4.2 Cognitive ergonomics

Mental fatigue can contribute to mistakes, especially when observing monotonous tasks that might suddenly change (Berlin & Adams, 2017). Thus, tasks that are designed with poor cognitive support can cause mental overload and thus increase chronic fatigue, leading to demotivation, ill health and mistakes.

There are several components involved in cognitive ergonomics. These include the senses, of which the most relevant are; hearing, vision and touch (Berlin & Adams, 2017). Vision is the most dominant sense when taking in information. Our sense of vision is connected to perception, which looks for patterns that our brain can recognize as meaningful. The vision worsens after the age of 40, which means the ability to detect low contrast small symbols for example. Clear visual cues are thus important when designing instructions for the whole work population.

2.5 Complexity

Complexity in manufacturing is an increasing challenge for companies. One of the main drivers is mass customization, which increases the number of product variants (Fast-Berglund et al., 2013). This in turn leads to a higher amount of information being transferred to and from operators (Fast-Berglund et al., 2013). Other sources of complexity in a production system are product type, layout, planning and work environment (Mattsson, 2013). The complexity of a production system affects quality, reliability, performance, and production time. Managing complexity is therefore connected to an increase in operator performance, decrease in process errors, higher quality, better working conditions and so forth (Mattsson, 2013).

One way of handling complexity is through automation. In mixed-model assembly, cognitive automation is especially useful. It allows the complexity to be reduced by supporting decision making, while still enabling the flexibility of manual assembly (Fast-Berglund et al., 2013).

2.6 Motivation and psychological needs

There are three basic psychological needs that need to be fulfilled to ensure motivation in individuals; competence, autonomy and relatedness (Deci & Ryan, 2000). The need to feel competent is that ones own work contribute to the performance of the whole organisation. The need to feel autonomy, is that one can work autonomously, without the constant supervision of a manager or a system. It has been observed that providing operators with the ability to stop the production line increases the sense of autonomy and results in higher productivity (Fowler, 2014). Relatedness is the need to feel a connection to other people; to care and to be cared for. If these basic psychological needs are not met, it will result in unmotivated employees, which in turn results in reduction of performance and well being.

There is a connection between psychological needs and self-regulation, called the Spectrum of Motivation model (Fowler, 2014). It entails that when a persons psychological needs are met to a high degree, it will result in an optimal motivational outlook. That is if autonomy, competence and relatedness are met in an individual, the result is an aligned, integrated or inherent motivational outlook. Likewise, if these psychological needs are not met, the result is a sub-optimal motivational outlook in the form of a disinterested, external or imposed motivational outlook. There is a connection among these factors, called the ARC domino effect (Fowler, 2014). If one of the factors are lacking, it naturally leads to the questioning of the other factors, resulting in a domino-effect ultimately leading to a poor motivational outlook. Poor motivation is widely recognized as a contributor to poor performance.

2.7 Information Quality

Information has a large impact on the success of a company. Employees that work with information of low quality work less effectively, make more errors and are less satisfied with their work (Conner & Douglas, 2005), (Lind, 2008). This also leads to further negative effects such as; low customer satisfaction, increased running costs and inefficient decision making processes (Haug, 2015). With this in mind, there are clear benefits of ensuring high quality of information.

Intrinsic informational quality is based upon the perception of the individual. There are six different types of intrinsic instructional information quality; Deficient instructions, Ambiguous instructions, Unneeded instructions, Incorrect instructions, Repetitive instructions and Fitting instructions (Haug, 2015). These six different information qualities can be described in terms of needed instructions and received instructions, where the former is the needed instructions by for example an operator to successfully perform the job correctly, and the latter is the actually received instructions by the operator. For deficient instructions, it means that one or more of the needed instructions are not included in the received instructions. For ambiguous instructions, one or more received instructions can be interpreted as different needed instructions. Unneeded instructions means that one or more received instructions are not included in the needed ones. Incorrect instructions imply that in the case of a received instruction, its information is incorrect. Repetitive instructions entail that several received instructions describe the same needed instruction. Fitting instructions mean that all needed instructions are equal to the received instructions.

The quality of instructions are also affected by extrinsic factors, which are more dependant on the specific environment where the instructions are used. Credibility and Reputation are two factors which affect how well employees choose to follow instructions (Haug, 2015). If the instructions for instance have a poor reputation among employees, this will in turn affect how well they are followed. The instructions must also be given when they are needed, which is refereed to as timeliness (Haug, 2015). The instructions given should also be the right amount of information. Too detailed and extensive instructions risk that the user find them tiresome or difficult to use. Instructions should also use the right language and symbols. This means that they should use an appropriate level of language, avoiding difficult terms and formulations (Haug, 2015). Furthermore, the language and symbols should also be consistent, universal and self-explanatory when possible.

3
Methodology

In this chapter the used methodology is explained. A mixed methods approach was used in this thesis to be able to accurately investigate and draw conclusions regarding the thesis aim, as convergence among results from multiple methods leads to increased credibility (Hesse-Biber, 2010). Additionally, the mixed methods approach made it possible to develop a fuller understanding of the studied environment, as the methods complemented one another by providing different types of information (Hesse-Biber, 2010). Thus, both qualitative and quantitative methods were used, leading to a more holistic view of the results.

3.1 Applied methods

The workflow seen in figure 3.1 shows what methods have been used and in what order. An information criteria formulation was performed to ensure high information quality for the developed instructions. An analysis of the current production system was then performed to be able to gather and analyse data in the production system. This knowledge was then applied when developing the digital assembly instructions. This step included selecting information content for the instructions, creating the instructions and deciding how and where to visualize the instructions. Ultimately, an evaluation was done of the digital assembly instructions to determine the usefulness and to be able to draw conclusions regarding further actions to take.

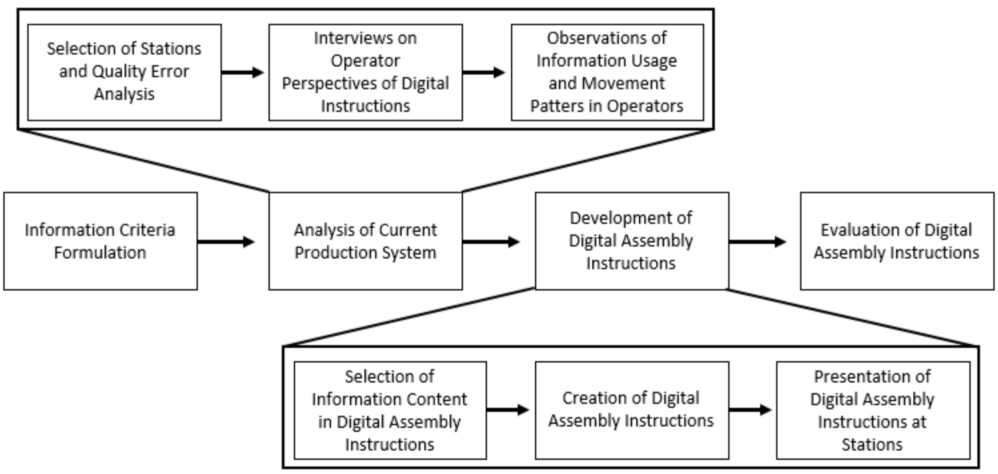

Figure 3.1: Sequence of applied methods

3.2 Information criteria formulation

A structured search was done to be able to determine what criteria are important for achieving good information quality, and thus also what information should be evaluated based upon. This could in turn be used to base the creation and evaluation of instructions on. One search combining several keywords was done to ensure that all interesting articles were found. This included both design principles for good information quality, as well as what information quality itself is, and how this related to assembly instructions. The search was done on Scopus due to both its large database of literature and its high publishing requirements. The search included the search terms:*(TITLE-ABS-KEY(information AND quality) AND assembly AND instruction) OR (TITLE-ABS-KEY(assembly AND information) AND manufacturing AND operator AND instruction)*. The string before the OR-term includes articles more related to assessment of information quality and the latter, after the OR-term, includes articles more related to design of assembly instructions. The structure of the literature search can be seen in figure 3.2.

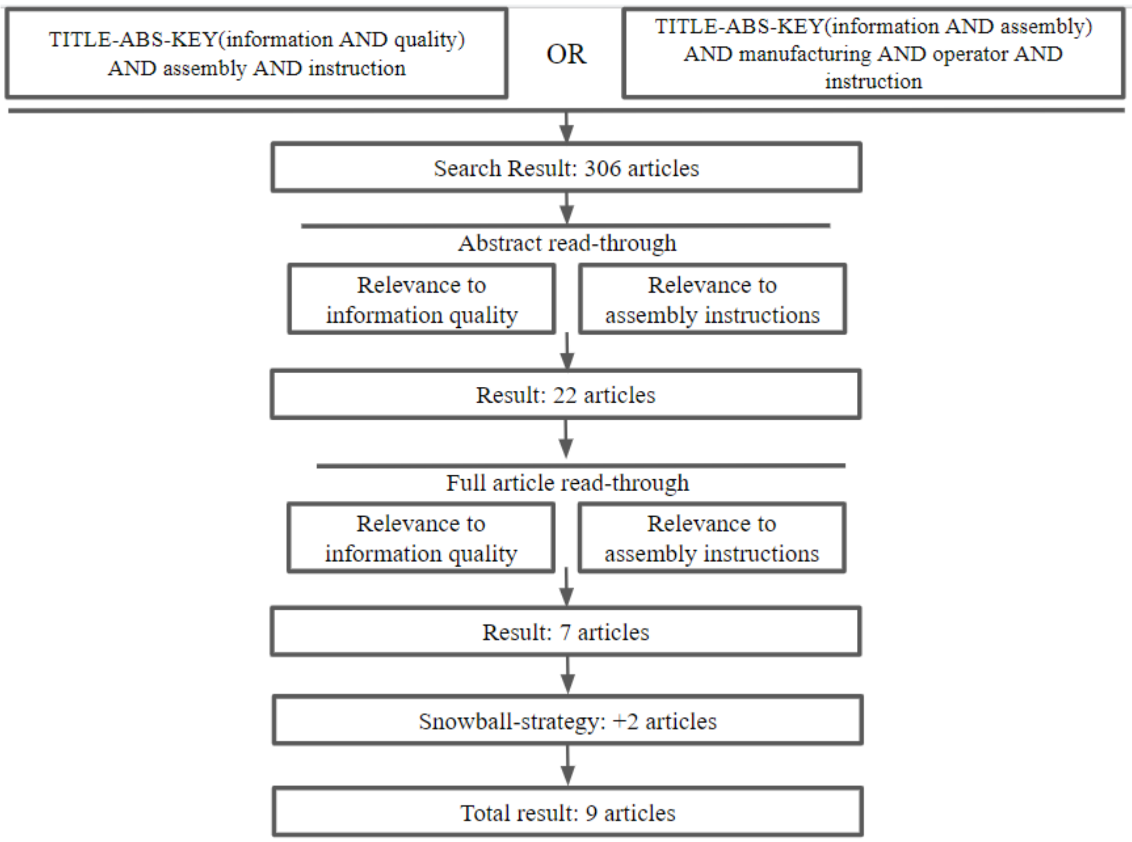

Figure 3.2: Structure of the literature review

The search terms were matched with the Title, Abstract and Keywords of articles that were relevant to the assessment of information quality or assembly instructions. The remaining keywords were used to limit the search results and to screen out irrelevant articles, in this case articles not related to operators, manufacturing, assembly and instructions. This resulted in 306 articles. The abstract of these articles were read-through and those relevant to information quality or design of assembly instructions were selected. This resulted in 22 articles. These articles were then fully read through and selected based upon the same criteria; relevancy to information quality and to design of assembly instructions. This resulted in seven articles.

The Snowball-strategy was used to find additional useful articles in the references among the found articles. What was searched for here were articles that could contribute with additional knowledge regarding the factors previously mentioned. Two articles were acquired through this method, resulting in a total of nine relevant articles.

3.3 Analysis of current production system

A gathering and analysis of data was performed for the current production system. This was used to create an understanding for how to design and use digital assembly instructions in this production system.

3.3.1 Selection of stations and quality error analysis

The first step in the analysis of current production system was to select two stations to develop digital assembly instructions for. To investigate the possibility of using digital assembly instructions as a support for operators in quality-related aspects, the program Atacq was used. This, since the program shows all quality errors registered in production. Historic data over quality errors for the five stations in the studied team was collected for a twelve-week period. This was done to ensure that the data was recent enough to describe the current production system, while also limiting the effects of possible temporary quality deviations. The quality error data was sorted based on error description, in order to see what types of errors existed and how frequent they were. The reason for this was to help create an understanding for if and how digital assembly instructions could be used as a support for operators to decrease quality errors and where this support was needed the most.

Two stations in team Alpha were to be chosen to develop digital assembly instructions for. When selecting the stations for development of digital assembly instructions, it was done based on the potential of possible improvements in terms of reduction of quality errors. The reason for this was that the quality aspect was believed to be the area where digital assembly instructions would have the largest benefits. The selection of two stations with the highest potential for improvements, included taking both the number of errors and type of error into account. The type of error was important as the digital assembly instructions were more suitable as support for certain quality errors. Meaning that some quality errors were believed to not be able to improve through digital assembly instructions.

3.3.2 Interviews on operator perspectives of digital assembly instructions

Interviews were held with operators in team Alpha working at the two chosen stations, to get perspectives from operators regarding digital assembly instructions. In total, eight interviews were held with operators from all three shifts. The interviews ranged between 15-25 minutes in length. Interviews were held in order to create a more practical understanding for how digital assembly instructions could support operators and to possibly support assumptions made during the analysis of quality data. The interviews aimed to gather knowledge about the interviewee's opinion on what operations to support with instructions, how to design the symbols and the placement of thin clients for visualisation of instructions. To successfully achieve this, questions were formulated not to steer interviewees in any direction. To ensure relevant input from the interviewed individuals, information about the idea of digital assembly instructions and background to the thesis were given. This was needed as a clear understanding of the digital assembly instructions was deemed necessary to be able to give relevant input.

To promote activeness and motivation from the interviewed individuals, the interviews were modeled after the funnel approach (Patel & Davidson, 2003). Meaning that it was a combination of open ended questions followed by more specific questions, see Appendix A for interview questions. In order to be able to further discuss certain areas that were found to be interesting during the interviews, possibly giving useful information, the interviews were semi-structured (Patel & Davidson, 2003). To motivate participation in the interviewees, the purpose of the interviews were explained and connected to interests of the interviewees (Patel & Davidson, 2003). This made sure that the interviewee understood that their contribution could impact their work environment. Participation was further motivated by clearly communicating that the participation of the interviewee would contribute to significant knowledge and impact in the project (Patel & Davidson, 2003). Trust was ensured by explaining that the interviews were confidential (Patel & Davidson, 2003).

3.3.3 Observations of information usage and movement patterns in operators

To decide on what type of information to include in the digital assembly instructions and how to visualize this at the stations, it was interesting to study the information usage of operators, as well as their movement pattern. This was done through observations of operators at the two chosen stations. What was observed here was when, where and how often operators used instructions during assembly work. The observations were equally split between the stations, with five observations for Station L and five for Station R. The duration of each observation was the time it took an operator to assemble 30 cars, roughly 30 minutes. This was done to ensure that a holistic view of the assembly work and information usage was given. Operators from all shifts were observed to ensure that all possible ways of working in operators were noticed. The observations gave an understanding for which operations operators used instructions and how the operators moved at the stations. This was interesting as it gave an indication on what operations to include in the digital assembly instructions. It also showed where to locate the screens to make them easily accessible for operators while working. The operators were informed that observations were to be performed, however the primary reason, to study the interaction with the instructions at line, was not given. The reason for this was to minimize the effect the observations had on the behaviour of the operators and to avoid changing how they normally worked (Patel & Davidson, 2003). During the observations, it was noted every time an operator looked at information, to get an accurate record of the usage of instructions. This included the location of both the operator and information and how often this was done.

3.4 Development of digital assembly instructions

The development of digital assembly instructions consisted of several steps. Firstly, a selection of information content to include in the instructions was done. The creation of instructions was later based upon this information and ultimately the instructions were evaluated to determine their usefulness in final assembly.

3.4.1 Selection of information content in digital assembly instructions

Before creating the digital assembly instructions, a decision regarding what information to include was needed. This was done through identifying several issues present that could be solved using digital assembly instructions. These issues were identified through a mixed-methods approach. Convergence in the results of these methods indicated what data was credible (Hesse-Biber, 2010). More specifically, issues found from multiple methods indicated that these issues were critical and suitable for solving with digital assembly instructions. The analysis of quality errors was the main base for deciding what operations to support. Interviews and observations were then mainly used to support the findings from this analysis. However some issues had no connection to quality errors and were a direct result from interviews and observations. Thus, the mixed methods approach helped interpret the data found, and also lead to additional beneficial information being found. This ultimately helped to make a decision on what information to include in the digital assembly instructions.

3.4.2 Creation of digital assembly instructions

Digital assembly instructions that supported the issues found for the two stations were created. The instructions were decided to be communicated through symbols as this was found to be the most optimal way of communicating information with the circumstances present in the production system (Palmqvist & Vikingsson, 2019). The design of symbols was based on the instruction criteria formulation combined with knowledge learned from interviews with operators. Already existing symbols, both from earlier research and those present in the production system, were used whenever possible as this was requested from operators. This principle is an important part of the criteria visual design, that is that the symbols should be self explanatory and universal, found in the information criteria formulation. New symbols were designed with the suggestions of simplicity, gathered through interviews, in mind, while still communicating the intended message. Operators, team leaders and technicians were consulted in this part of the process. They were shown the suggestions and could then give feedback on the design. It was made sure that the symbols fulfilled all criteria from the instruction criteria formulation. This ensured instructions that supported the found issues, with a design that had a high information quality.

3.4.3 Presentation of digital assembly instructions at stations

The digital assembly instructions were suggested to be visualized through screens located at the stations. These were to be mounted by the material racks were the operators can read the instructions while fetching material. In order to decide the placement of these, the knowledge gathered during the analysis of the current system was used. The information criteria formulation was also included in this step to ensure that a high level of information quality was reached. The observations of the movement patterns were important as they gave an understanding for where to place the screens to achieve accessible instructions. The interviews conducted with operators also gave valuable information regarding the placement of screens.

3.5 Evaluation of digital assembly instructions

The evaluation of the digital assembly instructions was done through an evaluation by an expert panel. The goal of the evaluation was to get an answer to both research questions. The expert panel consisted of four researchers in information handling of production systems, mainly from Chalmers University of Technology. It also consisted of one engineer and one technician connected to the studied stations at Volvo Cars. By including both researchers from Chalmers and employees at Volvo Cars, it was ensured that the evaluation of the digital assembly instructions was based on knowledge coming from both practice and research, and thus ensuring a holistic perspective. The evaluation was based on a selection of the criteria formulated in the information criteria formulation. Even though all found criteria were important, some of these criteria were not included for the evaluation of digital assembly instructions. This choice was based on the possibility for the expert panel to give an accurate evaluation of these criteria. The evaluation included discussing the possibility of supporting operators in assembly work, mainly based on the evaluation of information quality. This was interesting as it could give an answer to the first research question, *How do digital assembly instructions affect support for operators?* Furthermore, it was also discussed what effects the digital assembly instructions could have on production in terms of the possibility of reducing the total number of quality errors as well as increasing ergonomics. This was done to give an answer to the research question *How do digital assembly instructions affect ergonomics and quality errors?*

The evaluation by the expert panel was performed through a digital meeting with sound, screen and video sharing. In this meeting, the digital assembly instructions were explained and the use of it was demonstrated extensively. The goals of the thesis were also explained. This was done to ensure that the expert panel had the highest possible understanding of the digital assembly instructions to allow for an accurate evaluation. The evaluation by the expert panel was performed through a questionnaire followed by extensive discussions regarding the questions in the questionnaire, as well as new questions that arose from the participants. The use of a questionnaire ensured a quick way of collecting the general attitude towards the instructions from the participants, and also allowed for a base of discussion. The following discussions allowed the participants to further elaborate on their thoughts regarding the instructions, which allowed for a more nuanced evaluation of the instructions. For the questionnaire used, see appendix B.

4

Results

This chapter presents the results from the methods used in the thesis. The results from the information criteria formulation are presented, followed by analysis of current production system, development of digital assembly instructions and ultimately the evaluation of digital assembly instructions.

4.1 Information criteria formulation

The studied articles during the information criteria formulation lead to the formulation of seven information quality criteria; *1. Timeliness*, *2. Accessibility*, *3. Comprehensiveness*, *4. Visual design*, *5. Accuracy*, *6. Relevance* and *7. Reputation.* Table 4.1 presents a summary of what criteria was mentioned as important in each article.

Table 4.1: Information quality criteria presented in the studied articles.

Article	1	2	3	4	5	6	7
Digital Assembly Assistance Systems - A Case Study (Nikolenko, Sehr, Hinrichsen, & Bendzioch, 2019)	x	x	x			x	
Challenges of Handling Assembly Information in Global Manufacturing Companies (P. E. C. Johansson, Malmsköld, Fast-Berglund, & Moestam, 2019)	x	x	x		x	x	x
Effects of Information Content in Work Instructions for Operator Performance (D. Li et al., 2018)	x	x	x	x	x	x	x
Assessment Based Information Needs in Manual Assembly (P. E. Johansson, Eriksson, et al., 2017)	x	x	x		x	x	
Data and Information Handling in Assembly Information Systems - A Current State Analysis (P. E. Johansson, Enofe, et al., 2017)	x		x		x	x	
Evaluation of Guidelines for Assembly Instructions (Mattsson, Fast-Berglund, & Li, 2016)	x		x	x			
Work Instruction Quality in Industrial Management (Haug, 2015)	x	x	x	x	x	x	x
Development of Simple Guidelines to Improve Assembly Instructions and Operator Performance (Söderberg, Johansson, & Mattsson, 2014)		x	x	x			
Measuring a Company IQ (Kehoe, Little, & Lyons, 1992)	x	x	x		x	x	

1. Timeliness
Timeliness was mentioned in all but one article to be an important aspect to consider when evaluating information. Timeliness is referred to as the degree to which information is available when needed, as information should be presented only at the right time (P. E. Johansson, Eriksson, et al., 2017). Timeliness is an important factor when assessing the quality of information (Kehoe et al., 1992). A good way of ensuring timeliness of information is to present real-time updates of it, thus assuring that the information is provided when it is needed. This has been increasingly requested in future assembly (P. E. Johansson, Eriksson, et al., 2017).

2. Accessibility
Accessibility was mentioned in five of the articles to be an important criteria for evaluating the quality of information. Accessibility of information refers to how well it can be attained by the user. What determines the accessibility is primarily the location of information, which has a great impact on the quality of the information (Haug, 2015). If the information is inaccessible, and thus requiring greater effort to attain it, there is a risk that users do not use it (P. E. C. Johansson et al., 2019). No usage of information is an indicator that the accessibility of information is low. This is especially evident in assembly systems with short cycle-times where lack of time prevents the user from accessing information when it is not located at an accessible place (P. E. C. Johansson et al., 2019).

3. Comprehensiveness
Comprehensiveness was mentioned in all articles to be a great contributor to the quality of information. Comprehensiveness is referred to as the degree to which information is either redundant or lacking (Kehoe et al., 1992). It is important that the instructions contain the right amount of information (Haug, 2015), (P. E. Johansson, Eriksson, et al., 2017). This, since redundant information leads to it being too time consuming to obtain the needed information or that focus is put on unneeded information (P. E. C. Johansson et al., 2019), (P. E. Johansson, Eriksson, et al., 2017). This can in turn result in an increased risk for errors as too much information is presented, which makes it difficult to obtain the needed information (P. E. Johansson, Enofe, et al., 2017). Similarly, lack of information makes it difficult to obtain the needed information.

4. Visual design
Three articles included visual design to be an important aspect of information quality. What the articles suggest are that instructions should use the right language and symbols. This includes using symbols that are consistent, universal and self-explanatory (Haug, 2015). This will make the information easier to understand, as less complementary information or explanation is needed in order to understand its meaning. Furthermore, it is important that symbols are not too similar, to make it easy to differentiate them (Mattsson, Fast-Berglund, & Li, 2016). Inability to differentiate symbols could lead to increased complexity, removing the benefits of digital assembly instructions.

5. Accuracy
Accuracy is to what degree information is correctly describing what operations to perform, that is to what degree it is free from errors (Kehoe et al., 1992). This is important for information quality and is therefore mentioned by many of the articles as an important factor. Operators are largely dependent on that the instructions that they use are accurate (P. E. C. Johansson et al., 2019). It has been widely argued that even minor inaccuracies in information content can have major effects on quality and performance (Haug, 2015).

6. Relevance
The relevance of information entails whether it is useful for the user or not (D. Li et al., 2018). This criteria is similar to comprehensiveness. However, comprehensiveness is more focused on the amount of information and the detail of it, while relevance is focused on whether the information is useful or not. Providing operators with information that is not relevant to them can be seen as a pure waste, as it requires time to obtain and does not add any value.

7. Reputation
The reputation, termed validity in some articles, of information is highly important as it affects how well this information is believed and followed (Haug, 2015). This criteria is largely dependant on other criteria, such as accuracy. If, for instance, the accuracy criteria is not fulfilled, the information becomes less trustworthy to the users, which in turn leads to bad reputation (P. E. C. Johansson et al., 2019).

4.2 Analysis of current production system

The following section presents the results of the analysis of the current production system. The selection of stations is presented, followed by interviews on the operator perspectives of digital assembly instructions. Finally the results from the observations of information usage and movement patterns in operators are presented.

4.2.1 Selection of stations and quality error analysis

The quality data retrieved through Atacq showed for which stations there were problems with quality errors and what these problems were. Station R and L were chosen for developing the digital assembly instructions, based on this analysis. As can be seen in figure 4.1, the two stations had the highest and third highest number of total quality errors during the studied period. Both stations had a large proportion of quality errors suitable to solve using digital assembly instructions, see table 4.2 and 4.3.

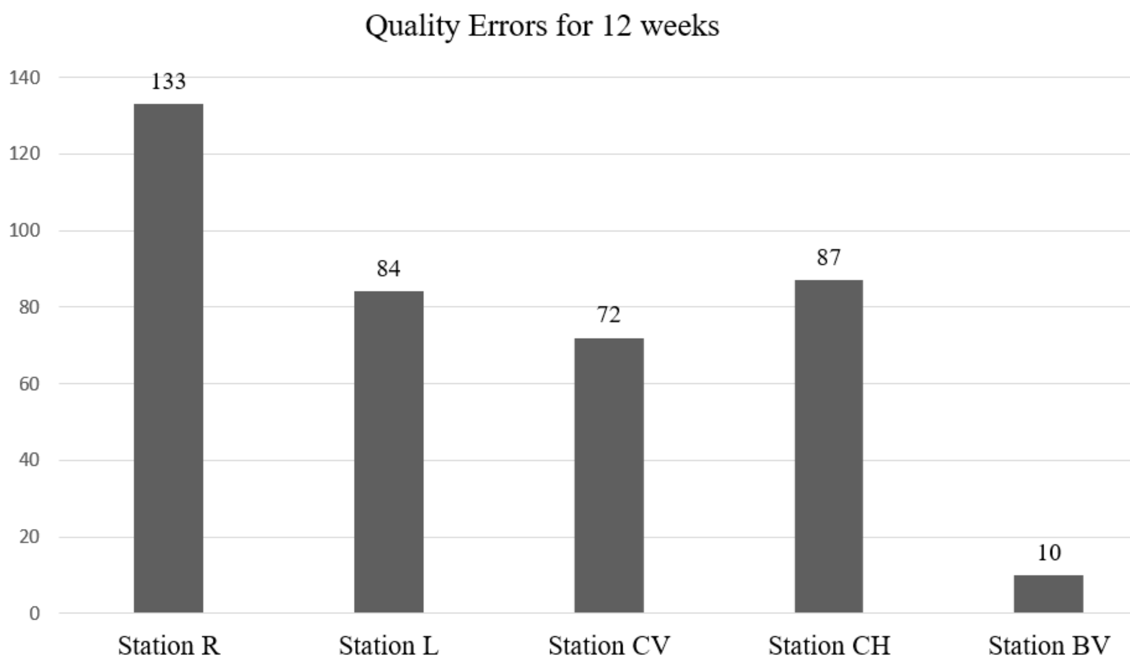

Figure 4.1: Quality errors during 12 weeks for stations in team Alpha.

In table 4.2 and 4.3, it can be seen what quality errors found in Atacq that were deemed possible to solve using digital assembly instructions, for station R and L. It can also be seen their respective percentage of total quality errors. For Station R, 46% of the total quality errors were believed to be possible to solve using digital assembly instructions. The corresponding number for Station L is 39%. The most common error for station R was that the side panel to be assembled in the operation was done so incorrectly, resulting in it being loose. The following were three errors linked to the connection of contacts. What happened was that operators sometimes forgot to connect these contacts.

Table 4.2: Error-description and the percentage of total errors for Station R during a twelve week period

Description of Quality error	Quantity Errors	Percentage of total errors
Side panel loose	23	17%
Contact A	15	11%
Contact B	12	9%
Contact C	12	9%
Total	62	46%

For station L, the miss-assembly of the side panel was not as common, with forgetting to connect Contact C being the most common followed by Contact B. The connection of Contact A is only performed on station R, explaining why it is not appearing in the quality data for station L.

Table 4.3: Error-description and the percentage of total errors for Station L during a twelve week period

Description of Quality error	Quantity Errors	Percentage of total errors
Contact B	6	7%
Contact C	22	26%
Side panel loose	5	6%
Total	33	39%

4.2.2 Interviews on operator perspectives of digital assembly instructions

What follows are the suggestions that were given from the interviews with operators regarding the digital assembly instructions. The suggestions given were regarding what operations to support in the instructions, how to design the symbols and how to place the screens for presentation of instructions. For a summary of the answers, see table 4.4.

Table 4.4: Summary of findings during operator interviews

	Operator suggestions
Operations to support:	Connection of contacts, Use of leather mallet,
	Assembly of Side panel
Design of symbols:	Simple, large, low detail, use familiar symbols
Placement of screen:	At sign-in sheet, adjustable angle, operator height

Operations to support

Most commonly, the connection of different contacts performed at the stations were described by most interviewees as an area leading to difficulties. The main issue was the high variation in the number of contacts to be connected. It could vary between one to four needed connections, depending on model and variant. Operators were currently informed about what contacts to connect through the specification of the car coming in to the line. The specification should be clearly visible in the trunk of the car, however it was not unusual that it was located somewhere else or hidden behind material. Many operators pointed out that reminders about what contacts to connect could be fit for inclusion in digital assembly instructions. A majority of the operators said that the focus could be both on which contacts to connect and in what order.

The usage of a leather mallet was also mentioned by a majority of operators as something for which the digital assembly instructions could be used as support. This tool is used in order to reduce forces needed for pressing the side panel into place and thus improving the ergonomics of the operator, where the alternative would be to use ones hand. All operators did not use the leather mallet, although most expressed the importance of using it. Reasons for not using the mallet were it being less favourable and more time consuming to use than just using the hands, or that it was simply forgotten. The suggestions given on what to include in the instructions was an illustration of the leather mallet as well as how many times to use it.

Lastly, the assembly of the side panel was mentioned as something that could possibly be supported using digital assembly instructions. The panel has to slide into its correct position and then locked into place by fixating it using clips. Both the placement of the side panel in the correct position and its fixation with clips are operations that were sometimes not performed correctly. This resulted in the panel being loose, which is visible for the operator. However, the operator did not always control that the panel was assembled correctly. Although this was a common error, the operators expressed that they believed it would be difficult to visualize this problem using symbols.

Design of symbols

When asked about the design of symbols, all operators expressed that it was important to make the design as simple as possible. They wanted large visible symbols, without too much detail. They believed that this would make it possible to take in information quicker and to do so from a distance. It was also mentioned by a few operators that already existing symbols, for instance in the existing instructions or on buttons in the car, should be reused if possible. It would be easier to understand what these symbols meant as they were already known and it could also be confusing to have different symbols communicating the same thing.

Placement of screens

The placement of the screens connected to thin clients was an important issue for all operators. According to them, this could have a large impact on how much the operators would use the digital assembly instructions and how well they would function. The area where they currently sign in to the station was pointed out as a good placement of the screens. They always pass this part of the station when moving between cars and fetching material and will thus be able to read the instructions with this placement. It would also be favourable to adjust the angle of the screen so that it was possible for the operator to look at the screen without having to turn their head. This would make it possible for the operator to use the same movement pattern and would thus not potentially introduce any new ergonomic risks. Lastly, the height of the current sign-in sheet was given as a good height for the placement of screens.

4.2.3 Observations of information usage and movement patterns in operators

The information usage of operators is summarized in table 4.5. As can be seen in the table, the operators use the specification more for Station R, where it was used in 43% of cars, compared to 13% for Station L. Operators mainly use the specification for knowing how many contacts to connect. The number of contacts to connect are between one and four on Station R and only varies between one and two for Station L. Thus the operators use the specification more on Station R.

Table 4.5: Average number of times operators checked the specification

Station	Avg. specification checks	Avg. percentage of cars checked
R	13	43%
L	4	13%

Figure 4.2 shows the movement patterns of operators. What can be seen here is a layout of Station R and L, where R is in the upper part of the figure and L is in the lower part. The material racks show the extent of the stations. Operators move from the trunk of the car just assembled, marked 1, to the material racks. When they have picked material, they move to the next car, marked 2, according to the Operator Path seen in the figure. The area marked A in this figure visualizes where the operators are usually finished with assembly on the stations and begin the next assembly-cycle. What was seen during observations was that operators were often finished with assembly before the cycle had ended.

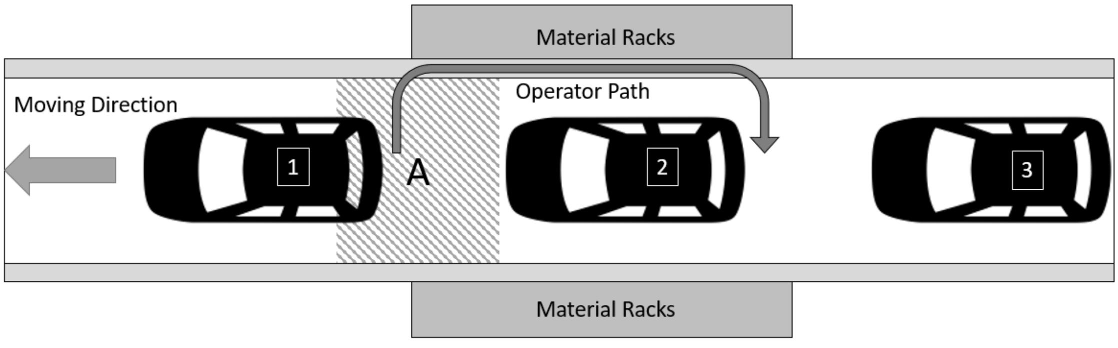

Figure 4.2: Movement pattern of operators for station R and L.

4.3 Development of digital assembly instructions

This section presents the results from the development of digital assembly instructions. The information content which was to be included in the digital assembly instructions is presented, followed by the created instructions. Lastly, the way in which the instructions are presented at the stations is explained.

4.3.1 Selection of information content in digital assembly instructions

The following is the information that was chosen to be included for the digital assembly instructions. What can be seen in table 4.6 are the most important issues found through the mixed methods approach, and the conclusions regarding how to solve these issues using digital assembly instructions. The connection of contacts were found through several methods to be a reoccurring problem, and was found to cause quality problems and lead to increased complexity for operators. A decision was made to remind about the contacts to connect for different variants in the instructions. The miss-assembly of the side panel was a frequent quality error, and a decision was made to remind about a quality check for the side panel in the instructions. The infrequent usage of leather mallet and the new clips tool was concluded to be a problem mainly through interviews. The reasoning behind these two issues, was mainly based on the input gathered for the leather mallet. However, it was decided to apply the same reasoning to the clips tool. The decision was made to remind about the usage of these tools in the instructions.

Table 4.6: Information content to include in the digital assembly instructions

Issue	Support
Connection of contacts forgotten	Remind about the differing connections in variants
Miss-assembly of side panel	Remind about quality error for side panel on relevant models
No usage of leather mallet	Remind about using the leather mallet during assembly
No usage of clips tool	Remind about using the new clips tool during assembly

4.3.2 Creation of digital assembly instructions

The created digital assembly instructions can be seen in figure 4.3 and 4.4. As the two stations are similar, the instructions are to a large extent the same. The instructions consist of symbols that were created based on the conclusions drawn in the selection of information content for the digital assembly instructions. What can be seen are five symbol-slots presented diagonally, where four out of five symbol-slots are used for station L and three out of five for station R. In the upper part of the figure, the model name is shown. The display of symbols is dependent on the variant coming in to the line. The first symbol illustrates a quality reminder to check that the side panel is not loose. This symbol is already used in the Volvo production system to illustrate quality and is thus already familiar to the operators. The quality reminder will either be present when needed, which is for a certain model, or there will be an empty symbol-slot. The second symbol-slot shows an illustration of the number of contacts to be connected. The number of contacts to be connected is represented by a number in the top right corner. This number varies between one and four for station R and one and two for station L. In the case where there is no reminder for connection of contacts, the second symbol-slot is empty. The third symbol illustrates the usage of a leather mallet, and the number of spots to hit, that is the number of clips to fasten. The number of spots to hit are represented by a number in the top right corner, and varies between three and four. When there is no reminder of the usage of a leather mallet, which is for one model, the third symbol-slot is empty. The fourth symbol illustrates the usage of a clips-tool. The symbol is present when a reminder is necessary and there is an empty symbol spot when it is not necessary. The tool is only used for one of the models on station L.

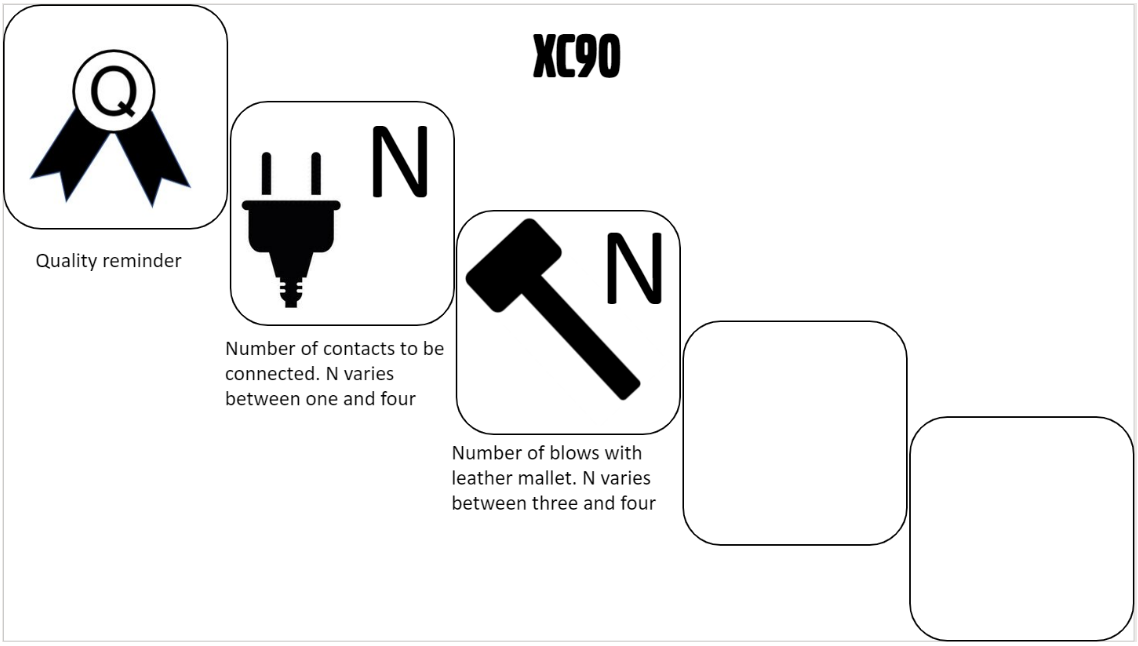

Figure 4.3: The created digital assembly instructions for Station R

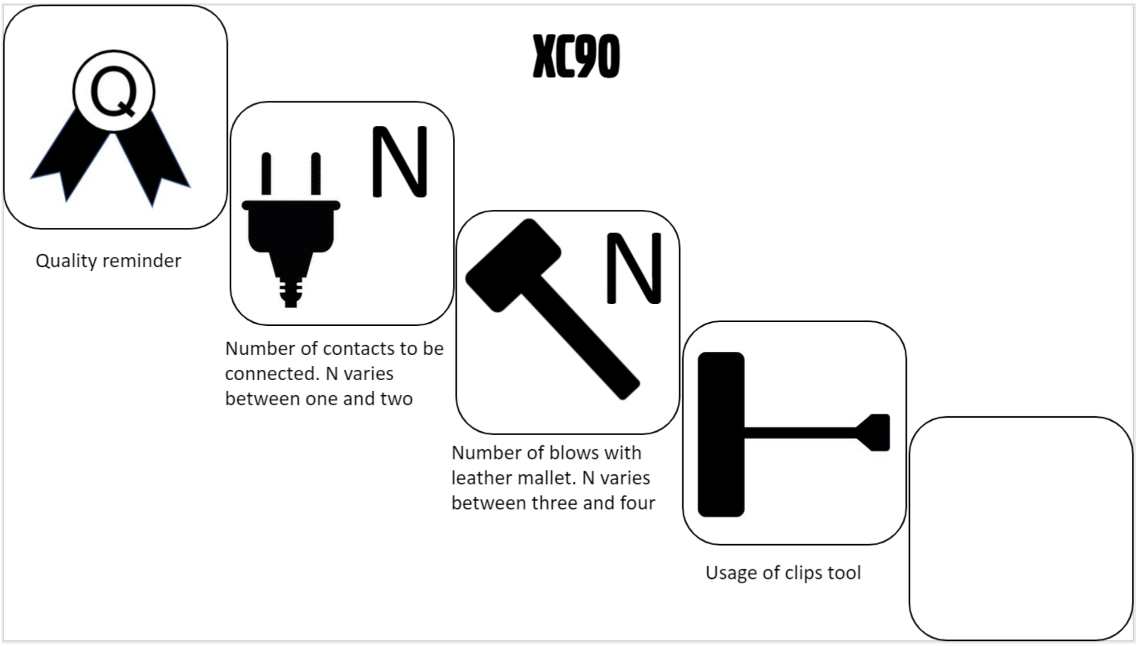

Figure 4.4: The created digital assembly instructions for Station L

4.3.3 Presentation of digital assembly instructions at stations

The digital assembly instructions will be visualized through screens located at the material racks, as can be seen in figure 4.5. The instructions will primarily be used in the beginning of the assembly, while the operators are fetching material. It was observed that it is common that operators finish assembling the car before it leaves the station, usually somewhere within area A seen in the figure, and begins assembly on the following car ahead of time. Thus, it was decided to not let the instructions follow the physical flow and instead show them slightly in advance. When the car is 0.5 meters from reaching station R and L, represented by a black line in the figure, the instructions for this car will be shown.

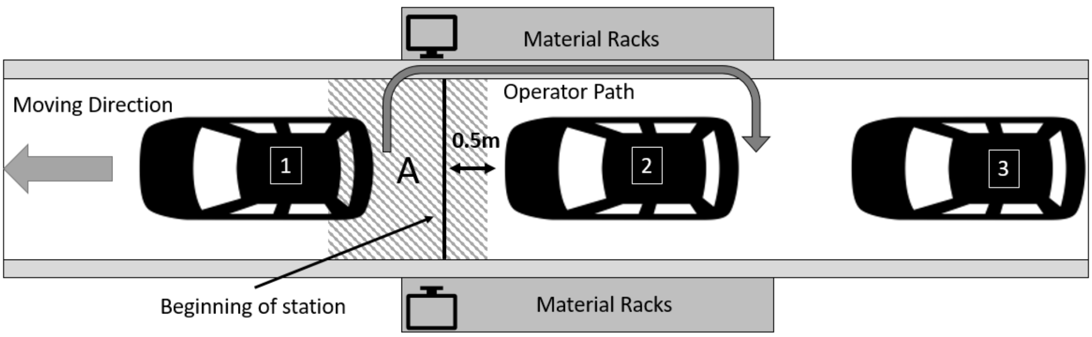

Figure 4.5: Layout of station R and L with placement of screens marked.

The operators will use the instructions as visualized in figure 4.6. This is the application of the digital assembly instructions at the line. As can be seen in step one, the operators are soon to be done with a car. Instructions will then appear, specific for the next car to be assembled, which can be seen in step two. This happens when the front of the new car is located 0.5 meters before the black line. The operators will when preparing for assembling the new car briefly look at the instructions while simultaneously fetching material needed for assembly, as can be seen in step three. In step four, the operators have started working with the new car and will know everything needed for assembly.

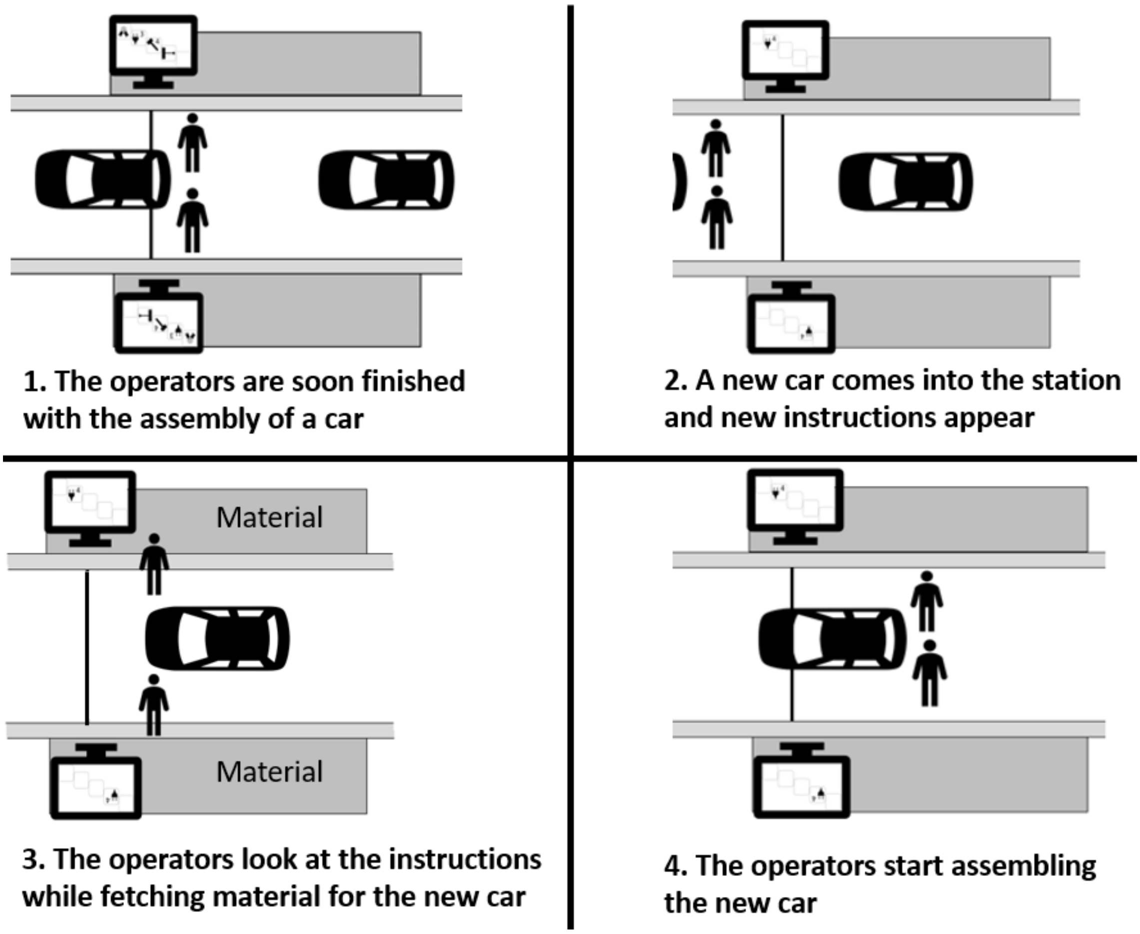

Figure 4.6: Operator interactions with digital assembly instructions

4.4 Evaluation of digital assembly instructions

This section presents the result of the evaluation of the digital assembly instructions. The evaluation is based on the evaluation from the expert panel, where the digital assembly instructions were graded from one to six based on the fulfillment of each criteria. As can be seen in table 4.7, the grading of the instructions related to the four criteria is around five out of six. This grading was further elaborated by the panel in a following discussion where the participants went in depth into the criteria.

Table 4.7: Grading on fulfillment of criteria

Criteria	**Avg. Grading (1-6)**
Timeliness	5.3
Accessibility	4.8
Comprehensiveness	5.1
Visual Design	4.8

Timeliness
The instructions are shown when the operators should obtain information about their assembly, which is in the beginning of each cycle. The panel pointed out that these operations are not performed immediately after the information is given, which could be problematic seeing as the information needs to be kept in memory for a period of time. The panel suggested that receiving information about an operation exactly when it is to be performed would be preferable, and described as more timely. However, it was also mentioned that due to the short cycle times it could be difficult to present information in a more timely manner.

Accessibility
The panel suggested no improvements related to the location of the screens. The height and angle of screens were mentioned as important matters for enabling good ergonomics while reading the instructions. The panel questioned if the current height and angle of screens were optimal, however the difficulty of finding a setting suited for all operators was brought up. Some suggested adjustable screens for solving this matter.

Comprehensiveness
What was discussed related to comprehensiveness was the possibility of complexity arising from the variants within the symbols of connection of contacts as well as usage of leather mallet. This, since the number of contacts to be connected and the number of blows with the leather mallet can vary from one to four. The argument was that it might be too much information with two different symbols showing two

numbers at once. However, when discussing the number memory abilities of the average person, it was concluded that the different numbers, their order and associated symbols, should not be a problem to remember.

The lack of information was also discussed. What was discussed here was the problems that would arise with the quality reminder symbol. This included the conclusion that the symbol itself did not give enough information about the operation to be performed, and that a complementary explanation would be needed when introducing the instructions.

Another aspect regarding lack of information that was discussed was the inability for the operator of knowing what operations that have been done. It was suggested by the panel that the comprehensiveness of information would be greater if the operators would know what information had been applied and what was left to do. This was regarded as difficult to achieve however as it would require some sort of confirmation system for the operator which would mean additional time consumption apart from the manual assembly work. This is not optimal in a fast-paced environment.

Visual Design

The symbols created are mostly based on realistic visuals of real objects. This was mentioned by the panel as a good thing as the visuals were good enough for the operators to easily recognise the connection of these symbols to the real world objects. A possible fatigue-effect from the same visuals being shown many times was raised as a concern. A suggested solution was more colour or varying visuals, which could remove this by varying the contrast.

Problems with the visual design was regarding the possible lack of self-explanation in some of the symbols. This was mainly the case for the quality reminder symbol, as it by itself does not indicate what operation is to be performed. Further implications are that the symbol requires an explanation before it can be understood and applied to the assembly work.

Another problem with the visual design that was raised by the panel was the possibility of mixing up the numbers of connection of contacts and usage of leather mallet. This related to the point that was discussed under comprehensiveness regarding complexity due to variation within these symbols. Similar conclusions were made that there should be no problems of remembering the number corresponding to its respective symbol along with the order of the symbols, thus there should be no chance of mixing up the symbols.

Ergonomics

The instructions are developed to support operators in ergonomics, both physical and cognitive. However the expert-panel did not see it likely that the digital assembly instructions would have any meaningful impact on physical ergonomics. The panel argued that this depends more on learned behaviour, and the general attitudes towards physical ergonomics present in the operator before using the instructions. The panel further explained that the choice to work with good ergonomics should be as attractive, if not even more attractive than choosing not to. This is not something that is possible to improve with the developed instructions according to the panel.

Improvement suggestions from the expert-panel to improve physical ergonomics was to include some sort of confirmation required by the operator that the ergonomic guidelines had been followed during assembly work. This was proposed either as a sensor detecting when the operator uses an ergonomic tool, or that the operator has to confirm on the screen that the ergonomic guidelines have been followed. This was concluded to be problematic however, as confirming the usage of ergonomic tools would require additional time consumption, which is not desirable in the fast paced assembly environment. The usage of sensors would also be problematic as the operator has the ergonomic tool hanging to the body at all times, which would require a sensor mounted on the operator in some way.

The instructions were believed to provide operators with a cognitive support. This is done by providing the operators with reminders that remove some of the load that is put on operators by having to remind variations. The instructions thus have a possibility of improving the cognitive ergonomics for operators.

Quality

To improve quality was regarded as the most fitting use for the digital assembly instructions. Many of the quality errors are a result of forgetting operations, rather than not knowing how to perform them. This is partly a result of the high variation in assembly operations. It was believed that a simple reminder of a certain operation would help the operator to remember to perform it to a higher extent, especially since the symbols were evaluated to effectively illustrate operations connected to common quality errors. This ultimately results in a reduction of the total number of quality errors.

5 Discussion

In this chapter the results are discussed. First, answers are given to the research questions, followed by a discussion of ethical aspects, quality of research, implications for industry and ultimately recommendations for future research.

5.1 Research questions

The two research question are a central part of this thesis and are answered in this section. The answer to these are based on an analysis of the evaluation of digital assembly instructions.

5.1.1 How do digital assembly instructions affect support for operators?

Based on the evaluation from the expert panel, it is likely that the digital assembly instructions will increase support for operators. This since the instructions were evaluated to be accessible, easy to understand, quick to apply and illustrative of the targeted operations. This suggests that the use of digital assembly instructions will require little to no additional time and effort from the operators, while simultaneously effectively reminding about operations connected to different quality errors in production. More precisely, this suggests that digital assembly instructions will increase support for operators in the sense that the operator will have an easier time identifying what operations to perform. By providing the operators with cognitive support, the digital assembly instructions has the possibility to reduce the complexity and thus also the mental load (Fast-Berglund et al., 2013).

The digital assembly instructions are however only believed to be able to remind operators of what they intend to do. If the operator deliberately performs an operation in a certain way, the digital assembly instructions are likely not able to change this behaviour. Furthermore, the instructions do also not confirm that an operator has performed the operations in the correct order. The confirmation system that was brought up by the expert panel would have the possibility of further increasing support for operators as it is a way of knowing what has been done. In the present environment, it is reasonable to dismiss this idea however due to the fast-paced nature of the assembly work, as it would only require additional time interacting with the instructions. This would mean less time available for assembly work, which in itself might reduce support for operators as they have less time to spend on the operation to be performed.

5.1.2 How do digital assembly instructions affect ergonomics and quality errors?

Based on the evaluation from the expert panel, it is likely that digital assembly instructions will reduce the number of quality errors. The instructions were evaluated to effectively illustrate operations that are connected to common quality errors. It is therefore reasonable to believe that the instructions will successfully remind operators about those quality errors, and thus the number of quality errors should reduce in production. However, as there has been no testing of the digital assembly instructions, no measurement of the effects on quality errors has been performed. The conclusion that the instructions will reduce quality errors cannot be drawn with certainty until the digital assembly instructions have been tested in production. The evaluation would have been more credible if quality errors had been measured after a time of using digital assembly instructions, and compared to the amount of quality errors before the implementation of instructions. This is therefore something that has to be done to fully answer this research question.

The cognitive support given through the digital assembly instructions is believed to reduce the mental burden on the operators. This is due to the operator having to keep less information about the different variations in mind. Information about these variations are instead given when needed. The cognitive ergonomics are thus improved in the operators.

Based on the evaluation of physical ergonomics, the digital assembly instructions will not affect this to any meaningful degree. The expert panel did not believe that physical ergonomic improvements would change only due to instructions, but that it instead is linked to the attitude and behaviour already present in the operator. During observations of operators in production, it could be seen that many of the operators chose not to use ergonomic tools even though they had been recommended to do so. This further supports the evaluation of the expert panel. To assume that these operators forgot to use their ergonomic tools and would change their ergonomic-related behaviour with reminders can be deemed as highly unlikely, unless the alternative was made attractive enough to encourage a change in the behaviour. Instead, it suggests that changes in physical ergonomic-related behaviour require additional actions apart from reminders.

A suggestion of using a system of confirmation, brought up by the expert panel, is a way of improving physical ergonomics. This kind of system might encourage improved ergonomic behaviour as the operator would then have to do this to proceed with the assembly work. This idea can be problematic in many ways however. Firstly it can be argued that such a system could still be abused so that it is possible to confirm the usage of ergonomics without actually doing so, for example confirming on a screen that an ergonomic tool has been used. An alternative would be having this system work in a way so that the operator actually has to use the ergonomic tool to proceed, however this would likely mean heavy restrictions as to how the operator can work. Restricting the operator in how to work in such a way might reduce motivation as it might give the operator a reduced sense of autonomy, which might ultimately reduce performance (Deci & Ryan, 2000). It might also make the operator feel less competent, if there is no trust that the operator has the competence to know in what order to perform the assembly work. This might further reduce motivation (Deci & Ryan, 2000). What has to be done to increase physical ergonomics likely goes deeper than using reminders in the form of digital assembly instructions, how this could be done is left to further research.

5.2 Ethical aspects

It was concluded by the expert panel that digital assembly instructions increase support for operators. Improved support for operators, through improved cognitive ergonomics, has the possibility to reduce the complexity in the assembly process. Reduced complexity will lead to reduced mental strains as well as reduced stress (Mattsson, 2013). Thus, there is an ethical incentive to implementing digital assembly instructions as they are likely to increase the overall well being of operators. It can therefore be argued that from a social sustainability standpoint, there are reasons for implementing digital assembly instructions even if there are no direct measurable performance benefits.

Digital assembly instructions likely imply the usage of visual information, such as symbols, as this was found to be optimal in a fast-paced assembly environment. The usage of symbols that are largely self-explanatory and related to the operation to be performed, can be deemed ethical. This, since symbols remove any possible language barrier that might exist among operators. This ensures that operators with different language skills get the same cognitive support from the instructions. This can be argued to be ethical, as operators with different backgrounds are able to work and and receive support on more equal terms.

5.3 Quality of Research

The quality of the performed research is of high importance. The results gathered are highly dependant on the quality of the methods used to create them. The results have in turn been analysed in order to develop instructions and to draw conclusions. The following section will discuss some of the possible issues due to the choice of methods in this thesis.

5.3.1 Selection of stations

It can be argued that the selection of two stations has given a limited understanding for to what extent digital assembly instructions are useful in the studied production system. The chosen stations are the two that were deemed most suitable. During the evaluation, it was concluded that the digital assembly instructions likely would have positive results on the performance on the two stations. This evaluation did however not show whether other stations would be affected in a similar way or not. Other stations might be more challenging to develop digital assembly instructions for and some might not even see any positive effects of it. The two stations chosen were also very similar, resulting in even less arguments for that there are other stations that would see a benefit. In a sense, this thesis has only shown that digital assembly instructions are useful on two very similar stations, in a production system with far more stations. What could have been done would be to choose one suitable station and one station where digital assembly instructions were deemed difficult to implement. This could have resulted in a more holistic understanding for the usefulness of digital assembly instructions for the production system. It can however also be argued that it is reasonable to start developing a concept for easy applications first, and then progressively develop this concept for more difficult applications. It can thus also be argued that this thesis has provided a good base in the evaluation of the usefulness of digital assembly instructions, where the beginning stages in the determination of the usefulness in final assembly have been covered.

5.3.2 Evaluation of digital assembly instructions

The evaluation of the digital assembly instructions was performed through the help of an expert-panel. The members of this panel were all knowledgeable within the area of assembly instructions and could provide interesting analyzes. This evaluation was therefore likely done based on widely accepted research, and should therefore mean that the usefulness of the digital assembly instructions was accurately evaluated. However, four out of six panel members, all except the practitioners from Volvo, had however not visited the two stations. The result of this was that they had a limited understanding for how the instructions were meant to be used on the stations. As pointed out by a member of the panel, this made it especially difficult for them to evaluate the instructions regarding timeliness and accessibility. These two criteria would be easier to evaluate by, while present at the location, testing how accessible the instructions are and whether the timing of them is correct. Although great effort was made to demonstrate and explain the intended use, it is not possible to create the same understanding that the experience from being at the two stations would have given. Therefore, it can be argued that the validity of the evaluation of these criteria is of lower standard than the remaining criteria. The other chosen criteria were not as affected by the limited practical experience however, so the evaluation by the expert panel of a majority of the criteria could be determined as accurate.

The operators at the two stations, which are the intended users, were not given the chance to evaluate the instructions. This has lead to many, possibly interesting results, not being able to be collected. One of these results is the reputation of the digital assembly instructions among operators. If the instructions would have a poor reputation, the operators would be less likely to use them (Haug, 2015). They would also be less likely to participate in further developing the digital assembly instructions. An evaluation of the instructions reputation among operators would be interesting during the development of the instructions. By including the operators in the evaluation, the criteria relevance would also be possible to evaluate. The operators would, with their knowledge about the assembly work, be able to evaluate to what extent the digital assembly instructions would have been useful for them, that is the relevance (D. Li et al., 2018). It is possible to draw some conclusions about this since the operators were largely involved in the creation of the instructions, where their insights into what could be included was taken into account. It could therefore be argued that even though the relevance for operators would have been interesting to study, there should be decent relevance present due to the involvement of the operators. In addition, the other four criteria included in the evaluation by the expert-panel, would also be interesting in an evaluation by the operators, as they will ultimately be the users of the digital assembly instructions.

5.4 Implications for industry

The automotive sector has been the primary focus in this thesis. The purpose was to develop and evaluate digital assembly instructions which in the future can be used to improve this industry. In the following section, the implications for industry are stated.

5.4.1 Cognitive support in final assembly

Digital assembly instructions are a way of providing operators with cognitive support. This in turn has the possibility to reduce complexity in final assembly (Fast-Berglund et al., 2013). The digital assembly instructions are real-time updated, which means that they only give the information that the operators need at the specific time. Thus, there is no need to search for information, which limits cognitive loads for operators. The instructions are also limited in the amount of information, which make it possible for the operator to quickly read them which further limits cognitive loads. Digital assembly instructions enable the industry to further customize their products while still enabling high production quality, with the help of cognitive support.

5.4.2 Reduction of quality errors in final assembly

The digital assembly instructions are, as previously explained, believed to be especially effective in supporting operators in quality. This is of great importance in both production efficiency (Hossain & Sarker, 2016) and for customer satisfaction (Bellgran & Säfsten, 2009). The implications for industry will therefore be that digital assembly instructions both will help ensure future good customer relations as well as ensuring production efficiency. The importance of production quality is largely based on the possibility of reducing waste. Every quality error results in some type of waste as a wrongly assembled component needs to be fixed and this requires time and resources (Hossain & Sarker, 2016). Digital assembly instructions will likely minimize the waste and thus highly improve the production quality overall.

5.4.3 Removing the language barrier in final assembly

As previously discussed in the section regarding ethical aspects, using digital assembly instructions in the form of symbols will remove the language barrier among operators as the symbols are self explanatory and illustrate the operation to be performed. This means that operators from different cultures, speaking different languages, will have an easier time to learn and understand the operations to be performed than if the instructions are in a language that might not be familiar or fluent to the operator. This might have effects on both the industry and the society as a whole, where people from different cultures can easier be employed in assembly work.

5.5 Recommendations for future research

Although this thesis extensively analyzes digital assembly instructions, there is room for improvement. This section states areas where it is recommended to perform additional actions or further research.

5.5.1 Test digital assembly instructions in production

The digital assembly instructions developed in this thesis were not tested in production. The reasons were unexpected disruptions of the production, caused by certain global circumstances out of control. A test of the concept in a real production system is therefore highly recommended for future research. Many important aspects of the digital assembly instructions will only be possible to evaluate with absolute certainty through a test. One aspect is the effects of digital assembly instructions on the total number of quality errors, which could be determined by comparing data gathered before and after implementation of the instructions. The conclusion in this thesis was that digital assembly instructions will reduce the number of quality errors, however better conclusions will be able to be drawn regarding this connection by measuring quality errors before and after an actual test of digital assembly instructions for an extensive period of time.

Another aspect that would be interesting to study is the effects on physical ergonomics of digital assembly instructions. The conclusion in this thesis was that digital assembly instructions will likely have an effect, however the actual result might be different in an actual test of the instructions. Furthermore, if digital assembly instructions are found not to affect physical ergonomics, it would also be interesting to study alternative actions that would lead to an increase in physical ergonomics.

5.5.2 Develop digital assembly instructions for a wide variety of stations

An additional recommendation before testing the usefulness of digital assembly instructions is to develop them for a wide variety of stations. Meaning, stations deemed both suitable and difficult to implement digital assembly instructions for, as this would give a more holistic view on how suitable the concept is in a final assembly environment. Further implications when such a holistic view has been given, is that better conclusions will be able to be drawn regarding what types of stations that would benefit from digital assembly instructions.

6 Conclusions

Digital assembly instructions have been developed and evaluated for operators in the final assembly of the automotive sector. The instructions will support operators through a cognitive support in their increasingly complex assembly environment. The support consists of reminders highlighting variations and important tasks through simple symbols. These symbols are presented in real-time, and show what the operator needs to remember for the particular car variant coming in to the line. An evaluation has shown that the digital assembly instructions have a high information quality. It also showed that the digital assembly instructions have the possibility to reduce quality errors in production and to improve cognitive ergonomics, however with a limited impact on physical ergonomics. Digital assembly instructions are excellent in environments of mass customization, as it acts as cognitive support of operators helping to handle short cycle times and large product variations. This makes digital assembly instructions a valuable tool for helping manufacturing companies stay competitive in a dynamic environment.

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A

Interview structure for creation of instructions

Confidentiality
This interview is confidential, meaning that your answers will not be possible to connect to you and it will not be mentioned that you have been interviewed in the report. However, your name will be noted in order to know who have been interviewed.

1. What is your first and last name?
2. Do you have any question before we proceed?

Background to interview and project
The goal of this project is to create instructions which will support operators in assembly. Thus, making the work easier. This interview aims to collect your suggestions and thoughts on how this can be achieved. This information will then be used during this thesis for creating instructions. Thus, your answers will have the possibility to greatly affect the end result.

This thesis builds on an earlier thesis. In this, a concept for how digital instructions could be presented was determined. The instructions will be visualized through screens located at the stations. These screens will show simple symbols containing information useful in the assembly work. The instructions aim to highlight variations and important tasks. In this thesis, this concept will be tested at two stations; H and V.

3. How long have you been working in the TC-plant?
4. How long have you been working at the two stations; H and V?
5. Do you have any previous experience of assembly work before this?
6. What characterise the two stations?
7. What do you think about the level of difficulty for the two stations?
8. What is leading to difficulties on the two stations?
9. Do you think that the concept explained earlier could be useful on the two stations?
10. For what operations do you think that this concept can be used?
11. How would you like to design symbols for these operations?
12. How do you get information about these operations today?

Ergonomics

This interview aims to collect information about how ergonomics can be included in this concept.

13. What do you think about the workload at the two stations?
14. Do you think that the stations are designed in a good way regarding ergonomics?
15. Do you think that the concept could be useful regarding ergonomics?
16. For what operations could the concept be used regarding ergonomics?
17. How do you get information about ergonomics today?

Placement of thin clients

In order to be able to use this concept, the thin clients must be placed at good locations at the stations.

18. Were do you think that the thin clients should be located at the stations?
19. What are the benefits of placing the screens here?

B

Expert panel questionnaire

Evaluation of information at line for station H and V
This questionnaire is connected to the four criteria found important for information quality.

Timeliness

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1. The information presented is when it is needed.

Incorrect | | | | | Correct
☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6

Accessibility

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2. The information is presented at a location where it is accessible in the assembly.

Incorrect | | | | | Correct
☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6

Comprehensiveness

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3. The right amount of information is presented.

Incorrect | | | | | Correct
☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6

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4. The information is easy to understand.

Incorrect | | | | | Correct
☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6

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5. The information can quickly be obtained.

Incorrect ... Correct

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Visual Design

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6. The symbols are self-explanatory.

Incorrect ... Correct

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

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7. The symbols are easily distinguished.

Incorrect ... Correct

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
