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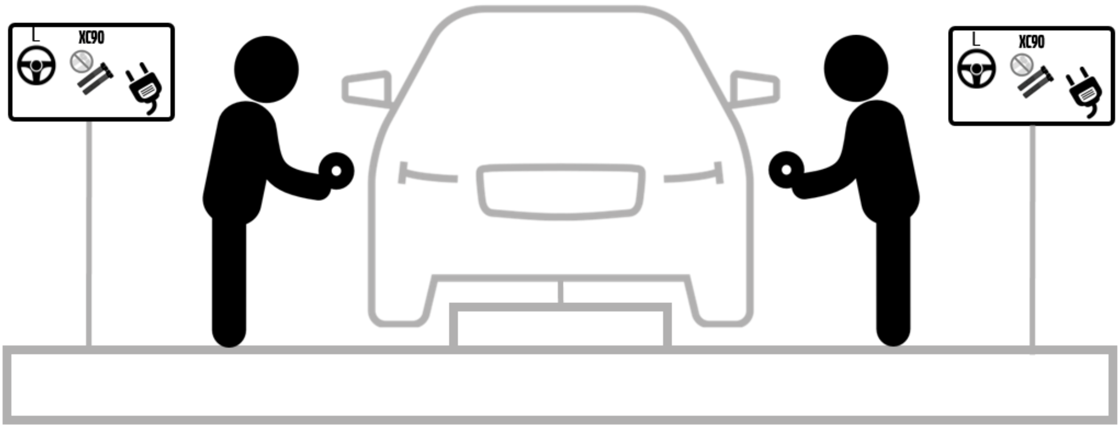

Digitalisation of Work Instructions, Coaching and Quality Follow-Up

Master's Thesis in Production Engineering

ANNA PALMQVIST
EMELIE VIKINGSSON

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

MASTER'S THESIS 2019

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ANNA PALMQVIST
EMELIE VIKINGSSON

Supervisor: Dan Li, Industrial and Materials Science
Supervisor: Niklas Lund, Volvo Cars Torslanda
Examiner: Åsa Fast-Berglund, Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Illustration of two operators assembling a car and using the digital work instructions intended for running production.

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Abstract

The demand for high quality, customised and priced worth products is increasing, pushing production towards mass customisation. The complexity of production systems increases as well as the complex work environment for the operators. The perceived complexity of a system can be reduced by supporting cognitive processes with effective and simple information presentation, while at the same time increase operator performance and satisfaction. With decreasing takt times, it sets different requirements on how and what type of information should be presented to be able to support the operator. This thesis, therefore, investigates, evaluates and creates a prototype visualising a system which presents digital work instructions in a mixed model final assembly with a low takt time of about one minute.

The main focus of the thesis is to develop a system with corresponding digital work instructions for its end-users, the operators. By applying a mixed methods approach, an understanding of the operators' need for two types of digital work instruction was established. The first type, on-line work instructions, are simplified instructions which are presented when the production is running. The second type, off-line work instructions, are more comprehensive instructions which are available when the production is not running.

The best-fitted format for on-line work instructions are real-time updating variation symbols and for off-line work instructions are videos. By using two types of work instructions, the operators can find information which is both simplified and supportive but also detailed and explanatory. The collaboration with operators during the system development will increase the probability of the system being used, leading to standardised work and enhanced product quality.

Keywords: Digitalisation, Work Instructions, Assembling Operator, Takt Time, Final Assembly, Mixed Model.

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Anna Palmqvist and Emelie Vikingsson, Gothenburg, June 2019

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Acronyms

AR Augmented Reality.

CAD Computer Aided Design.
CID Car Identification.

FTT First Time Through.

GIF Graphics Interchange Format.

IoT Internet of Things.
IQ Interview Focus Questions.
IT Information Technology.

LoA Levle of Automation.

MSD Musculoskeletal Disorders.

OIS Operating Instruction Sheet.
OP Operator.

RFID Radio-Frequency Identification.
RQ Research Questions.

SR Safety Representative.
SSI Simplified Station Instructions.
SV Supervisor.

TC Torslanda C-Factory.
TL Team Leader.
TMU Time Measurement Unit.
TPS Toyota Production System.

VCC Volvo Cars Corporation.
VCMS Volvo Cars Manufacturing System.
VCT Volvo Cars Torslanda.
VR Virtual Reality.

WES Work Element Sheet.

Glossary

atacq A comprehensive operator feedback system developed in-house at Volvo Cars Ghent and used globally.

cognitive Relating to or involving the processes of thinking and reasoning.

digitalise Using the digitised information in a smart way to develop the company.

digitise Converting existing information from a analogue format into digital format without changing the information.

information control An internal information message sent to specific assembly lines or the whole factory. It could contain any type of information.

knowledge matrix A table with an operator's personal operator feedback history and experience level.

off-line work instruction A work instruction which is used when the operator is not standing on the line and production is standing still. The interpretation time is long.

on-line work instruction A work instruction which is used when the operator are standing on the line and productions is running. The interpretation time is short or limited.

one-piece errors Assembling errors which occurs a maximum of one time per shift.

operator feedback The feedback an operator gets after they have assembled something wrong.

running production When the assembly line is moving and the operators are working on the product units.

smart factory A factory which is fully connected and flexible which can react to rapid changes.

system A number of components which operates together towards a common goal.

takt time The average time between the start of production of one unit and the start of production of the next unit at one station. The starts of production should match the rate of customer demand.

1 Introduction

The introduction covers the Background of the thesis with existing research and literature. It also describes the Purpose of the thesis as well as the Scope and Delimitations. The introduction finishes with the formulation of Research Questions and a Case Description.

1.1 Background

Customers are today demanding more customised products, which results in an increased amount of possible product combinations and thereby more complex production systems (Fast-Berglund & Mattsson, 2017). At the same time quality, deliverability and cost are also important aspects for the customers, which makes the demand for mass customisation higher (Olhager, 2017), see figure 1.1. An effect is that companies using flow lines are forced to start using mixed model assembly to be able to deliver towards the new demands (Zeltzera, Aghezzaf, & Limèreb, 2017). A consequence of mass customisation is the difficulty for companies to decrease the complexity of their production and still be able to be competitive on the market (Mattsson, Fast-Berglund, & Stahre, 2014). Complexity in a system can be defined as a system which is "difficult to understand, describe, predict or control" (Sivadasan, Efstathiou, Calinescu, & Huatuco, 2006, p.209).

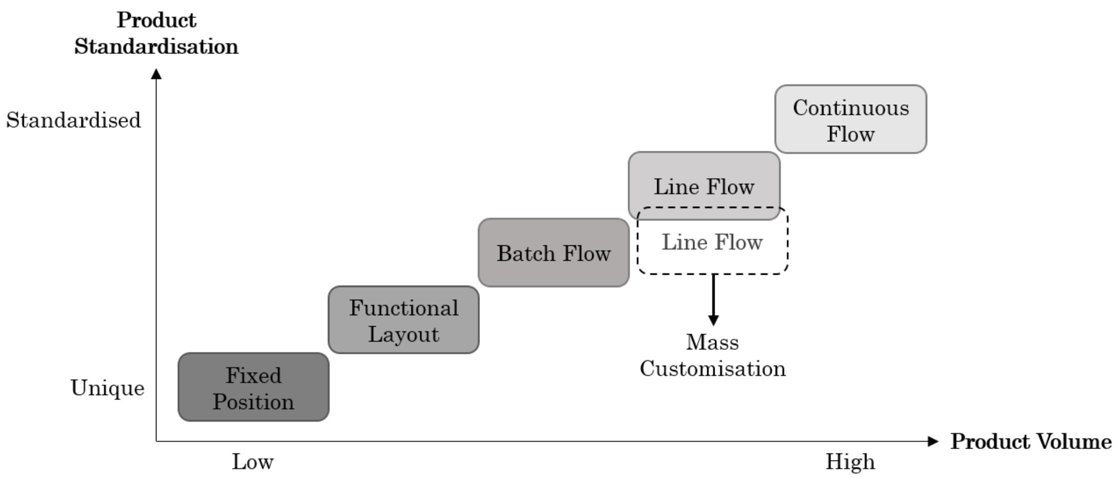


Figure 1.1: Adapted illustration of the relation between product type and production processes due to consequence of mass customisation (Olhager, 2017).

Automotive industries are often divided into three separate factories with different demands on flexibility. The factories with lower demands can be highly automated, such as body-shops and paint-shops. However, final assembly often demands higher flexibility, leading to mostly manual work in these factories (Fast-Berglund & Mattsson, 2017). Customised final assembly results in operators working in a complex production system, the perceived complexity can, however, be reduced. This by supporting cognitive processes and simplifying the way information is presented to the operators, resulting in saved time, increased performance and higher operator satisfaction (Mattsson et al., 2014).

Independent of the experience level of the operator, the operator will encounter situations where they are not familiar with the assembling tasks (Söderberg, Johansson, & Mattsson, 2014). These situations can occur when a new product variant is introduced and the operator will, in these situations, rely on support from colleges, experts or available work instructions to be able to perform the task. The performance will thereby be affected by the quality of the received support (Söderberg et al., 2014). Work instructions have the benefit of providing a standardised way of working, but work instructions are not used as they should in many industries. The reason is often the poor quality of the work instructions or that the instructions contain too much irrelevant information (Söderberg et al., 2014).

For industries, to be able to have a production system which is flexible enough to produce mass customisation, Industry 4.0 is a key aspect (Devezas, Leitão, & Sarygulov, 2017). Moving towards Industry 4.0 will also create a more dynamic company which easier can react to changes in customer demands (Schuh, Anderl, Gausemeier, Hompel, & Wahlster, 2017). Many companies are currently trying to implement the first step of Industry 4.0; Computerisation (Zeller, Hocken, & Stich, 2018). Computerisation means that different technical information solutions are implemented into the existing production system (Schuh et al., 2017). A recent trend in production facilities, in order to move towards computerisation, has been to present work instructions with the help of a computer or a screen located at the work stations (Berlin & Adams, 2017). The operators gain the necessary information from the screen which could provide instructions in both text, pictures, and sound (Berlin & Adams, 2017). Nevertheless, when the takt time is about one minute in final assembly, it sets different demands of the simplicity and availability of the instructions presented. It is therefore important to investigate digital work instructions for takt times of about one minute when the demands for quality, deliverability, cost, and flexibility in the automotive industry continuously increases.

1.2 Purpose

The purpose of the thesis is to use an operator-centred approach when investigating, evaluating, and illustrating a system which will support the operators in a production environment. The system should increase cognitive support and the quality of the produced products in a mixed model final assembly production with takt times of about one minute.

1.3 Scope and Delimitations

The existing production system was not changed due to company restrictions, meaning the way to assemble or its order was not modified. Therefore, the solution only targeted how to design and present work instructions for the existing production system.

Continuing, a functional software was not developed due to the complexity of the existing data structure at the company. Therefore, the scope included developing a conceptual model for the system instead.

The built prototype was not tested during running production as this may have disturbed the production. Instead, a prototype operating offline was built to prove and illustrate the concept of the solution. Finally, the solution only targeted educated operators since it was assumed that the personnel gets a proper education before they started assembling on their own.

1.4 Research Questions

The aim of the thesis is concluded in two research questions. The questions are answered throughout the report with the help of the selected methodology. The research questions apply to a mixed model final assembly system in the automotive industry with a takt time of about one minute.

RQ1: Which possibilities and limitations are currently existing for implementing digital work instructions?

RQ2: How can a system including digital work instructions, coaching and quality follow-up be designed?

1.5 Case Description

Volvo Cars Corporation (VCC) is today designing, manufacturing and selling cars in the premium segment. Volvo Cars Torslanda (VCT) manufactures the models XC90, XC60, V90, V90CC, V60, and V60CC. Around 5'000 employees are working at VCT and together they deliver around 300'000 cars per year, approximately one car is built each minute. The final assembly is performed in the C-factory (TC), which has around 2'500 employees, divided upon three shifts and around 500 stations. To limit the size of the thesis, two stations from the same line was selected as the target stations. The stations were named α and β, and they contain both manual and automated work tasks.

Each assembly line has a supervisor (SV) who is responsible for a handful of teams. Each team has one team leader (TL) and around eight operators (OP), which are doing the majority of the assembling work. The work structure is illustrated in figure

1.2. As a complement, each assembly line has its own Safety Representative. The safety representative (SR) is normally an operator who has a more comprehensive responsibility making sure the company is following the Swedish work environment laws.

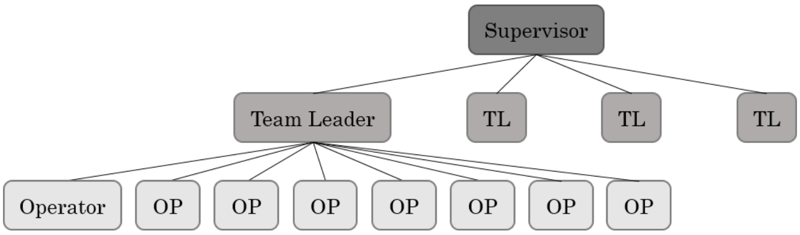


Figure 1.2: Relation between supervisors, team leaders, and operators in TC.

VCC has decided to develop their own production system, Volvo Cars Manufacturing System (VCMS), whose design is influenced by lean production. VCMS follows five key concepts; Teamwork with Involvement, Stability through Standardisation, Right from Me, Demand Driven Flow, and Continuous Improvements. It can be seen that VCMS is influenced by the Toyota Production System (TPS) by its similarities, such as common lean tools and their core values. The advantage of developing their own version of TPS is that it is adapted to the existing culture at VCC and has been developed with the company's employees in focus.

Different types of changes are applied to the operators' tasks in the final assembly every day, the common denominator is that they are all processed fast. Every station in the final assembly has its own Operating Instruction Sheets (OIS), stating the working order, where key activities have a Work Element Sheet (WES), which states how the activities should be performed. The OIS:es and WES:es are today in paper format and are currently placed in a cabin which is not easily available for the operator during running production. However, each team has a team computer with access to the information.

Every operator is part of an education program before they are allowed to work during running production. The quality of the work is measured using First Time Trough (FTT), where the majority of the errors are represented by one-piece errors. Every car has its unique Car Identification (CID), making it possible to track the cars in the factory to a certain location.

There have not been any previous attempts to include digital work instructions in TC as the project has been seen as "too big" to realise. Nevertheless, the company thinks that including more cognitive support in their mixed model assembly will increase the quality. One assembly line was chosen as the target for the thesis, where two specific stations were selected. The targeted line has made tries to present the work instructions in a better way. Each station has today Simplified Station Instructions (SSI) which presents main activities, equipment to use and the current working order. The SSI are big papers suspended beside each station which gives the operators the possibility to gain necessary information about the work station.

2
Frame of Reference

The chapter states relevant theory for the thesis. Various areas of literature have been reviewed and key points summarised to create the Frame of Reference. The content of each sub-chapter will lay the foundation for the different areas of the thesis. The chapter starts at a broad perspective with Production Systems and works itself down to a narrow perspective with Digital Instruction Presentation.

2.1 Production System

When producing a product or service, despite the end customer or type, the production process will be part of a larger system. A system can be defined as an organisation of personnel, various machines, and selected methods that are able to perform actions towards common goals (Bellgran & Säfsten, 2010). A production system can, moreover, be seen as a transformation system with different inputs and outputs (Bellgran & Säfsten, 2010; Olhager, 2017; Wu, 1994), see figure 2.1.

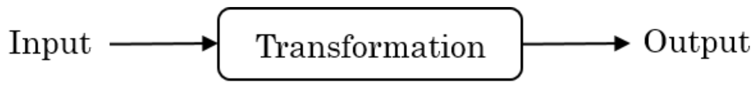


Figure 2.1: Adapted illustration of a simplified Transformation System (Bellgran & Säfsten, 2010).

The output from one system may be the input to another, and the actual transformation is represented by black boxes which may contain any type of content (Wu, 1994). Olhager (2017) describes the transformation system in a more extended way. The system then includes feedback loops from both customers and the system itself, see figure 2.2. The feedback is given at any time when information about the output can be used to develop the operations of the transformation (Wu, 1994).

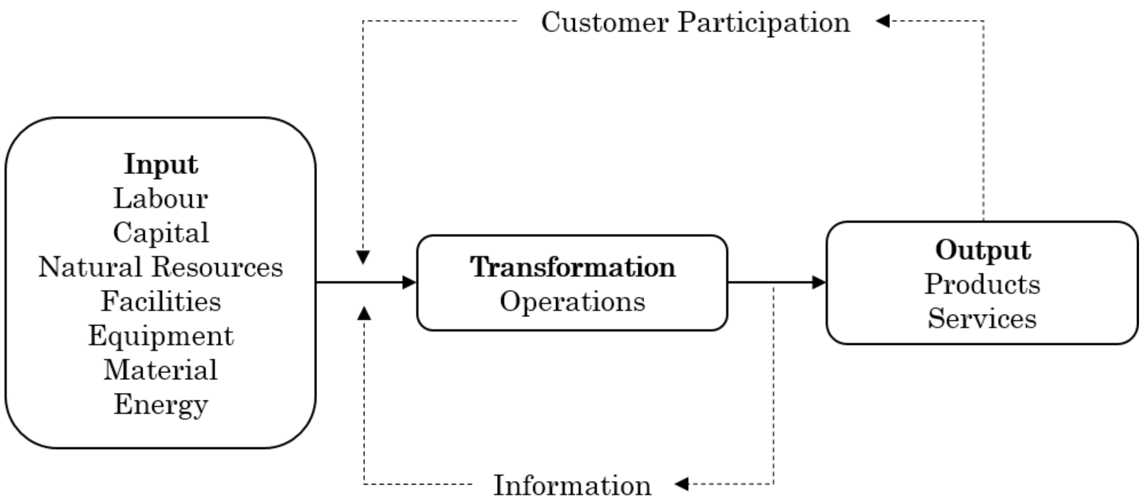


Figure 2.2: Adapted illustration of a Transformation System with feedback loops from the system itself and from customers (Olhager, 2017).

Systems are hierarchical by nature and system boundaries can be drawn at different levels depending on the level of detail needed. Everything outside the boundaries is seen as the external environment (Wu, 1994). Despite where the lines are drawn, the production system will always be at the centre with supporting functions subordinated at different levels in the external environment (Olhager, 2017).

2.1.1 Assembly Line

An assembly line is a system with a sequence of stations, in which product units are transported through without backtracking (Baudin, 2002). One of the first assembly lines were designed and used by Henry Ford when producing the Model-T Ford (Bellgran & Säfsten, 2010; Bidanda, Sunanta, Carnahan, Billo, & Minnich, 2001). To be classified as an assembly line the units need to be processed in a one-piece flow, if batches are applied it may not be called an assembly line (Baudin, 2002). The direction of the flow does not affect the definition of an assembly line, operators can also work on both sides of the product unit. Assembly lines can generate a positive gain in both productivity and quality if there are an appropriate volume and level of customisation (Baudin, 2002). Nevertheless, they are often seen as controversial compared to functional layouts if the volume is too low, have too high customisation or the work performed by operators is not appreciated (Baudin, 2002).

2.1.2 Mixed Model Assembly

The traditional mass production in the automotive industry is moving towards mass customised production as the manufacturers try to keep high customer satisfaction (Zeltzera et al., 2017). Therefore, the concept mixed model assembly lines are used to be able to assemble a wide range of varying components even if the base models are the same (Bidanda et al., 2001). The complexity increases when a large number of models with different variants are being assembled at the same line (Fast-Berglund & Mattsson, 2017; Zeltzera et al., 2017). This will require more effort and quality in coordinating material, planning the production and balancing the work tasks compared to using a functional layout (Bellgran & Säfsten, 2010). The enhanced complexity further increases the risk of the operator not being able to finish all the work tasks within the takt time (Zeltzera et al., 2017).

2.1.3 Lean Production

The terminology Lean was firstly found in the 1980s with principles from Japan and TPS (Bellgran & Säfsten, 2010). The four key principles in lean production are Continuous Improvements, Respect for People, Eliminate Waste, and Create Value for End-Customers (Emiliani & Stec, 2005; Liker, 2004). Liker (2004) describes TPS as an iceberg where only the tip, its tools, can be seen from the outside, but under the surface hides the actual cultural change. Aspects which are included in cultural change are how involved people are in continuous improvement and how companies become a learning organisation. It is not empowered to implement existing concepts and tools directly from TPS since all organisations have different prerequisites (Liker, 2004). Despite this, it is often interpreted that only by implementing various lean tools an organisation will "become" lean (Emiliani & Stec, 2005). Leaders should instead focus on the culture within the company as a lean transformation is a continuous journey with no finish line (Emiliani & Stec, 2005).

Standardised Work

When working standardised all operators work according to a predefined optimised way, meaning there is not an infinite number of ways to perform a task (Berlin & Adams, 2017). If operators work standardised the way of working will be stored in their long-term memory. It will take less energy and time to perform, but can also work as a cognitive support for the operators (Berlin & Adams, 2017). Using work instructions will increase the level of standardised work (Söderberg et al., 2014). Benefits of working standardised are guaranteeing high quality, keeping the takt time in production as well as developing a basis for continuous improvements (Olhager, 2017). To be able to achieve a standardised production, the used methods must be trustworthy and suitable to the processes and personnel (Olhager, 2017).

Andon

While applying a lean production philosophy, building correctly the first time is of great importance since few buffers can be relied upon and problems could potentially shut down the line (Liker & Meier, 2006). A system for controlling this is the andon system, used to indicate, with flashing lights and/or sounds, when an operator is in need of help (Liker & Meier, 2006). This is done by an operator pushing or pulling an andon button to get their team leader's attention and help. The team leader has until the part moves to the next station to help with the problem, otherwise, the line stops until the problem is fixed (Liker & Meier, 2006). No shame should be put on the operator for using the andon system, and if it is used correctly the line should not have to stop as the quality problems should be solved right away.

Continuous Improvements

In the concept of Lean Production, continuous improvements can be seen as a culture within the company, making the employees strive to always improve and develop their work (Liker & Meier, 2006). The employees' work should develop the company's processes in various ways, which can only be made if the processes are stabilised and standardised (Liker & Meier, 2006). One way of working with continuous improvements is through improvement events, involving employees to do some kind of improvement which has a qualitative or quantitative benefit for the company such as money savings, work process development, or waste elimination (Chan & Tay, 2018).

Pick-By-Light

Confusion between parts is a common reason for errors in assembly, especial as the variation between parts increases due to mass customisation (Baudin, 2002). One way of reducing the risk for this kind of errors is to use a Pick-By-Light system. The system gains the operator attention by lighting a LED-light close to the correct bin, it can also indicate quantities to pick (Baudin, 2002). The operator may confirm the pick by touching a button, pulling a cord, or activating a sensor. Except for reducing the likelihood of wrong picks, the system may decrease the picking time as the operator do not have to search for the correct item (Baudin, 2002). Variations of pick-by-light have been developed as companies have different needs and environments to adapt to. Pick-by-light should not be confused with Poka Yoke.

Poka Yoke

The concept of Poka Yoke is built upon the belief that no person wants to do mistakes, but despite this, they occur for various reasons anyway (Liker & Meier, 2006). At Toyota they do not see an error as a mistake made by a person rather a fail of the system or the method used (Liker & Meier, 2006). Therefore, poka yoke is a strategy to develop tools and components together which makes it impossible to assemble them wrong (Baudin, 2002). An example of a poka yoke solution is different shapes of a hole, making it impossible to place a part in the wrong direction when assembling it.

2.1.4 Level of Automation

Level of Automation (LoA) within manufacturing is defined as "The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic" (Frohm, Lindströn, Winroth, & Stahre, 2008, p.18). LoA is divided into two categories with seven levels each; Physical Automation and Cognitive Automation (Fast-Berglund & Mattsson, 2017). The levels are presented, including its characteristics, in figure 2.3. Physical automation is defined as “Technical solutions helping the operator to assembly the products e.g. WITH WHAT to assemble” and cognitive automation as “Technical solutions helping the operator e.g. HOW to assemble (Levels 1-4) and situation control (Levels 5-7)” (Fasth, 2012, p.53).

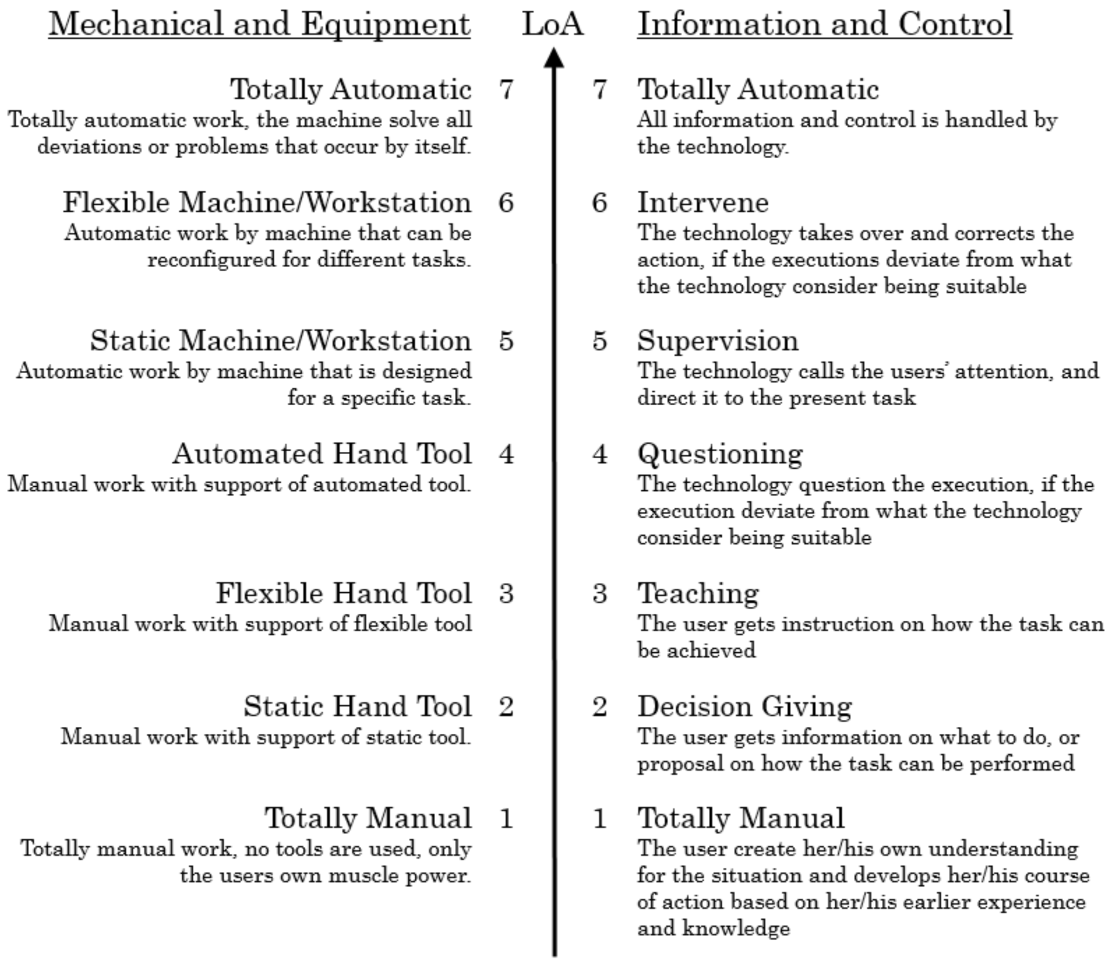


Figure 2.3: Adapted Level of Automation-scale (Frohm et al., 2008).

It has been evidenced by studies, that 90% of the work tasks in final assembly have physical automation which is level 1, totally manual (Fast-Berglund & Mattsson, 2017). 76% of these are based on the operator’s own experience and therefore have a cognitive automation which is also level 1, totally manual (Fast-Berglund & Mattsson, 2017). In the automotive industry, it is common that companies start to focus their work on physical automation rather than the cognitive one as work tasks may harm the operators physically (Fast-Berglund & Mattsson, 2017).

2.2 Industry 4.0

Devezas et al. (2017) present that the concept Industry 4.0 first appeared in 2011 at Hanover Fair, as a concept for the high-tech industry in Germany. In April 2013 was a report finalised by a German group working with Industry 4.0 (Kagermann, Wahlster, & Helbig, 2013) which defined the characteristics of Industry 4.0. The definition included a strong customisation of products while at the same time have a flexible mass producing system. Requirements for achieving this was self-organised systems that could create a suitable linkage between the real and virtual world (Devezas et al., 2017). Industry 4.0 is named after the three other industrial revolutions which have changed the industry for the past centuries; Mechanisation, Electricity, and Information Technology (IT) (Gilchrist, 2016).

There are three main characteristics of Industry 4.0 (Kagermann et al., 2013; Ustundag & Cevikcan, 2018);

1. **Vertical Integration and Networking of Manufacturing or Service Systems**
   Different hierarchical levels of an organisation get cross-linked and digitalised in an intelligent way.

2. **Horizontal Integration via Value Chains**
   Horizontal Integration enables the transformation to a smart factory, where the factory can be flexible and produce more customised products.

3. **End-To-End Engineering of the Overall Value Chain**
   This refers to product development including digital support as well as costumer requirement, product design, maintenance, and recycling.

So far, no company has successfully aligned with Industry 4.0 (Schuh et al., 2017). The reason has been that companies only have performed test projects and thereby overlooked the key aspects of integration, company culture, and organisational structure. There are also problems in the flexibility of the production system as well as product development, making it difficult to proceed with major changes. When moving towards Industry 4.0 it enables a better understanding of how different components are connected enabling the company to be more dynamic and reactive to customer demands (Schuh et al., 2017). Industry 4.0 creates an opportunity for companies to apply more agile working methods, one of its biggest opportunities. Working agile has become one key feature for successful companies as it enables faster changes (Schuh et al., 2017).

2.2.1 Industry 4.0 Maturity Index

Schuh et al. (2017) have developed a maturity matrix within the area of Industry 4.0, defined by six stages in Digitalisation and Industry 4.0, see figure 2.4. The matrix has then been complemented with Pre-Industry 4.0 by Li (2019), which has two stages.

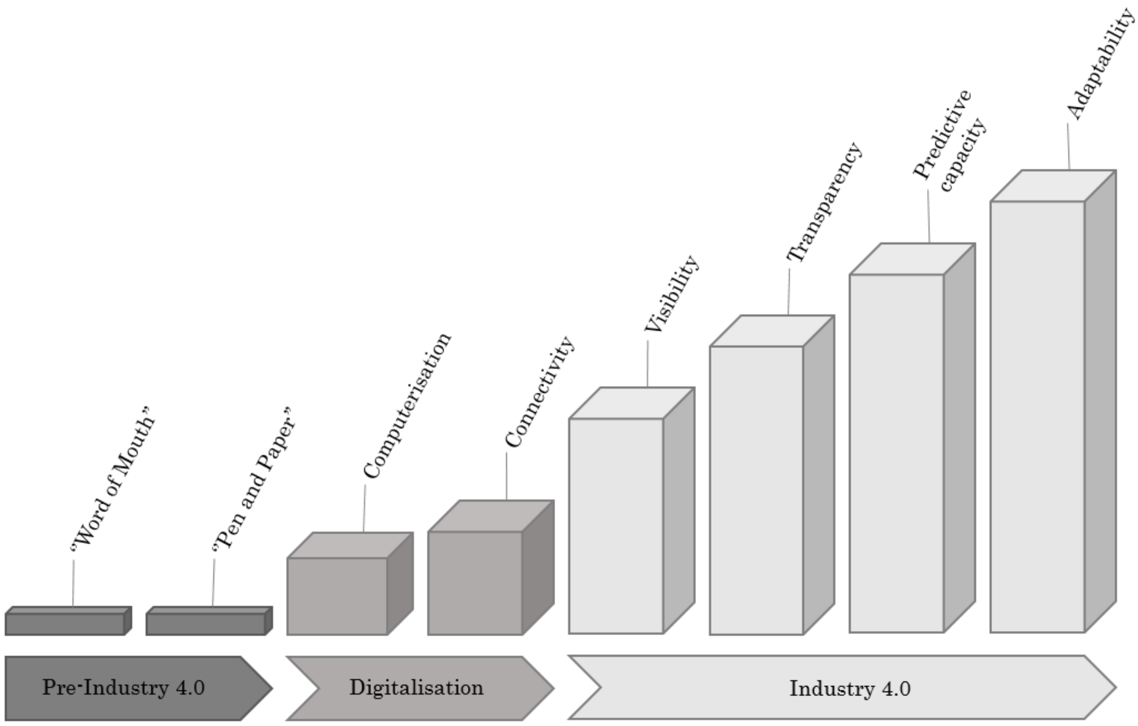


Figure 2.4: Adapted Maturity Index for Industry 4.0 (Li, 2019).

Pre-Industry 4.0

Word of Mouth and Pen and Paper are methods used in industry before moving towards digitalisation. The communication is done orally or written in these stages (Li, 2019).

Digitalisation

Computerisation is the starting point for digitalisation and means that different technical information solutions have been used, but they are not connected to each other (Schuh et al., 2017). Many companies have progressed and implemented this step of digitalisation. Computerisation has the benefits of enabling cheaper manufacturing at a higher standard (Zeller et al., 2018).

Connectivity entails that the different technical information solutions are connected and together make a digital system, also known as Internet of Things (IoT). Connectivity enables manufacturers to perform remote maintenance on products and monitor the manufacturing system in real time (Schuh et al., 2017).

Industry 4.0

Visibility implies that with the help of different technologies a company can be recorded in real time, making it possible to keep up-to-date digital models of factories at all times, i.e. a digital shadow or digital twin. A digital shadow can enable the management to do decisions based on real-time values (Schuh et al., 2017; Zeller et al., 2018), one of the fundamental keys for later stages in Industry 4.0 (Schuh et al., 2017). The problem with accomplishing visibility is that many companies have different systems which are not integrated and combined into one source. The captured data is furthermore only available for a limited amount of people and are often difficult to understand. A reason is that many companies perform specific analysis for one problem or task instead of an overall digital shadow which could perform different analyses (Schuh et al., 2017).

Transparency can be achieved by using digital shadows as means for analyses of root causes to problems (Schuh et al., 2017; Zeller et al., 2018). To do this, engineering knowledge and big data tools need to be able to properly analyse the huge amount of data generated by such a system. Transparency will, among other things, enable condition monitoring of machinery and equipment (Schuh et al., 2017).

Predictive Capacity implies that a company can simulate and analyse future scenarios to evaluate which scenario is most likely to occur. The result can be used to make decisions and take actions in precaution. The precautions still need to be initiated manually but have the possibility to reduce disruptions (Schuh et al., 2017; Zeller et al., 2018).

Adaptability enables a company to automatically react to expected scenarios (Zeller et al., 2018). It is important to asses the risk in automatic decisions making for each kind of decision. The final goal is to be able to use the data from the digital shadow to assess which scenarios are most likely to occur and then perform suitable automatic actions as fast as possible (Schuh et al., 2017).

2.3 Motivation and Feedback

The world is constantly changing, why companies' successes depend on the performance of its people (Sheppard, Canning, Anderson, Tuchinsky, & Campbell, 2014). Therefore, the involvement of employees in improvements processes are of the greatest importance and also imply several benefits. Firstly, the ones performing the job know the job best, meaning they are also most suitable for making improvements and modifications (Mylan & Schmidt, 2001). Secondly, by involving the employees they feel ownership, which often increases the workers' motivation and involvement. This can also result in better communication, commitment and higher trust levels (Mylan & Schmidt, 2001).

Motivation can be defined as "The mental state where a task or overall goal carries meaning for the person performing it, which increases their willingness to take action to complete specific goals" (Berlin & Adams, 2017, p.112). There are three physiological needs which affect motivation; Autonomy, Relatedness, and Competence (Fowler, 2014). Autonomy is about humans perceiving they have freedom and a choice over their own actions. Relatedness is the need of caring for and feeling cared about by others, a feeling of contribution to something bigger than oneself. Competence is the need of feeling personal growth and increasing skill over time (Fowler, 2014).

A person can not simply be motivated or not, since people are always motivated by something (Fowler, 2014). However, companies can create an environment which gives the opportunity to get the three physiological needs satisfied. If a person feels satisfied with autonomy, relatedness and competence, the person will have an optimal motivational outlook (Fowler, 2014). Further, there are two kinds of motivation; Intrinsic and Extrinsic (Berlin & Adams, 2017). Intrinsic motivation is when a person voluntarily invests time, effort and energy into a task simply because it is seen as meaningful enough. Extrinsic motivation is when the person needs a reward, external recognition or similar to perform the task (Berlin & Adams, 2017).

Feedback helps individuals know whether they are on the right or wrong track to receive successful final output, so-called decision-quality feedback (Thornock, 2016). Decision-quality feedback can help improve performance. The timing of the given feedback is also of importance since it has a big effect on future performance. Thornock (2016) states that future performance will maximise if the feedback is delivered a short delay after an incorrect decision is made. If the feedback is given before the individual has made an incorrect decision, it will have the lowest enhancement impact on future performance. Intermediate and long delay after the incorrect decision is done will also result in decreased future performance (Thornock, 2016).

2.4 Processes for Human Learning

When humans practice something, they gradually develop skills (Berlin & Adams, 2017). The most commonly used learning curve is called the Power Curve which is defined as

$$y(n) = y(1) \cdot n^{-b} \tag{2.1}$$

where n is the number of cycles, $y(n)$ is the time it takes to assemble the nth cycle, $y(1)$ is the time it takes to assemble the first cycle, and b is the learning curve constant (Dar-El, Ayas, & Gilad, 1995). In industrial tasks it has been proven that the learning curve actually is a combination of cognitive Learning and Motor Learning (Dar-El et al., 1995), see figure 2.5. Both of the learning curves are assumed to be calculated with the same formula as for the power curve, but the learning curve constant is set differently. This as the cognitive learning is decreased with an increased number of cycles as the person is gaining more skills and are slowly moving towards the motor learning (Dar-El et al., 1995).

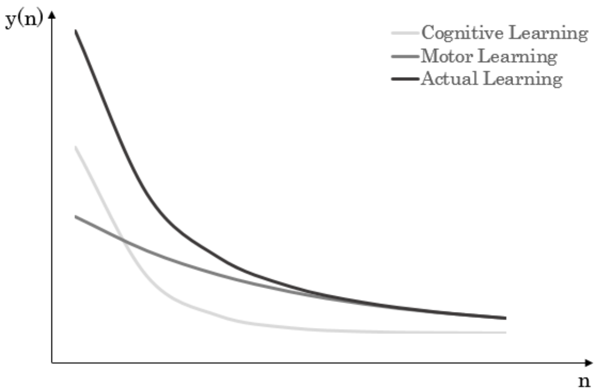


Figure 2.5: Adapted Combined Learning Curves (Dar-El et al., 1995).

In the beginning, when being novices, people are dependent on instructions to be able to perform the right actions (Berlin & Adams, 2017). The more complex a task is, the more cognitive learning is applied (Dar-El et al., 1995). The motions are not stored in peoples long-term memory until they have practised enough to become experts (Berlin & Adams, 2017). People are then experiencing motor learning and tasks are performed based on experience (Dar-El et al., 1995).

Further, Rasmussen (1983) presents a model for human performance in three different levels; Skill-, Rule-, and Knowledge-based performance. Skill-based behaviour is characterised by performing actions without awareness or control (Rasmussen, 1983). A person often has a hard time to describe how they control the action and what information their performance is based upon. Rule-based behaviour, on the other hand, is categorised by using information that has been gathered at earlier occasions, by oral instructions from other persons, instructions from books or similar (Rasmussen, 1983). The person can easily name the rule their actions are based upon. Finally, knowledge-based behaviour implies that the goal with the performance is explicitly expressed and a plan to fulfil the goal is defined and tested (Rasmussen, 1983).

A novice is operating in the knowledge-based domain, thus dependent on the short-term working memory (Berlin & Adams, 2017) and on cognitive elements for their learning process (Dar-El et al., 1995). Therefore, novices may need more time to interpret and perform tasks, they also make more mistakes due to forgetting or misinterpreting instructions (Berlin & Adams, 2017). The more the novice practices, the more rule-based their performance become (Rasmussen, 1983). An expert often reacts instinctively and on a skill-based level, meaning fewer mistakes are done while at the same time performing at a higher speed. The errors are due to slip of concentration instead of not knowing how and what to do (Berlin & Adams, 2017).

2.5 Work Instructions

Work instructions for assembly tasks should include a description of what to assemble, which components to use and how the assembly should be performed (Fast-Berglund & Mattsson, 2017). Depended on the work task, the work instructions could have different purposes such as remind the operator of specific details in the work activities or ensuring a standardised work procedure (Berlin & Adams, 2017). For the information to be used, it is important that the quality of the information is high, without quality the information is useless (Kehoe, Little, & Lyons, 1992).

To make the operators more likely to use the work instructions, a reduced amount of presented information is to prefer. This is especially important when designing work instructions for takt times of about one minute (Fasth-Berglund & Stahre, 2013). By decreasing the amount of presented information, the cognitive strain will also decrease due to the reduced need for filtering out the important information (Fasth-Berglund & Stahre, 2013). By effectively supporting the operator by presenting the information at the right time and place, the quality of the produced products will increase (Bäckstrand, Thorvald, De Vin, Högberg, & Case, 2008).

Kehoe et al. (1992) describe six attributes information need to fulfil to be used;

1. **Relevance**
   The information should be relevant for the user and have the ability to support the users in decisions and actions. Relevant instructions will also lead to better decision making.

2. **Timeliness**
   The information should be delivered during the time when the user performs decisions or actions.

3. **Accuracy**
   The information should be correct, free from errors, correspond to reality and be precise in defining activities.

4. **Accessibility**
   The information should be easy to access, as information cannot be put in use unless it is easily accessible to its users. Osvalder & Ulfvengren (2009) state that information used frequently should be easy to find and be placed close to the operator, decreasing the time and energy needed to find relevant information.

5. **Comprehensiveness**
   The information should be precise and clear and not contain redundant information.

6. **Format**
   The importance of presenting the information in the right format. The information should be perceived as efficient and be able to use in decision making.

2.5.1 Instruction Design

The vision is the most dominant sense where the central field of vision should be used for viewing detailed information, such as work instructions (Berlin & Adams, 2017). Hearing is the second most dominant sense used to distinguish information, it can be used as a compliment to vision when there are too many visual stimuli (Berlin & Adams, 2017).

There are five key factors to consider when presenting visual information; Intensity, Choice of Colour, Strength of Lighting, Contrast, and Angle of Vision (Osvalder & Ulfvengren, 2009). The visual presentation of information gets more crucial the more demanding or stressful a situation is (Osvalder & Ulfvengren, 2009). Good lighting, size of text and symbols, and duration of stimuli are of importance to consider when designing work instructions for an older work population (Osvalder & Ulfvengren, 2009). It is common that various colour codes are used when presenting visual information. Nevertheless, primarily a grey scale should be used as people may have defected colour vision (Osvalder & Ulfvengren, 2009).

When designing the present auditory information, the sound should only be used to indicate that something has happened. It should not be used unnecessarily and if some sound distracts the operator more then it informs it needs to be avoided (Osvalder & Ulfvengren, 2009). Further, the duration of the information is of importance as visual information may be watched several times compared to a sound which disappears as soon as it has been displayed (Osvalder & Ulfvengren, 2009).

The short-term working memory can store 7 ± 2 entities (Fast-Berglund & Mattsson, 2017; Berlin & Adams, 2017) and therefore it is recommended to limit the objects shown to the operator to these limitations. The work instructions should, therefore, be reduced and simplified (Fast-Berglund & Mattsson, 2017). Osvalder & Ulfvengren (2009) recommend to combine figures, letters, checklists and reference values in a smart way to show information and not burden the short-term memory. However, if there is too much information presented at the same time, the operator can have a hard time interpreting and understanding all information (Osvalder & Ulfvengren, 2009). To be sure that operators interpreter the information in the right way, redundancy can be used by combining different information formats (Osvalder & Ulfvengren, 2009). For instance, colour and placements are used by a traffic light, making it harder to misinterpret the information.

Descriptions and pictures that are used need to be distinct, big enough, have high contrast, avoid shadows, and use text, arrows, numbers and enlargements (Fast-Berglund & Mattsson, 2017). If illustrations or photos are being used, they should have strong connections to reality (Osvalder & Ulfvengren, 2009).

An effective way to deliver information can be trough symbols, but each symbol needs to be well known and easy to understand (Osvalder & Ulfvengren, 2009). If the symbol is not known, the information delivery becomes meaningless. The benefits of using symbols instead of text are that symbols can be seen from further away, the information can therefore be perceived more quickly and with fewer errors (Osvalder & Ulfvengren, 2009). Symbols can also work in an international environment, independent on the language of the user (Osvalder & Ulfvengren, 2009). A successfully used symbol is memorable with minimal effort. If a person from the targeted group cannot memorise the symbol after several tries, the icon is valueless and should be eliminated (Watzman & Re, 2008).

Where to place information on a display is of importance as an operator often scans information from left to right (Fast-Berglund & Mattsson, 2017). Important information should be placed along the diagonal from the left upper corner to the right lower corner. If information is placed in the lower left corner and the upper right corner, it takes longer time for the operator to notice the information and it might be missed (Fast-Berglund & Mattsson, 2017).

2.5.2 Digital Instruction Presentation

The most commonly used senses for a human to receive information are with vision, hearing and touch (Bellgran & Säfsten, 2010). There are several technologies supporting the presentation of digital instructions through these senses.

Stationary Display

There are different kinds of stationary displays, see figure 2.6. The display serves as a medium between the technical back-end system and the human using the system (Osvalder & Ulfvengren, 2009). The display presents what the system is doing, what needs to be done and how the system works (Osvalder & Ulfvengren, 2009). One advantage is that the display can show both text and different kinds of graphics (Osvalder & Ulfvengren, 2009). Production facilities have, in modern time, started using displays to be able to deliver relevant and necessary information on how assembly operations are performed (Berlin & Adams, 2017). One disadvantage of using displays is that other equipment can be placed in front of the display and thereby be in the way of the information. Also, when the operators are using a screen, problems with glare can occur (Osvalder & Ulfvengren, 2009).

Figure 2.6: Two examples of Stationary Displays; Screen and Projector.

Portable Display

One of the most common wearable technologies are smartwatches (McTear, Callejas, & Griol, 2016), other types of portable display are Mobile Phones and Handheld Devices, see figure 2.7. The problematic with portable devices is the limited space for providing information due to small screens (Schlick, Ziefle, Park, & Luczak, 2008). To be able to fast present visual information on portable screens, objects and letters need to be big enough. The information density should also be low as too high information density may be confusing for the users (Schlick et al., 2008). Smartwatches and mobile phones may have connected apps, enabling them to support various functions. The devices can be interacted with by using touch screens, buttons, or voice control (McTear et al., 2016). The gains from a portable screen are the possibility of on-the-go information, quick communication and instant messaging (Schlick et al., 2008).

Figure 2.7: Two examples of Portable Displays; Smartwatch and Iphone with an Armband.

Audio Support

The humans' auditory system is designed to seek both actively and passively information from the surroundings (Osvalder & Ulfvengren, 2009). Audio support can be delivered by different technical devices, see figure 2.8. One of the advantages of using sound to deliver information is that persons cannot completely ignore the sound, regardless of what the person is currently doing or focusing on. However, if there is too much sound displayed at the same time, it can be distracting for the person (Osvalder & Ulfvengren, 2009). It can also be difficult to hear audio support in a noisy environment. In lean production, pick-by-voice is often used as a way to support operators with information (Berlin & Adams, 2017). The operator uses a headset as an aid while performing assembly operations (Berlin & Adams, 2017). Audio support is, however, less time efficient than visual supports when performing assembly operations (Fager, Hanson, Medbo, & Johansson, 2019).

Figure 2.8: Two examples of Audio Support; Headset and Speaker.

Augmented Reality Glasses

Unlike ordinary glasses, Augmented Reality (AR) glasses have video cameras attached to them, providing the glasses with the possibility to scan the surrounding and create a navigation function for the user. Adding a wireless connection makes it possible to provide virtual information dependent on what the person is looking at (McTear et al., 2016). There are several types of AR-glasses available, nevertheless, most of them are beta versions both regarding software and hardware (McTear et al., 2016), see figure 2.9. The requirements to use AR-glasses in the industry are that they need to be light to wear as well as not giving the user any discomfort. Known issues that may arise are the AR-glasses possibility to record both video and audio which could cause privacy issues (McTear et al., 2016).

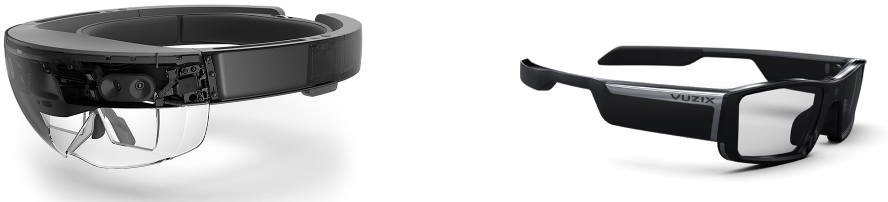


Figure 2.9: Two examples of Augmented Reality Glasses; Microsoft HoloLens and Vuzix Blade.

Virtual Reality Glasses

Virtual Reality (VR) has developed since the 1960s and includes different features in various industries including manufacturing (Gong, 2018). One of these features are the VR-glasses, see figure 2.10. What differs VR-glasses from AR-glasses are their ability to show a fully computer-generated 3D-environment which is real-time interactive and centred around the viewer (Gong, 2018). As the VR-glasses only presents a 3D-environment it is not recommended to use as a support tool during running production as the operators may harm themselves. Nevertheless, if it should be used in the industry it needs to be light to wear and avoid discomfort for the user, the same requirements as for AR-glasses (McTear et al., 2016).

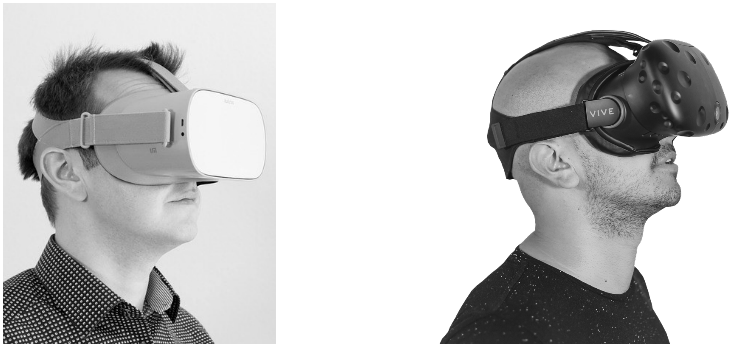


Figure 2.10: Two examples of Virtual Reality Glasses; Oculus and Vive.

Social Robots

A conversational interface is the best known method to communicate with smart objects. One way to implement a conversational interface is through a Social Robot (McTear et al., 2016), see figure 2.11. The robot has the ability to hold conversations, the complexity of its interactions vary depending on the robot type. Conversations can be held in various languages and may be used to deliver instructions to an operator. Social robots are not socially accepted yet, nevertheless, it gets more and more common to use social robots to help and facilitate in different professions (McTear et al., 2016).

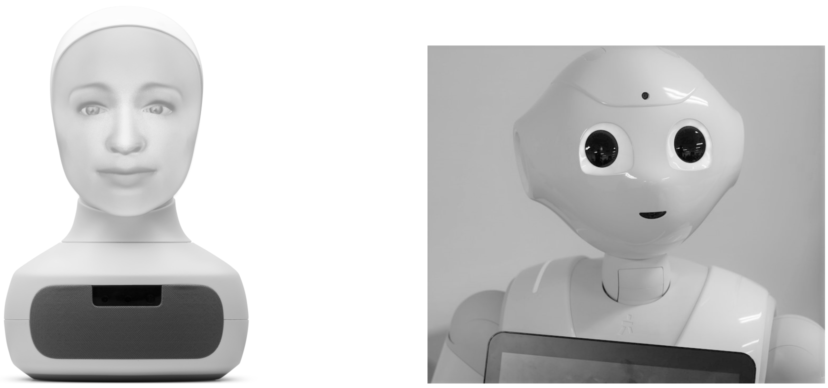


Figure 2.11: Two examples of Social Robots; Furhat and Pepper.

3

Methodology

The following chapter describes the Research Approach and the Proceeding Order of the thesis. It further describes the used methods for gaining data and knowledge making it possible to answer the research questions.

3.1 Research Approach

Mixed methods, by using various methods and actions, were applied to answer the research questions. Using different study methods in the same project has the ability to make the accuracy in the findings more confident (Denscombe, 2014). Mixed methods usually contain both qualitative and quantitative methods to gain a wider range of perspectives and a clear overview of the matter (Denscombe, 2014).

The term triangulation is often used in connection to mixed methods (Denscombe, 2014). The triangulation in the thesis included questionnaire, observations and interviews. All three methods collected qualitative data, where the interviews contributed with the majority of it. The quantitative data was collected by the observations and questionnaire. The triangulation gave an analysis of the problems and needs for the current situation (Denscombe, 2014).

The Project Proceeding Order is illustrated using a network diagram, see figure 3.1. The thesis with a basic literature review to gain an understanding of various topics that concerned the thesis. Afterwards, different tasks were performed parallel to each other. The broaden literature review was used as a complementing tool to gain deepened knowledge. The prototype development included a feedback loop before a finalised prototype was completed and verified by relevant stakeholders.

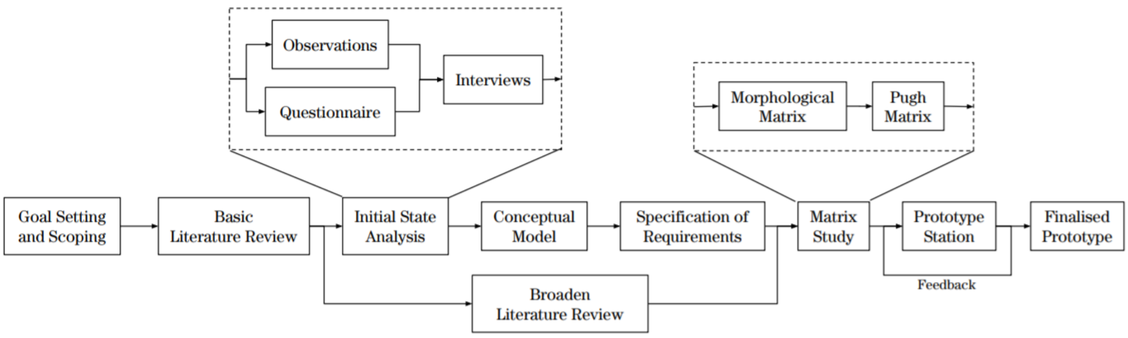


Figure 3.1: Network diagram visualising the Project Proceeding Order.

3.2 Observations

Mainly two different kinds of observational research are used by social science; Systematic and Participant (Denscombe, 2014). Systematic observations were selected as the type to use as it generates mostly quantitative data while participant observations only generate qualitative data. Characteristics for systematic observations are direct observations with the eye as evidence, the field work is performed in a natural setting and personal perception by the observers may affect the collected data (Denscombe, 2014).

As operators will be observed, some ethical aspects were considered. Firstly, each operator was informed about the aim of the observation and which actions were being observed. Secondly, each operator was asked before the observations started if they were okay with being observed and they had the opportunity to cancel the observations at any time. They could also request that the collected data was deleted, which they were informed about before the observations started.

The aim of the observations was to gather information and knowledge about the existing production. The observations were made without video recordings.

3.2.1 Preparations

The observations were treated as a work sampling study. Proceedings described by Brisley (2001) were followed to prepare for the observations;

1. **Gain acceptance for conducting the observations**
   Meetings with supervisors and team leaders were conducted, where the purpose and procedures were presented. The operators were informed about the project by an informative document and personal introduction before the observations started.

2. **Define the Problem**
   The aim of the observations was to find information about the work order at the two stations to be able to develop a solution suitable for various station. Also to collect quantitative data and state support areas about occasions when an operator may need support or guidance, to be able to give support where there is a need for it and not just support for the sake of it.

3. **Create an Observation Template**
   Two templates were designed; one for work tasks and one for possible support areas, see appendix A.1 and A.2. The definition of each activity observed is presented in appendix A.3. The data from the work tasks were divided upon car models to know that all variation had been observed. For the support areas, the data was divided per operator, to be able to observe a spread of working habits.

4. **Select Frequency and Estimate Number of Observations**
   There is no exact science stating how many observations that need to be made, but it is recommended to study enough cycles to be able to gain a normal distribution among the observed disturbances. One session was defined to start when a new operator arrived at the station and stop when the operators rotated.

5. **Create a Unanimous Understanding between the Observers**
   To minimise the difference between the observers the observations were done in pairs, to be able to create a consensus and calibrate the observations after each session.

3.2.2 Execution

Some factors that may disturb the observations are if the operators are nervous, if the operators are experienced and feel confident about their work, if the operators want to be observed, or if the operators try to "trick" the observer (Brisley, 2001). This was addressed by following the presented preparations but also to observe different operators during whole sessions. The number of observations performed of each type at each station is presented in table 3.1. The observations stopped when no new trends were observed. The majority of the observations were performed during the day shift and some during the evening shift, none during the night shift.

Table 3.1: Number of observations and operators observed at each station.

	Work Order		Support Areas	
	Station α	**Station β**	**Station α**	**Station β**
Cars Observed	31	29	114	111
Operators Observed	3	3	6	6

3.2.3 Data Processing

The analysis of the quantitative data was made with the help of basic descriptive statistics (Denscombe, 2014). The data collected were discrete data as it had occurrences which can only be measured in integers (Denscombe, 2014). It was used to determine how often a specific situation occurred and the incidents were therefore normalised using the number of cars observed. The processing of the qualitative data was done by writing shorter summarising texts of the work order and support areas. No further data processing was used to handle the qualitative data.

3.3 Questionnaire

The questionnaire was used to gathering demographic information and grading opinions from operators and team leaders. The information was used to get a greater understanding of what kind of needs the system should fulfil.

There are two different types of questions; Open-Ended and Close-Ended (Dillman, Smyth, & Christian, 2014). Open-ended questions are defined as questions where the participants answer the question with their own words. This is advantageous as the participant can elaborate on their answers. The disadvantage is that the data is quite raw, leading to increased time for answering and analysis (Dillman et al., 2014). As the opposite, close-ended questions have pre-defined answers. The advantage is that it is easier to analyse, being quantified and compared. The disadvantage is the possibility to miss important aspects of a question (Dillman et al., 2014).

3.3.1 Preparations

When the questionnaire was developed, the first step was to develop relevant focus questions (Dillman et al., 2014), see figure 3.2.

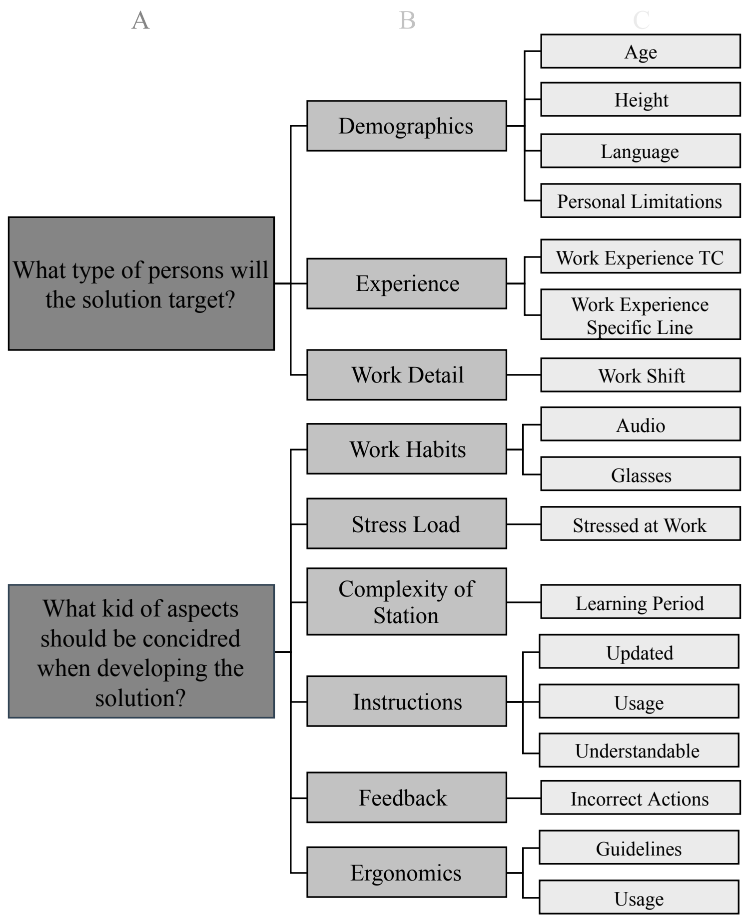


Figure 3.2: The development method tree used to generate questions for the questionnaire (Dillman et al., 2014).

Section A represents the questionnaire's focus questions. The focus questions were elaborated upon, to find sub-domains (Dillman et al., 2014), represented by section B. Further, the sub-domains were elaborated on to reach a level where every area was developed into a question (Dillman et al., 2014), represented by section C. As the questionnaire was planned well before distribution, it made it easier to only include vital and relevant questions (Denscombe, 2014).

The questions in the questionnaire were grouped together by subject and more sensitive questions were placed at the end of the questionnaire (Dillman et al., 2014). The questionnaire was conducted in Swedish, an English translation is included in appendix B. For each question, a suitable answer style was selected based on the information wanted, the amount of effort the participants needed to put into the questionnaire, and how easy the data could be analysed (Denscombe, 2014).

Testing the questionnaire before proceeding to implementation have the benefits of detecting problems before the questionnaire is handed out (Dillman et al., 2014). The questionnaire was sent to relevant stakeholders to get eventual feedback.

3.3.2 Execution

A questionnaire should include informative background information including six aspects; responsible persons, purpose, confidentiality, voluntary to answer, a time-indication, and some way of showing gratitude to the respondents (Denscombe, 2014). Ethical aspects were addressed by no questions being mandatory to answer and all answers were treated anonymously. The background was presented both orally and written to the participants. The background information was presented in Swedish, an English translation is presented in appendix B.

The amount of motivation from the participants will influence the effort and time the participant invests (Denscombe, 2014). Four aspects were taken into consideration when distributing the questionnaires; Interest, Enthusiasm, Gratitude, and Circumstances (Denscombe, 2014). The respondents were invited one or two at the time, making it less likely for them to feel group pressure. Operators and team leaders from all three shifts answered the questionnaire, see table 3.2.

Table 3.2: Number of people filling in the questionnaire.

	Day	**Evening**	**Night**
Answers	31	27	28
TOTAL		86	

3.3.3 Data Processing

Three different kinds of quantitative data were collected; Nominal, Ordinal, and Continuous. To analyse the quantitative data, the same method as for analysing the quantitative data from the observations were used; basic descriptive statistics (Denscombe, 2014).

The nominal data, like the demographic data, cannot be used for mathematical manipulation, only for determining amounts, frequencies or proportions (Denscombe, 2014). The ordinal data was collected by the five-point scale questions and used to determine statements like "more than" or "less than" (Denscombe, 2014). The age and work experience can be classified as continuous data which will change over time, it is therefore important to state the boundaries of the data (Denscombe, 2014).

The mathematical manipulations used for analysis were mean value, median value, and mode value. Those calculations were made to gain a better understanding of the initial state in production, but also to be able to present some data during the interviews. The mean values were calculated as

$$M(x) = \frac{x_1 + x_2 + ... + x_n}{n} \tag{3.1}$$

and the median values were defined as the value "in the middle" after sorting the ordinal and continuous data by size. The median values were used to consider the extreme values, as the mean values can be affected by them (Denscombe, 2014). The mode value is the value which is the most common one, one question may have several mode values (Denscombe, 2014).

To easier analyse the qualitative from the open-ended questions, the answers were divided into a suitable amount of different sub-categories (Kvale & Brinkmann, 2014). Question 18 and 19 were analysed together since they gained similar answers. The data that was outside the scope, was noted as "irrelevant".

3.4 Interviews

Interviews were selected as a method to gain knowledge about suitable solution possible to be implementable. Interviews were appropriate to conduct as there is value in gathering insight information from persons with relevant roles or experience (Denscombe, 2014).

The interview study contained six phases (Kvale & Brinkmann, 2014);

1. **Thematisation**
   The aim of the interview study is defined. Aspects which should be considered are why the study is conducted and what information should be gathered.

2. **Preparation**
   Formalise a plan for the study. Consider how the interviews should be performed to achieve the aim of the study. Ethical aspects should be discussed.

3. **Execution**
   Consider and discuss the relationship between the interviewer and the person participating in the interview. Conduct the interviews, according to the plan developed in stage two.

4. **Summarise of Interviews**
   Prepare the gained information for data processing.

5. **Data Processing**
   Analyse the gained data. The method for data processing is determined on the characteristics of the interview.

6. **Documentation**
   Document the result in a way that is understandable and ethical viable.

3.4.1 Preparations

The interview focus questions define the aim of the study (Kvale & Brinkmann, 2014), the questions should also invite to exploration and discovery (Agee, 2009). Three interview focus questions were developed for the study;

IQ1: How is the initial cognitive support for the operators designed?
IQ2: What kind of cognitive support would the operators need to increase their performance?
IQ3: How should the system be developed and implemented to get accepted by the operators?

There are three kinds of interview-styles; Constructed, Semi-Constructed, and Unstructured Interviews (Denscombe, 2014). The project conducted semi-constructed interviews with a pre-defined interview protocol in Swedish, an English version is presented in appendix C.1. The format was chosen as it enables the interviewees to be flexible and elaborate in their answers. The interview questions were developed by elaborating sub-questions within each focus question (Agee, 2009) and based on the results of the questionnaire. The first draft of the interview protocol was reviewed in four steps (Castillo-Montoya, 2016);

1. Ensure interview questions align with focus questions.
2. Construct an inquiry-based conversation.
3. Receive feedback on interview protocol.
4. Pilot the interview protocol.

An interview protocol matrix was conducted to ensure that the interview questions aligned with the focus question, see appendix C.2. Further, the questions were improved by formulating them in an everyday language rather than theoretical language (Castillo-Montoya, 2016).

Four types of questions should be included throughout the interview; Introducing Questions, Transition Questions, Key Questions, and Closing Questions (Castillo-Montoya, 2016). Introducing questions aim to give an introduction to the interview. The transition questions function as a segue to the key questions (Castillo-Montoya, 2016). The key questions relate to the focus questions and the aim of the study the most. Closing questions summarise the interview protocol, which prepares the interviewee for the closure of the interview (Castillo-Montoya, 2016). All these types of questions were used in the developed interview protocol. A script for oral information, to support a more common conversation style, was included in the interview protocol as well (Castillo-Montoya, 2016).

Feedback on the interview protocol was received by relevant stakeholders using a checklist, see appendix C.3. The piloting of the interview protocol was done by conducting the first interview, with one of the supervisors, and thereafter improving the interview protocol.

Ethical aspects related to the interview were also included in the preparation phase. Questions regarding consent to the study, confidentiality and anonymity for the participants were considered (Kvale & Brinkmann, 2014). None of the questions was mandatory to answer and a summary of each interview was showed for respective interviewee where they had the opportunity to freely decide what information should be included in the study.

3.4.2 Execution

The interviews had a maximum length of 45 minutes each. When conducting interviews it was important to make the interviewee feel as conformable as possible, to be able to gain personal knowledge about the perspective and the world of the interviewee (Kvale & Brinkmann, 2014). The interviews started with an introduction where the aim of the study was clearly expressed, consent for recording the interview was gained and the interviewees had the opportunity to ask questions before the start. Some benefits with recording the interview were that it did not disturb the interviewee it also gave a permanent record to double-check information (Denscombe, 2014).

Personnel at different positions in production were interviewed, see table 3.3. The purpose was to get personal with varying working shifts, positions and experiences. The number of people from each shift was evenly distributed. The variety of people gave the study different perspectives and a fuller picture.

Table 3.3: Number of people interviewed.

	SV	TL	OP	SR
Interviewed	3	3	6	2
TOTAL		14		

3.4.3 Data Processing

The interviews were summarised for data processing and analysis (Kvale & Brinkmann, 2014). The summarises were divided into seven categories including sub-categories, see table 3.4. Using categorisation created a structure in the complexity of answers (Kvale & Brinkmann, 2014).

Table 3.4: Categories and sub-categories for the data processing.

1.	**Demographic Questions** • Difference in work tasks compared to others with the same title • Experience assembling work • Experience targeted assembly line • Best thing about the work • Most difficult part about the work
2.	**Work Instructions** • Initial state of work instructions • Preferred work instructions • Work instruction updates
3.	**Comments on Questionnaire Results** • Usage of WES:es • Stress Load • Ergonomic Guidelines
4.	**Operator Feedback** • Initial state of operator feedback • Preferred operator feedback • Advantages with operator feedback • Disadvantages with operator feedback
5.	**Ideas for a Working System**
6.	**Acceptance from Operators**
7.	**Other Comments** • Current problems • General recommendations

The summaries made it possible to thematise similar data from different interviews and find similar patterns in the interview material. After the data processing, the data was documented (Kvale & Brinkmann, 2014) into four different areas; Work

Instructions, Working Habits, Quality Follow-Up, and Change Management. The demographic distribution was not documented in the report, as ethical aspects of being anonymous were respected.

3.5 Specification of Requirement

A Specification of Requirements is a method to determined the demands set on the functions of a product and what it should manage (Johannesson, Persson, & Pettersson, 2013). The specification also determines what the development group wants to achieve to become satisfied with the product (Ulrich & Eppinger, 2012). The requirements were set with the basis in the results from the initial state analysis.

The specifications of requirements were developed through five steps (Ulrich & Eppinger, 2012);

1. **List Stakeholders' Requirements**
   The requirements of the solution were listed in the language of the stakeholders, typically in subjective terms, it helped to make sense of important issues. The stakeholders were operators, supervisors, team leaders and project owner, where the operators' opinion were prioritised.

   There are two main types of requirements; requirements related to the product's expected function and requirements that set limits of which solutions that are allowed (Johannesson et al., 2013). The requirements were defined in three areas of interest; Hardware, Instructions and Control System. Hardware was, for this project, defined as the option used to present the work instructions. Instructions aimed to define what stakeholders require from the design of the work instructions. Control System aimed at defining the demands on the back-end system.

2. **Set Importance Values**
   There are two ways importance values are determined; relying on consensus from team members' experiences or based on an assessment by stakeholders. The importance values were set by experience from communication with stakeholders, but also questionnaire and interview answers. The importance values were set from one to five, one was seen as the least desirable by the stakeholders and five was seen as highly critical.

3. **Set and Relate Metrics**
   To be able to convert the expectations from the stakeholders into a viable design, one must translate the expectations into design parameters (Silverstein, Samuel, & DeCarlo, 2012). The most efficient way of developing metrics from the requirements is to consider each requirement and find specific measurable values that fulfil the requirement. Some requirements needed more than one measurable metric to be fulfilled.

4. **Set Values**
   The metrics have four different types of values; at least X, at most X, between X and Y or binary. The values were set based on gained information from the initial state analysis as well as careful consideration of which values were reasonable.

5. **Assess Requirements**
   When all requirements were developed with their respective metrics, they were reviewed and assessed to find inversely related requirements. The requirements were then refined by resolving different trade-off without jeopardising the performance of the product. Further, the requirements were assessed with help from stakeholders to verify their implementability.

3.6 Conceptual Model

The conceptual model was used as a way to visualise and define requirements for the solution to work in reality. The first development step for the model was to list concepts and functions in the control system. Those were generated from information gathered during the literature study and initial state analysis.

When creating a flow chart of a system, it may be used at various levels. The numbers of levels are dependant on the detail level needed for the system (SIS, 1990). Figure 3.3 presents the figures used when developing the flow chart visualising the control system. The conceptual plan was verified with relevant stakeholders from both the production and IT-department.

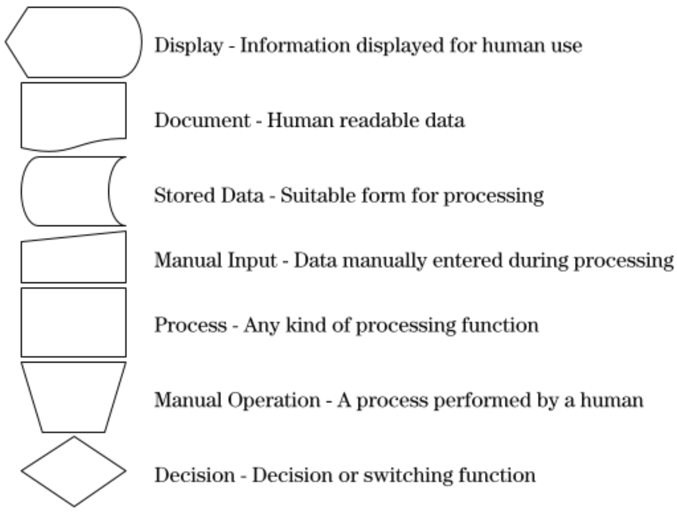


Figure 3.3: Standardised figures from SIS (1990) which were used in the Conceptual Model.

3.7 Morphological Matrix

A Morphological Matrix is a tool to generate different solutions based on various functions (Silverstein et al., 2012; Johannesson et al., 2013). The morphological matrix was used to find design concepts for the hardware, work instruction, and the control system. In total five steps were conducted (Silverstein et al., 2012);

1. **Determine the System's Sub-Functions**
   The sub-functions were found through brainstorming based on the results from the literature study, initial state analysis and specification of requirements. Important for the sub-functions were that they all needed to be part of the whole system and they were not allowed to overlap each other.

2. **List the Design Options for each Sub-Function**
   A minimum of two and a maximum of six Design Options were listed for every sub-function. Fewer than two would have lead to a lack of alternative routes and more than six would have lead to a too complex system to analyse. At this stage, the design options were only listed, not judged.

3. **Assess Feasibility for Design Option**
   The design options were systematically structured and assessed per function, see figure 3.4. The design options were removed when it was proven that they were not possible to move forward with, due to constraints related to design, cost, or outcome of the project. Notable in this step is that if one option was removed it may have lead to problems moving forward with other options, therefore those options were removed as well.

	Option 1	Option 2	Option 3	Option 4
Function A	A1	A2	~~A3~~	
Function B	B1	B2	B3	~~B4~~
Function C	C1	C2		

Figure 3.4: A conceptual example of the design of the matrix used to generate and assess Design Options.

4. **Generate Design Concepts**
   The Design Concepts were generated by combining one option from each sub-functions until all combinations were listed. The number of concepts generated was calculated as

$$N_{DesignConcepts} = \prod_{i=1}^{n} (N_{Options})_n \tag{3.2}$$

   where n is the function (Johannesson et al., 2013). At this stage, the design concepts were only listed, not judged.

5. **Assess Feasibility of Design Concepts**
   Preliminary evaluation and assessment of all the generated concepts, based on constraints on a system level, were made. When there was a possibility that the design concept might function it was left in the matrix, see figure 3.5. With this approach, no concepts were eliminated at a too early stage. The result from the morphological matrix was the remaining concepts.

Solution	Function A	Function B	Function C
1	A1	B1	C1
2	A1	B1	C2
3	A1	B2	C1
4	A1	B2	C2
5	A1	B3	C1
6	A1	B3	C2
~~7~~	~~A2~~	~~B1~~	~~C1~~
8	A2	B1	C2
~~9~~	~~A2~~	~~B2~~	~~C1~~
10	A2	B2	C2
~~11~~	~~A2~~	~~B3~~	~~C1~~
12	A2	B3	C2

Figure 3.5: A conceptual example of the design of the used Morphological Matrix, with an example constraint between A2 and C1.

The advantage of using a morphological matrix was that it was good at generating design concepts that might not have been thought of before (Johannesson et al., 2013). Prerequisites to use the matrix were that the group had enough competence within the system to be able to evaluate the relevancy of the solutions and their possibility to work in reality (Silverstein et al., 2012).

The negative aspect of using morphological matrices is that they may, depending on the number of functions and options, generate a large number of potential concepts which will take a long time to analyse (Johannesson et al., 2013). Nevertheless, the method is simple to use and has the ability to organise solutions in a structured way. It provided the project with traceability and opportunity for documentation (Silverstein et al., 2012).

3.8 Pugh Matrix

A Pugh Matrix is a tool to evaluate different ideas or design options with relation to a Baseline, also known as Concept Screening (Silverstein et al., 2012; Johannesson et al., 2013). The advantage with Pugh matrices was that they work as a risk management tool where concepts are prioritised in a structured and objective way rather than based on gut feel (Silverstein et al., 2012). Four steps were followed when creating the Pugh matrices (Silverstein et al., 2012), which are exemplified in figure 3.6.

	Concept 0	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Criteria 1	BASELINE	+ 1	+ 1	– 1	0	– 1
Criteria 2		0	+ 1	0	– 1	+ 1
Criteria 3		0	+ 1	0	+ 1	+ 1
Criteria 4		– 1	– 1	+ 1	0	+ 1
Criteria 5		0	– 1	– 1	+ 1	0
Comparison		0	1	-1	1	2

Figure 3.6: A conceptual example of the design of a Pugh Matrix used to make comparisons between different concepts based on different criteria.

1. **Determine a Baseline**
   At the beginning of each iteration, a baseline concept was chosen for the comparison. This helped to do a more objective comparison between the alternatives as concepts could be either better, worse or the same as the baseline concept.

2. **Select the Concepts to be Evaluated**
   The concepts to start to evaluate were given by the results from the morphological matrix. Several iterations were performed and the concepts being assessed at following iterations were the ones left from the previous Pugh matrix. A benchmark was to eliminate approximately half of the concepts in each iteration.

3. **Define Evaluation Criteria**
   The evaluation criteria were set based on important aspects found in the initial state analysis. Important for these criteria was that a defined line of what was good and bad existed, otherwise, complications occurred when the comparison started. No more than 15-20 criteria should be listed (Johannesson et al., 2013).

4. **Use the Criteria to Compare Concepts**
   Each concept was compared with the baseline concept for each criterion. If the concept was better than the baseline it was assigned "1", if it was worse "-1", and if it was the same "0". When all concepts were compared the Comparison Scores were calculated as

$$\text{Comparison Score} = \sum_{i=1}^{n} (\text{Criterion Value})_n \tag{3.3}$$

   where n is the criterion number. The higher the comparison score, the better the concept was, in relation to the baseline concept.

The pugh matrices were performed in four iterations, as there were a lot of design concepts to evaluate from the morphological matrix. By doing it in several rounds the baseline concept changed and it was easier to conclude the most suitable concepts. The concepts left after the fourth iteration were the input data for the prototype station.

3.9 Prototype

A prototype is a representation of an interactive system used to envision and reflect upon the final system (Beaudouin-Lafon & Mackay, 2008). It is often used to gain knowledge about the feasibility of a technical solution. By developing a prototype based on the operators' feedback, the method has participative properties as the system is developed together with the users. Development with the users is the method that often gives the best results, compared to development for or by the users (Osvalder, Rose, & Karlsson, 2009). A prototype was therefore designed and build to test, evaluate, and improve the seven design concepts remaining from the Pugh matrices. The prototype also included an interface for presenting both coaching and quality follow-up, but also to enable the users to interact with the prototype.

The development of the prototype was done with iterations influenced by agile principles, where every iteration included Development, Feedback from Operators, and Analyse. Boral (2016) states that agile is a mindset and culture including tools and practises to adapt to rapidly changing requirements. The agile methodology is frequently seeking feedback from its users, making it possible to refine the system according to the users' requirements and requests. When adapting some agile principles, the development was flexible to changes based on the feedback.

3.9.1 Generation of Work Instructions

The previously used methods resulted in guidelines that were followed when generating the work instructions, see table 3.5 and 3.6. In the first iteration, two kinds of on-line and four kinds of off-line work instructions were designed. These were created, written, photoed, filmed and edited according to the guidelines, where key activities in the OIS:es were the focus. The following two iterations of the work instructions were based on the feedback from the validation sessions and the work instructions were changed accordingly. Instruction types were further eliminated and merged throughout the process, where the decision when to do so were based on the results from the analyse of the feedback.

Table 3.5: Guidelines for work instructions generation in running production

On-line work instructions	
Text	**Variation Symbols**
• One language at the time	• Maximum of five letters/numbers
• Simple descriptions	• Strong connection to reality
• No difficult technical terms	• Well known
• Units in everyday language	• Big enough
• Fast interpretation	• Include ergonomic guidelines
• Include ergonomic guidelines	

Table 3.6: Guidelines for work instructions generation in Not Running Production.

Off-line work instructions	
Text	**Photo in Production**
• One language at the time	• Strong connection to reality
• Simple descriptions	• Big enough
• No difficult technical terms	• High contrasts
• Units in everyday language	• Avoid shadows
• Comprehensive enough	• Clarifying symbols, texts, figures and arrows
• Include ergonomic guidelines	• Include ergonomic guidelines
GIF	**Video in Production**
• Strong connection to reality	• Strong connection to reality
• Big enough	• Big enough
• High contrast	• High contrast
• Avoid shadows	• Avoid shadows
• Clarifying symbols, texts, figures and arrows	• Clarifying symbols, texts, figures and arrows
• Include ergonomic guidelines	• Short sequences
	• Include ergonomic guidelines

Ethical aspects were considered when gathering material for the work instructions. Every operator was asked to sign a contract of approval if they wanted to participate in the photo and filming sessions. Further, the operators were never interrupted when working and the material was gathered during working cycles.

3.9.2 Validation of Work Instructions

The validation of the work instructions was performed by using a mixed-methods sequential explanatory design. Initially, quantitative data was collected, followed by qualitative data assisting to explain and elaborate on the answers (Ivankova, Creswell, & Stick, 2006). By first collecting numeric data, it was possible to easy rank the different formats, the ranking could be either changed or confirmed by the quantitative data.

The purpose of the validation was to establish which type of work instructions the operators preferred after testing different formats. Validation was also used to find areas of improvement for the chosen formats. Mainly operators were interviewed, moreover, supervisors and production technicians were also participating to gain a broader perspective. The amount of participants in each iteration is presented in table 3.7. The validation stopped when it was seen that the majority of the feedback gained was the same or similar as before.

Table 3.7: Number of people part of each iteration.

	Iteration 1	**Iteration 2**
Interviewed	5	3
TOTAL	8	

The validation was conducted by letting one person at the time evaluate the different work instructions, this to avoid group pressure and give the interviewees time to express their thoughts and feelings. One format at the time was showed and different validation orders of the formats were used for each person. Nine statements were then presented, see table 3.8. The interviewees had to rate and comment upon the different formats based on a four-point scale; Do not agree at all (1), Partially do not agree (2), Partially agree (3), and Agree fully (4). The optimal score was Agree Fully (4).

Table 3.8: Statements for Validation of Work Instructions.

No.	**Statement**
1.	The work instruction is clear.
2.	The work instruction is easy to understand.
3.	The work instruction can be interpreted fast.
4.	The work instruction contain relevant content.
5.	The work instruction is supportive.
6.	The work instruction helps me understand what to do.
7.	The work instruction does not contain any difficult terms.
8.	The work instruction clearly shows how to work according to standards.
9.	The work instruction clearly shows ergonomic guidelines.

The final verification of the work instruction format was done while performing the system validation, verifying that the operator felt satisfied with the final format of the work instructions.

3.9.3 Generation of System

The previously used methods resulted in guidelines that were followed when generating the system, see table 3.9. The system was generated by creating an interface in Microsoft PowerPoint since it was time efficient and simple to use to create and visualise the necessary functions of the system.

Table 3.9: Guidelines for system generation.

Guidelines for System Generation
• Have a log-in function to be able to personalise the interface • Present the working order at the station • Maximum 5 ± 2 entities visible during running production • Sort work instructions based on the car model • Use colour coding to make the interface more usable but also be able to be adapted to persons with defect colour vision • Information should never be more than three clicks away • Efficiently present work instructions for different interpretation times • Left diagonally information presentation

Before, during and after the generation of a system, five questions should be answered (Watzman & Re, 2008). These were answered before the development started to gain insights on what to consider when developing a suitable system.

1. **Is it appropriate?**
   The system had the aim to support the operators in their daily work. It was important throughout the project, including the development of the prototype, to always consider the operator first and making an operator-centred solution.

2. **Is it durable?**
   The system's purpose was to become durable and changeable. It was thereby important to develop a prototype which could be changed and redefined after the thesis has ended.

3. **Is it verifiable?**
   The end users were the operators, which also tested the prototype and provided feedback. To verify the system further, the validation also included other stakeholders. The verification was an iterative process where the feedback from each iteration was used to refine the concepts.

4. **Does it have impact?**
   Earlier methods in the project have determined what kind of hardware was used to fulfil the needs of the stakeholders. The interface was designed in close collaboration with the operators, making it more likely to fulfil their requirements and requests.

5. **Is it cost effective?**
   Maintenance and implementation is something that was not the main scope of the thesis. However, the cost was considered when the final system was generated to make it more likely to implement the solution in running production.

3.9.4 Validation of System

When validating a system, the number of people used in the usability test could be as few as five people and they will still find the most severe problems of the system (Dumas & Fox, 2008). By finding the most severe problems, other smaller problems will be solved as well due to them being subsequent errors (Dumas & Fox, 2008). The iterative process ended when the operators felt satisfied with the system and no severe problems were found. Six characteristics define a valid usability test for a system (Dumas & Fox, 2008), where step one to five were used in the thesis, and step four and five were performed repetitively in the iterative process;

1. **The focus is on usability**
   The focus of the tests was only to determine the usability of the system as the work instructions were validated at an earlier stage.

2. **The participants are end users or potential end users**
   The participants for the tests were mainly operators, but also team leader, supervisors and production technicians did the test. As all groups of people have different perspectives and focused on different things, all feedback gathered were considered in the development of the system. The number of participants for each iteration is presented in table 3.10.

Table 3.10: Number of people part of each iteration.

	Iteration 1	**Iteration 2**	**Iteration 3**
Participants	3	8	5
TOTAL		16	

3. **There is a product or system to evaluate**
   The prototype system was the target to evaluate, containing a touch screen with an interface and already verified work instructions.

4. **The participants perform tasks, usually while thinking aloud**
   The participants were given a short oral introduction to the purpose and procedures of the test. Further, all participants were asked to think aloud and notes were taken during the tests. The participants were given a set number of tasks to perform and the first and final task was simpler ones as the participants then felt happy and satisfied with their test session (Osvalder et al., 2009). The tasks were given in Swedish, an English version is presented in appendix E.

5. **The data are analysed**
   The majority of the data that were analysed were dependent on the think-aloud protocol, therefore it was clearly communicated to the participants to thoroughly describe what they were doing and thinking. In combination with the think-aloud protocols, usability problems were noted when observing the sessions. The analyse gave indications of improvements that could be performed to the system. The following iterations verified that the improvement was accepted and worked as it should.

4
Results

The chapter presents the results gained from the selected methods. The results presented in this chapter give valuable information to be able to answer the research questions.

4.1 Observations

The results from the observations are divided into the initial state of the assembly line and initial state of the support areas. The support areas focus on the occasions when the operator may need additional support.

4.1.1 Initial State Assembly Line

The takt time of about one minute leads to decreased room for mistakes and hesitations by the operators. A mixed model final assembly is used and some variations between the models occur at each station. The level of variation varies between stations, and the observed ones have a quite low variety compared to other stations in the factory. Both of the observed stations are connected to the line's andon system. One of the observed stations use pick-by-light to assist the operators, but this technical solution was observed in other parts of both the assembly line and factory.

Station α

Station α starts with the operator flipping the sun visor. Thereafter the operator assembles three components on the left side of the car; one A-panel, one front threshold and one rear threshold. The components are attached by various amounts of clips. There is no possibility of visual inspection of the clips, therefore the operator needs to act on experience or instinct. A rubber hammer is available as it increases both quality and ergonomics. The thresholds are assembled on top of a rubber lip which is adjusted to seal the threshold to the car by the help of a pull cord. If the rubber lip is not aligned the operators need to manually adjust it by hand. The technique, speed and success rate for doing this vary significantly between operators. Variations between models occur such as additional choice of a LED light on the thresholds, it is connected with one connector at each threshold. The connectors are designed to be poka yoke, however, the connector needs to be manually quality inspected through a push-and-pull function. Figure 4.1 presents the working order at station α including the decisions the operators have to make.

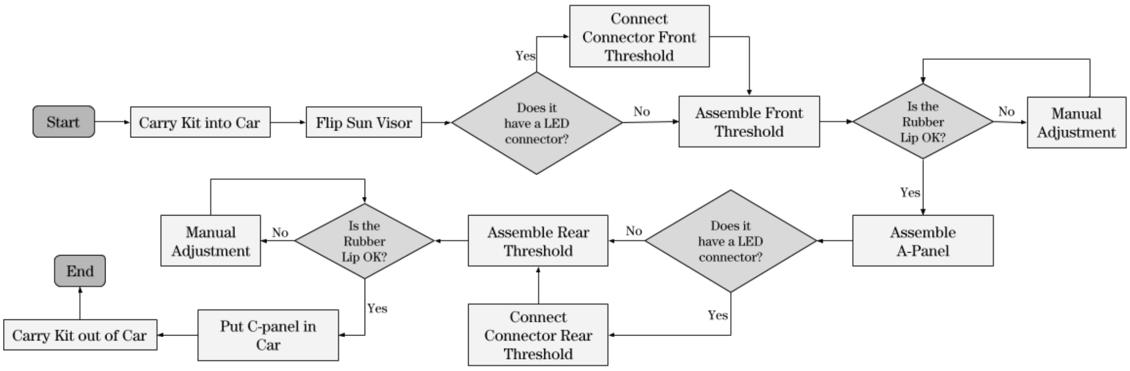


Figure 4.1: A Flow Chart showing the Work Order at Station α.

Station β

Station β starts with the car key being scanned and placed inside the car. Thereafter the main task starts, which is to fasten the front left seat of the car. There are four bolts that need to be attached to the car to secure the front seat and the first occurring variation is the different length of the bolts. The operators keep track of which kind of bolts the model needs by themselves as there is no poka yoke applied to the bolts. The bolts are attached with the help of a nut runner and a display shows the operators if the bolts have been assembled with the correct torque or not. If the torque is not approved, the operators need to re-do the task and the line stops if this is not completed within the takt time. The operators start to assemble the bolts in the front of the seat before moving the seat forward to be able to attach the bolts behind the seat. If the car has electric seating the operators connect an electrical connector to the car and push a button to move the seat forward. If the car seat is not electric the operators move the car seat forward manually. When the last bolt is fastened the operators remove the electrical connector and the car leaves the station. 4.2 presents the working order at station β including the decisions the operators have to make.

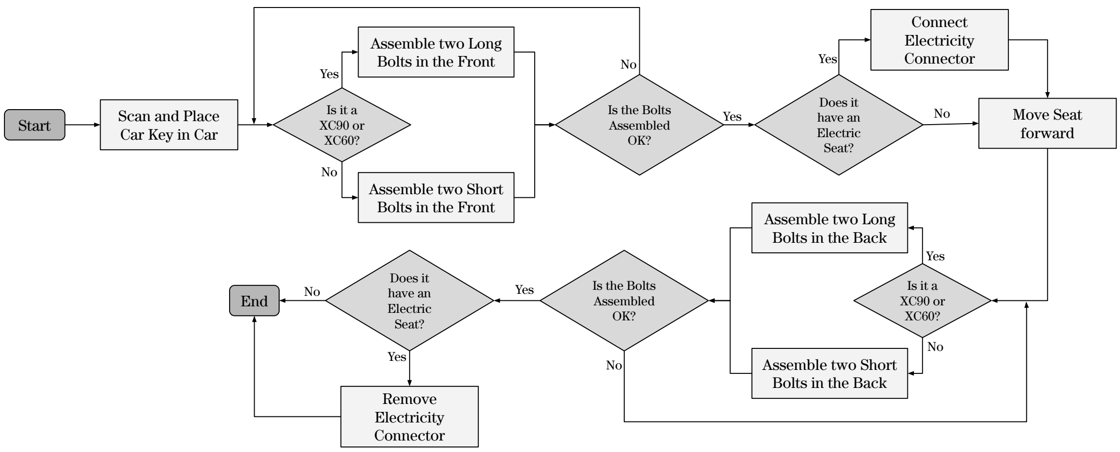


Figure 4.2: A Flow Chart showing the Work Order at Station β.

4.1.2 Initial State Support Areas

Common results for both stations are that the operators working at the line are keen to help each other. Further, the line stopped one time due to problems at station α and none due to station β during the observation sessions.

Station α

During the observations, it was noticed that the operators have some deviation in their assembling, see figure 4.3. The deviations were defined as not getting the clips correct which lead to several tries, the rubber lip did not adjust properly as well as material was in the way of assembling the thresholds. Sometimes the operators got help with the assembling from co-workers without asking for it, but no frequent repetitiveness could be observed. Other deviations that were observed falls under grabbing tools and components, but they did only occur at half of the frequency compared to deviations when assembling.

Figure 4.3: The operators deviate from the normal state 1 out of 6 cars when assembling at station α.

When attaching the A-panel or thresholds the clips did not align leading to the operators removing the component and then assemble it once more. This together with reworks of adjusting the rubber lip was done several times at station α, see figure 4.4. In total, the andon cord was pulled five times during the observation sessions.

Figure 4.4: The operators have to do rework 1 out of 6 cars at station α.

At station α the determined ergonomic guidelines are, among other things, to use the rubber hammer when assembling the thresholds. When observing it was seen that the usage of it varied between operators and cars, see figure 4.5.

Figure 4.5: The ergonomic guidelines are not followed 1 out of 5 cars at station α.

Station β

Similar to station α, station β also had some deviations when assembling, see figure 4.6. The deviations occurred when the nut runner did not attach properly to the bolts, the nut runner got stuck in the plastics protecting the seat, as well as the operators were not sure if it was an electric seat or not.

Figure 4.6: The operators deviate from the normal state 1 out of 4 cars when assembling at station β.

The type of rework that was performed at station β was when something was wrong with the bolt and it did not get attached with the correct torque. The operators then had to do some rework before assembling it correctly, see figure 4.7.

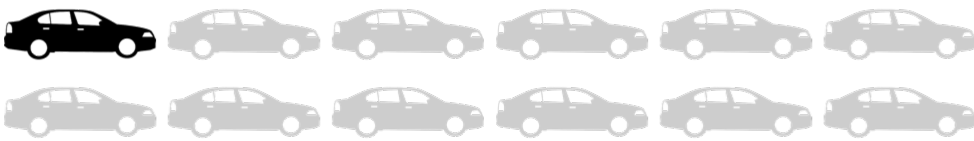


Figure 4.7: The operators have to do rework on 1 out of 12 cars at station β.

When observing it was seen that the operator quite often finished the assembling at the beginning of the next station. The operator at that station then helped finish the remaining operations such as disconnecting the electricity cable or moving the tools. This was done without the operator asking for any help, see figure 4.8.

Figure 4.8: The operators get help with assembling without asking for it at 1 out of 7 cars at station β.

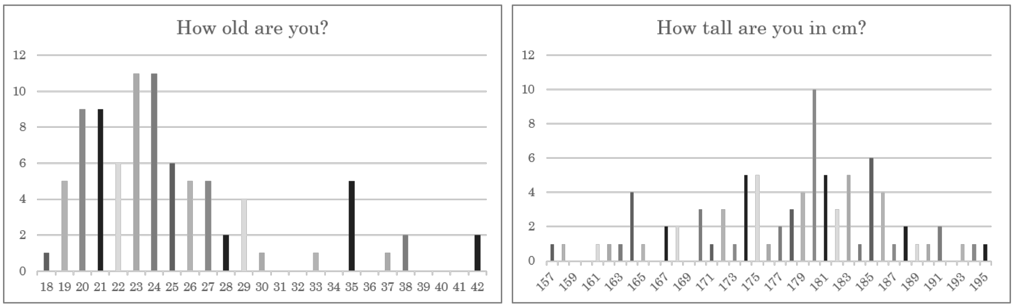
All the cars observed at station β were assembled according to the set ergonomics guidelines. Further, the andon cord was never used when observing station β.

4.2 Questionnaire

The answers from the questionnaire have been divided into its respective subdomains; demographic, grading and qualitative answers. As none of the questions where mandatory to answer, the number of respondents varies.

4.2.1 Demographic Questions

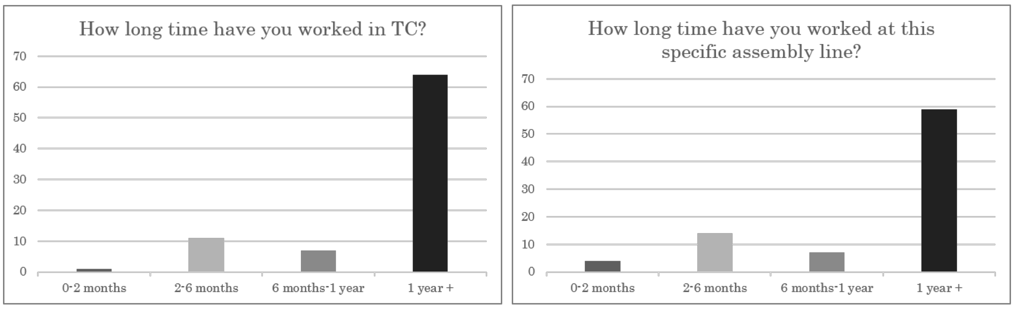
The data from the first two questions, regarding age and length, are presented in figure 4.9. Further, it was seen that in total 20 languages are mastered by the respondents. 92% answered that they master two or more languages, which mean that 8% answered Swedish as their only language. The result regarding the respondents work experience are presented in figure 4.10. The distribution among the shift was almost a third each, with a few more respondents at the day shift. Continuing, 14% of the respondents answered that they had problems with defected hearing, defected vision or reduced memory, the most common one were defected hearing.



(a) Mean: 25.0. Median: 24. Mode: 23 and 24.

(b) Mean: 177.9. Median: 180. Mode: 180.

Figure 4.9: Age and length distribution among the respondents.



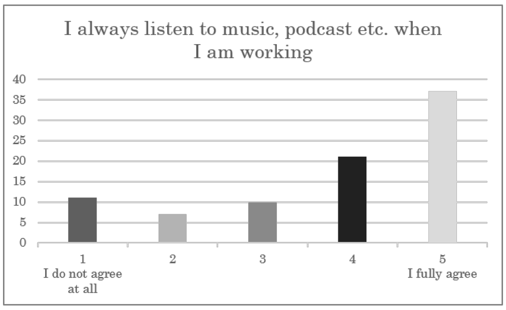
(a) Median: 1 year +. Mode: 1 year +.

(b) Median: 1 year +. Mode: 1 year +.

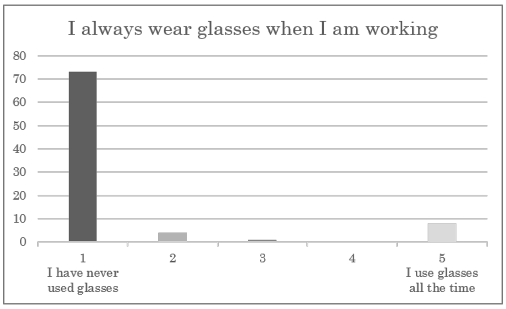
Figure 4.10: Experience of being an operator and experience at the specific assembly line.

4.2.2 Grading Questions

The data from the first two grading questions regarding the usage of headphones and glasses are shown in figure 4.11. It does not cover ear or eye protection as this is not used at the targeted assembly line. Stress level data and the complexity of the stations at the targeted assembly line are presented in figure 4.12. Grading data from questions regarding the WES:s are shown in figure 4.13. Data regarding ergonomics are presented in figure 4.14. After how long time the operators get feedback if they have assembled something wrong is shown in figure 4.15.

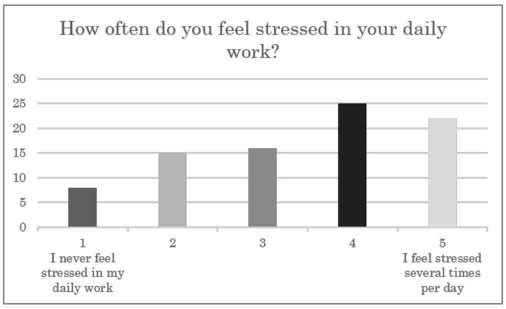


(a) Mean: 3.8. Median: 4. Mode: 5.

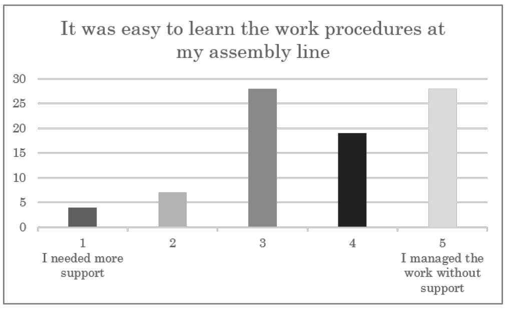


(b) Mean: 1.4. Median: 1. Mode: 1.

Figure 4.11: The usage of headphones and glasses.

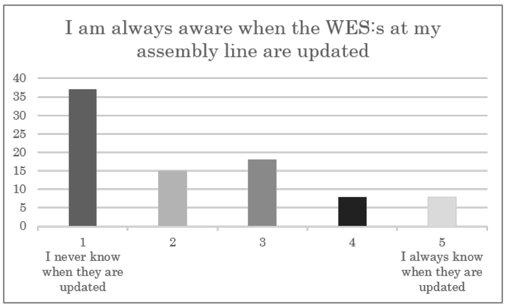


(a) Mean: 3.4. Median: 4. Mode: 4.

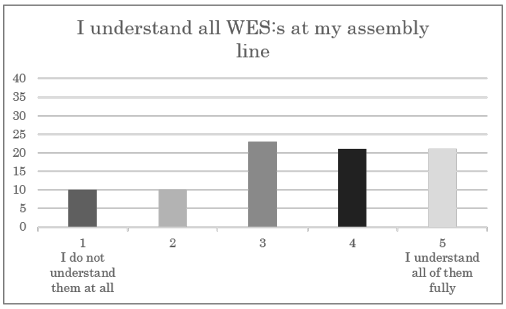


(b) Mean: 3.7. Median: 4. Mode: 3 and 5.

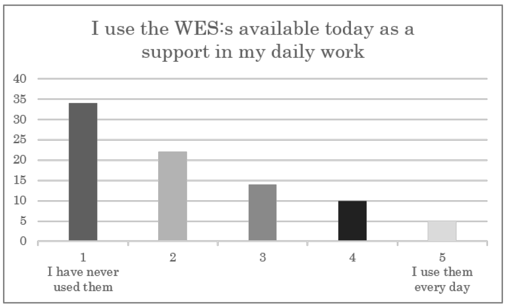
Figure 4.12: The stress level and complexity of the stations at the assembly line.



(a) Mean: 2.2. Median: 2. Mode: 1.

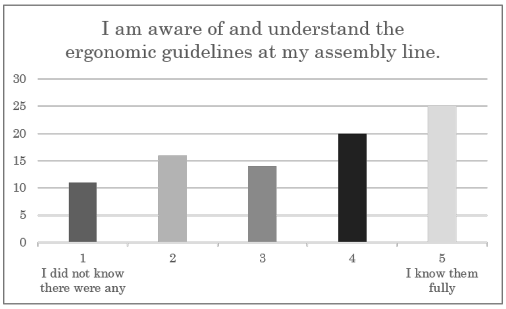


(b) Mean: 3.4. Median: 3. Mode: 3.

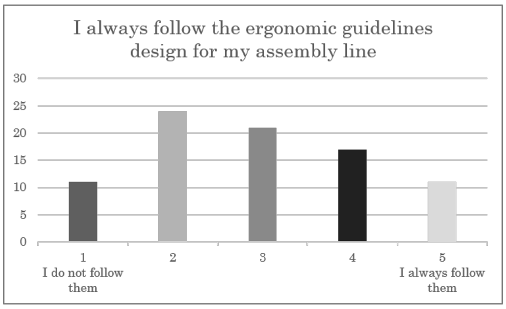


(c) Mean: 2.2. Median: 2. Mode: 1.

Figure 4.13: The awareness of updates, understanding, and usage of the WES:es.



(a) Mean: 3.3. Median: 4. Mode: 5.



(b) Mean: 2.9. Median: 3. Mode: 2.

Figure 4.14: The understanding and usage of ergonomic guidelines.

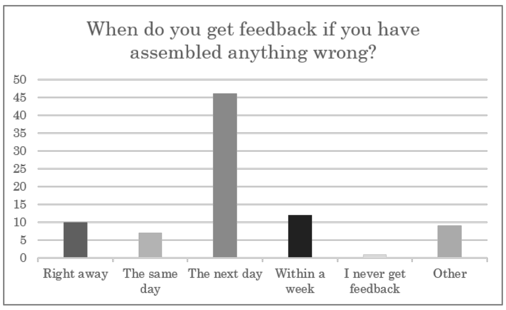


Figure 4.15: How long time it takes before the operators get feedback when they have assembled something wrong. Median: The next day. Mode: The next day.

4.2.3 Qualitative Data

The received qualitative data was divided into four different categories to simplify the analysis; work instruction design, updates of work instructions, proposed system design, and general recommendations.

Out of 86 respondents, it was 55 persons, who answered the open-ended questions. Nine of these persons thought they did not need any additional help with instructions and seven people could not come up with any ideas. 19 of the answers were categorised as irrelevant.

There were 25 persons who mentioned work instruction design in. Eight of them answered that the instructions should be simplified. Seven of them thought visual instructions were important to include and six persons recommended to make them both more simplified and include visual instructions. Other recommendations were to include step-by-step instructions for each car model, be as concise as possible, and avoid specific corporate language as it was perceived as complicated. The language should be easy to understand independent of work experience.

Four people mentioned improvement areas regarding the update of the work instructions. Operators rarely notice when an update happens, which was recommended to be solved by operators getting a digital message. There is no visual support when an update is made, making it difficult to understand the changes. To solve this, a recommendation was to include a picture with the new way of working. It was also stated that the visual instructions are updated to seldom, making them not up-to-date with existing ways of working.

Nine recommendations for the proposed system design were given;

- RFID-tags at the stations.
- Direct operator feedback.
- Digital WES and OIS.
- An interface showing whenever a car requiring longer assembly time is approaching.
- Show the different key symbols (ergonomic, safety etc.) for the specific station.
- Functions which enables the operators to get the team leaders attention without pulling the andon cord.
- The estimated time for each of the work tasks at the station.
- The work instructions should be easily accessible.
- The hardware should be a screen of some kind.

A general recommendation was to listen to the operators' opinions as they are working in production and will use the system in their daily work. One person stated the importance of informing the operators about why work instructions need to be followed and are of importance.

4.3 Interviews

The answers from the interviews have been categorised into four main areas; Work Instructions, Working Habits, Quality Follow-Up, and Change Management. As the safety representatives also work as operators their answers are presented as both operator and safety representative, dependant of their choice.

4.3.1 Work Instructions

Several interviewees stated that the OIS:es and WES:es presents work instructions with the standardised working order. Nevertheless, no-one of the operators told that they use them in their daily support or as coaching, due to the work instructions being placed far away from the stations. Further, they do not include up-to-date information and are in paper format. The majority of the interviewees stated that the information in the WES:es are too detailed and complicated to understand, even if you are an experienced operator. The texts used are written in both Swedish and English, has specific technical terminology and uses Time Measurement Units (TMU), areas the majority of the operators feel are difficult to understand. Instead, most of the operators and team leaders state that the practical knowledge gained during their first training lays the foundation for their knowledge. The knowledge the operators gained from reading the WES:es on their own was, according to themselves, close to a minimum.

Recommendations from both operators, team leaders and supervisors were to have work instructions digitally, making them easier to update. Also, the work instructions should be simplified, structured based on models, and some operators mentioned simplified and understandable pictures or videos instead of complicated texts. One operator mentioned that the work order could be colour coded to make it easier to follow the instructions. One supervisor suggested that the instructions should be designed with the same style as IKEA-instructions. A general recommendation from almost all interviewees was that the operators should be the ones creating the instructions, updating them and writing the texts due to it being the operators performing the assembling work and the operators know which kind of instructions are useful.

Some operators mention the SSI:s and a common response were that they do not use them. The main reasons were that they already know what to assemble and the instructions do not cover the specific deviations at certain models as well as them being suspended too far up. Recommendations were to place digital work instructions close to their log-in stations as they have a natural way to examine them there. The instructions should work as reminders of the working order, deviation between special model and ergonomic guidelines.

Several interviewees recommended using a screen at each station but commented on the importance to not add unnecessary things or more warning lights. A touch screen would make it possible to include other kinds of support functions and to make it easier to navigate in the system. Both operators, team leaders and supervisors expressed their concern for the screen to break. Nevertheless, a new TV screen would be too big and most likely be placed too high up. Team leaders mentioned that a smaller screen could easily include videos, showing the standardised way of working, or more detailed information which may be reviewed during shorter stops. Supervisors and safety representative stated that AR-glasses would not work as they might break or cause too many stimuli. Further, the supervisors did not think that any audio support would be a good idea as several operators use headphones. Several operators expressed the importance of removing aids which overlap each other, especially if a system including digital working instructions would be implemented.

4.3.2 Working Habits

Some operators and supervisors mentioned that pressure due to different contradictory company goals contributes to the increased stress load. A high FTT goal and the demand for always following the ergonomic guidelines while the existing culture does not appreciate stopping the assembly line causes high pressure on the operators. By this, the operators are placed in a difficult situation where they need to choose between delivery, their health and quality.

Both operators, team leaders and supervisors pointed out that many of the stations had the perception of having a high workload with many different work tasks, which made these station having a higher stress level. There was also an aspect of the stress load being connected to the experience of an operator, meaning novices felt more stressed than experienced operators. The main reasons for the stress load, agreed by the majority of the interviewees, are the problems with not stopping the line when operators feel stressed, having problems or getting wrong prerequisites.

Supervisors, team leaders and operators have the same perception for what ergonomic guidelines are; methods for standardised ways of working that have been risk-analysed and is sustainable for the operator. The ergonomic guidelines result in making it possible for operators to work for a long time without getting Musculoskeletal Disorders (MSD). Some operators stated that the factory is not able to be individually tailored to each operator and the difficulty of following ergonomic guidelines due to various body types. Some interviewees mentioned that it is an active choice every operator make, to follow the ergonomic guidelines or not. There is a perception that operators do not take the consequences of not following the ergonomic guidelines seriously since they feel the consequences will not affect them. Many of the ergonomics ways of working are considered reasonable but do not work in a reality where there are variations of the prerequisites for the operators. Most of the interviewees further stated that the ergonomic guidelines are not followed properly is due to the high stress load and that there is not enough time at each station to be able to follow them properly.

4.3.3 Quality Follow-Up

Defects or deviations are reported into an internal quality follow-up system called atacq. Critical errors are communicated directly to the team leaders while less critical errors are stored in atacq until the next day. They are then transformed, manually by an operator, to an operator feedback report stating which operator made which error. The operator and team leaders said that this process consumes between 0.5-2 hours per day, dependent on the experience.

The majority of the operators mentioned that they usually do not care how many errors they have. Despite this, some operators also said that it can be a mental burden to know that all of your colleagues see how many and which errors you have done. Also, a handful of operators expressed that it sometimes is difficult to understand what you did wrong as the error messages can be difficult to interpret. On the other hand, almost all interviewees see the operator feedback as something positive as it gives you an indication on how you are performing, what you can improve, if further education is needed or if there is an opportunity for improvements of the work standards.

Several interviewees mentioned that they would like to have the operator feedback reported digitally. This would save time from manually reporting as well as provide the operators with direct feedback whenever an error is detected. Some operators said that this would be beneficial as it is now difficult to know why they assembled something wrong since they did it the previous day. Further, a couple of persons mentioned that a digital log-in solution would simplify the handling of the error reporting as well as save time for the operators while rotating stations. Further recommendations from some operators were to include more constructive feedback in the quality follow-up messages, such as smaller explanatory texts or pictures to explain the errors, especially when being a novice.

4.3.4 Change Management

The interviewees expressed that there are mainly two types of changes applied in production; Temporary and Permanent Changes. The temporary changes are announced and communicated through internal massages called information control. Those information controls are, similar to the daily quality follow-up, printed on paper and signed when read. Suggestions were to have the information controls in a digital format, as this would enable the operators to read them once more if they feel that they have forgotten any important information.

Several people stated that changes in production are seen as something negative and demanding by the operators. The reasons, expressed by the operators, are lack of education, enforced changes and ignorance of operator opinion. In general, changes which make the work easier for the operators are greeted positively according to the interviewees. The operators should be included in all phases of a change. Another recommendation made by both team leaders and supervisors was to increase the system's autonomy by individualising and personally adapt it to each operator.

This will, according to the same people, increase the likelihood that the operators use, accept and appreciate the implemented change.

Some people expressed that improvements and changes are applied in production without considering the existing systems which lead to overlapping systems. One operator recommends to first clean the targeted area from "unnecessary" aids and information channels before implementing something new, which will give the new system a defined function and decrease the stimuli for the operators. The opinion is confirmed by supervisors which also state that this method is not commonly.

A supervisor mentioned that when permanent changes are applied to the existing production system it is of importance to think about the change's robustness and maintenance. Further, recommendations were made by several interviewees to set up test stations and let the operators test new solutions which have, according to some operators, been done before in various forms. Nevertheless, the difference was that the operators' opinions and suggestions were disregarded and the operators felt overlooked. Something which made them contradict the changes from the start, according to themselves.

4.4 Specification of Requirements

Three Specification of Requirements were developed; for the work instructions, figure 4.16, for the hardware, figure 4.17, and for the system, figure 4.18. Each number in the specification of requirements presents a requirement which has an importance value and a related stakeholder(s). Further, each requirement has at least one metric with a defined target value and unit.

No.	Requirement	Metric	Target Value	Unit	Imp.	Stakeholder(s)
1	*Have easy to interpret work instructions*				5	Operator
		Understandable at first sight	> 80	%		
2	*Support language restrictions*				3	Operator
		Languages per instruction	< 2	-		
3	*Remind the operator about the variations between the models*				5	Operator
		Number of variation symbols presented at the time	3 - 7	pcs		
4	*Have a plan for update*				1	Team Leader
		Have a step-by-step instruction generation	1	binary		
5	*Easialy find specific work instruction*				3	Operator
		Car model specific work instructions	1	binary		
		Work order specific work instructions	1	binary		
6	*Be able to visually present work tasks through videos*				4	Operator
		Have a visual presentation of each tasks	1	binary		

Figure 4.16: Specification of Requirement for the Work Instructions.

No.	Requirement	Metric	Target Value	Unit	Imp.	Stakeholder (s)
1	*Usable in industry environment*				4	Supervisor
		Withstand dust and water	> 33	IP		
2	*Have a resonable cost*				4	Project Owner
		Unit purchase cost	< 25 000	SEK		
		Implement cost				
3	*Take the operator's personal needs into concideration*				5	Operator
		Enable use of regular and safety glasses	1	binary		
		Enable use of headphones according to safety regulations	1	binary		
		Preserve the operators integrity	1	binary		
		Not put the operators saftey at risk	< 1	injury		
4	*Clearly visualise the application for the operator at the station*				3	Operator
		Possibility to attach to different stations	1	binary		
		Height from ground (Standing operator, Fixture)	153-181	cm		
		Gain information ragerdless of work position at station	1	binary		
5	*Naturally interact with the operator*				2	Supervisor, Operator
		Additional steps during running production	0	steps		
6	*Display more colors than black and white*				3	Operator
		Color Screen	1	binary		
7	*Present notification in real time*				3	Project Owner
		Enable internet connectivity	1	binary		

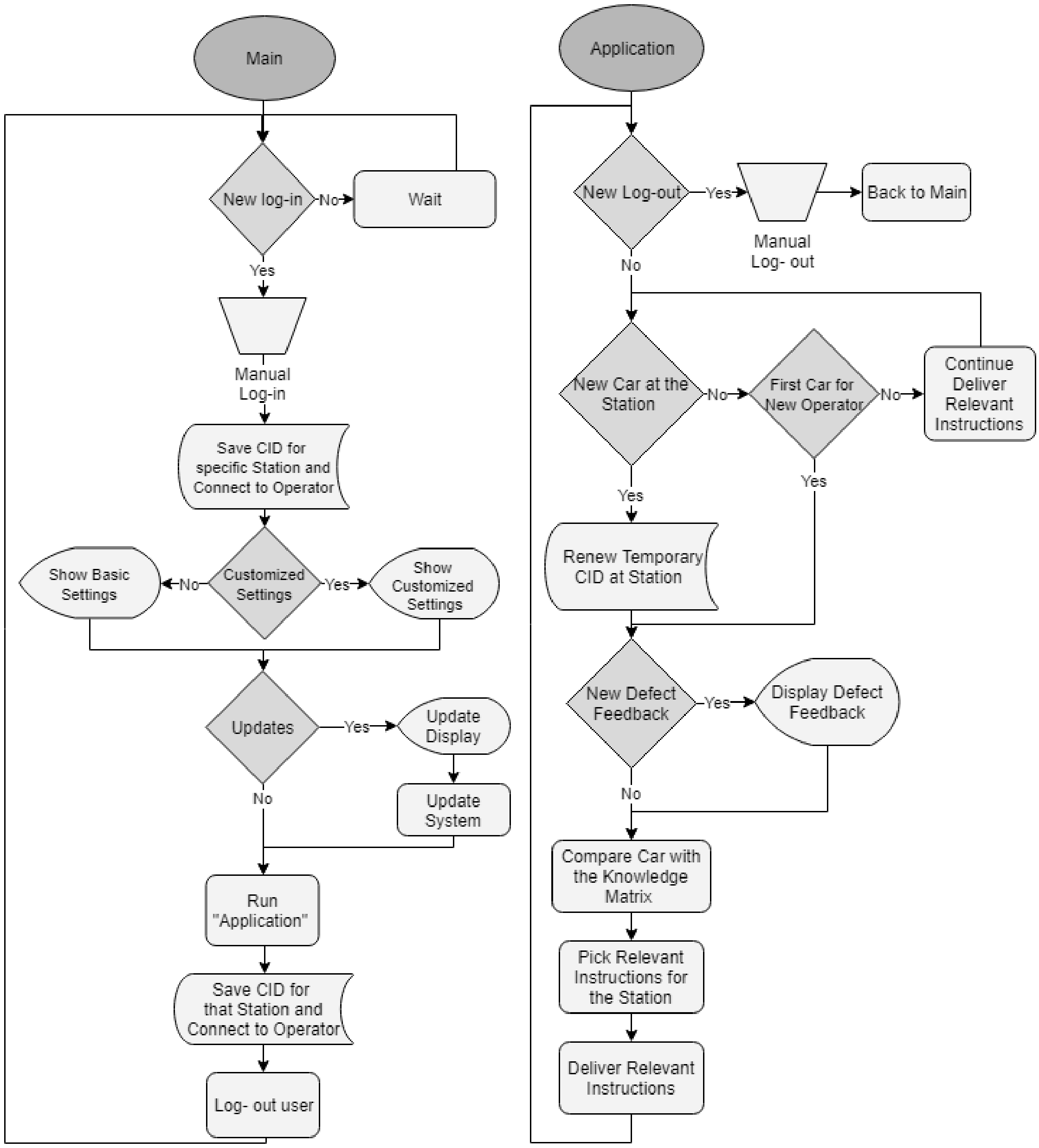
Figure 4.17: Specification of Requirement for the Hardware.

No.	Requirement	Metric	Target Value	Unit	Imp.	Stakeholder
1	*Enable customised settings for operators*				2	Supervisor, Project Owner
		Be able to have a log in fuction for each operator	1	binary		
		Be able to change settings to operator personal preferences	1	binary		
		Change display according to operators personal preferences	1	binary		
2	*Be able to induvidually coach each operator*				4	Supervisor, Project Owner
		Develop a knowledge matrix depended on assembly mistakes and education for each operator	1	binary		
		Deliver instructions according to the knowledge matrix for each car variant	1	binary		
3	*Be able to be integrated with existing IT-system*				4	Project Owner
		Be verified by relevant stakeholders within the IT-area	3	people		
4	*Develop an application that is, for an operator, easy to integrate with*				4	Operator, Team Leader, Supervisor, Project Owner
		Be verified by operators	10	operators		
		Amount of operators that pass the first try test	80	%		
5	*Can easily interact and find more instructions if wanted*				2	Operator, Team Leader
		Number off clicks to find further instructions	3	clicks		

Figure 4.18: Specification of Requirement for the Control System.

4.5 Conceptual Model

The conceptual model describes the back-end of the control system. The functions have their foundation in the system's specification of requirement. The conceptual model is divided into two different flow charts; Main Function and Application Function. They represent detail level one and two in the system, see figure 4.19.



(a) Detail Level 1: Main Function.

(b) Detail Level 2: Application Function.

Figure 4.19: Flow Charts for the Conceptual Model

The system starts when a new operator manually log-in to the system. The CID is then saved and will later be used to deliver accurate operator feedback to the right operator. The operators can choose to have a personalised interface or show a basic view, the system will update the view accordingly to the chosen settings. The system will then be updated with information about operator feedback, information control and new work instructions. As the operator feedback is connected to a certain model, the system will be updated with this information to notify the operator when the same model is reoccurring. After the updates, the application function will run.

The application function starts with checking if the user is manually logged out, the system will save the CID at the specific station and log-out the user. If the user has not logged out, the system will check if there is a new car at the station, if that is the case the system will renew a variable with a temporary CID. The temporary CID will be compared with a knowledge matrix for the operator, which contains information about operator feedback history and the operator's experience level. If there is not a new car, but it is the first car at the station for the operator, the CID is already saved in the main function and the CID is thereby compared with the knowledge matrix for the operator. If it is neither the first car nor a new car, the system will continue to deliver the relevant work instructions and will do so until there is a new car at the station. After each car, the operator feedback system will be updated to check new feedback connected to the operator. If that is the case, the display will be updated with the new information and the application function will continue. If there are not any updates, the system will compare the current car with the knowledge matrix, pick the most relevant instruction and then deliver the instruction to the operator.

4.6 Morphological Matrix

For the Morphological Matrix five sub-functions were listed with respective four to six design options, see table 4.1. In appendix D all the options are defined more thoroughly. The morphological matrix generated a total of 2400 potential design concepts. The design concepts were assessed with three constraints related to the specification of requirements, see table 4.2, and 24 constraints related to physical and technical restrictions, see table 4.3. The tables are categorised by constraints and sorted based on their design options. Each constraint has a reason for its appearance, as well as a number of how many alternatives that were removed. The number of removed alternatives vary as they are dependent on which order the alternatives were removed as well as how many alternatives there were from the beginning. After the assessment, 242 potential design concepts were left as input for the Pugh matrices.

Table 4.1: Sub-Functions and Design Options generated for the Morphological Matrix.

Sub-Functions	**Design Options**
A. Digitally Show How to Assemble *(On-line work instructions)*	**A.1** Photo from Production **A.2** CAD-drawing **A.3** Variation symbols **A.4** Text
B. Digitally Show How to Assemble *(Off-line work instructions)*	**B.1** Video from Production **B.2** Computerised Animation **B.3** Photo from Production **B.4** CAD-drawing **B.5** GIF **B.6** Text
C. Digitally Present Information	**C.1** Stationary Display **C.2** Projector (+ Control Unit) **C.3** AR-glasses **C.4** Smartwatch (+ Control Unit) **C.5** Portable Display
D. Attach Hardware to Station	**D.1** Movable Arm **D.2** Attached to Body **D.3** Stationary Fixture **D.4** Removable Fixture **D.5** Stand
E. Interaction Between Operator and System	**E.1** Touch Screen **E.2** Computer Mouse **E.3** Keyboard **E.4** Voice Control

Table 4.2: Constraints related to the Specification of Requirements.

Constraint	**Motive based on Specification of Requirements**	**Removed**
C.3	Disable the use of regular or safety glasses.	480
D.5	May harm an operator if it falls.	384
E.4	Disable the use of headphones.	384

Table 4.3: Constraints related to Physical and Technical Restrictions.

Constraint	Motive based on Physical and Technical Restrictions	Removed
C.1 + D.2	Too big to wear when working.	72
C.2 + D.1	Contradictory Functions regarding mobility.	72
C.2 + D.2	Too big to wear when working.	72
C.2 + D.4	No common design available.	48
C.2 + E.1	No physical screen available.	48
C.4 + A.1	Too small screen to show photos.	18
C.4 + A.2	Too small screen to show drawings.	18
C.4 + B.1	Too small screen to show videos.	6
C.4 + B.2	Too small screen to show computerised animations.	6
C.4 + B.3	Too small screen to show photos.	6
C.4 + B.4	Too small screen to show drawings.	6
C.4 + B.5	Too small screen to show GIF:s.	6
C.4 + D.1	Contradictory Functions regarding mobility.	72
C.4 + D.3	Contradictory Functions regarding mobility.	72
C.4 + D.4	Contradictory Functions regarding mobility.	72
C.4 + E.2	No common design available.	2
C.4 + E.3	No common design available.	2
C.5 + D.1	Contradictory Functions regarding mobility.	72
C.5 + D.3	Contradictory Functions regarding mobility.	72
C.5 + D.4	Contradictory Functions regarding mobility.	72
C.5 + E.2	No common design available.	24
C.5 + E.3	No common design available.	24
D.4 + E.2	Contradictory Functions regarding mobility.	24
D.4 + E.3	Contradictory Functions regarding mobility.	24

4.7 Pugh Matrix

In total 17 criteria were used to assess the alternatives from the morphological matrix, see table 4.4. Each criterion has a defined considered area to make sure every relevant domain was covered.

Table 4.4: Criteria for Pugh Matrices.

No.	Criterion	Area
1.	Do not need any additional control units. (Computer, mobile phone etc.)	Economy & User Friendly
2.	Minimise the need of backup devices. During charging etc.	Economy & Maintenance
3.	Can be used at various stations	Flexibility
4.	Minimise the need for physical space at the station(s)	Flexibility
5.	Maximise flexibility when re-designing station(s)	Flexibility
6.	Easy to replace hardware	Maintenance
7.	Easy to update on-line work instructions	Maintenance
8.	Easy to update off-line work instructions	Maintenance
9.	Not possible for the operator to fastened due to the device and cause injury	Safety
10.	Support ergonomic guidelines (Placed at the right height etc.)	Safety
11.	Clearly visible from the whole station	User Friendly
12.	Enable smooth rotations for the operators when changing stations	User Friendly
13.	Easy for the operator to interact with the system	User Friendly
14.	On-line work instructions support language restrictions	Understandability
15.	Off-line work instructions support language restrictions	Understandability
16.	Easy for the operator to comprehend the on-line work instructions	Understandability & Usability
17.	Easy for the operator to comprehend the off-line work instructions	Understandability & Usability

The assessment decreased the number of alternatives from 242 to seven. This was done by proceeding with four iterations, presented in detail in appendix F. All seven final alternatives had a Stationary Display, a Movable Arm, and a Touch Screen. The Design Options for the remaining two sub-functions are listed in table 4.5.

Table 4.5: The seven alternatives which represent the final result from the Pugh Matrices.

No.	On-line	Off-line
1	Text	GIF
2	Text	Photo From Production
3	Text	Video From Production
4	Variation Symbols	Text
5	Variation Symbols	GIF
6	Variation Symbols	Photo from Production
7	Variation Symbols	Video from Production

4.8 Prototype

The prototype is presented in three domains; on-line work instructions, off-line work instructions and system interface.

4.8.1 On-line Work Instructions

It was concluded by the validation of the instructions, that during running production the on-line work instructions should be variation symbols. Table 4.6 shows the normalised scores retrieved from the validation tests. During the qualitative parts of both the iterations, the majority of the interviewees preferred the variation symbols. The reasons were due to them being clearer, interpreted faster, contained less text and did not have any language barriers.

Table 4.6: Normalised scores for all statements, scale-categorised for the on-line work instructions.

Iteration	(1)	(2)	(3)	(4)
Text 1	0.6	1.2	2.0	5.2
Variation Symbols 1	0.4	0.8	1.6	6.2
Text 2	1.7	2.3	2.3	2.7
Variation Symbols 2	1.3	0.7	2.0	5.0

After two iterations the variation symbols had four common characteristics; only represent variations between models, contain shorter texts with a maximum of 5 ± 2 letters and numbers, contain simplified pictures, and include colours which are easy to distinguish, see figure 4.20.

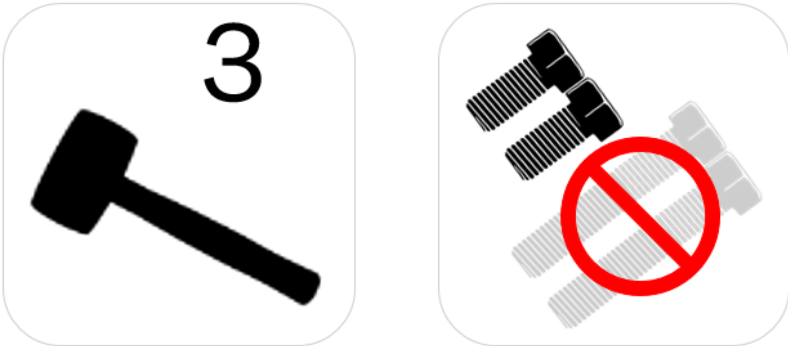


Figure 4.20: Two examples of Variation Symbols representing how many times to use the hammer and which bolts to use.

4.8.2 Off-line Work Instructions

It was concluded by the validation of the instructions, that during not running production the off-line work instructions should be videos. Table 4.7 shows the normalised scores retrieved from the validation tests. According to the qualitative data the videos were preferred as they presented more relevant information, was comprehensive enough and showed clearly what activities should be performed at the station. The GIF was removed after the first iteration as it was considered too similar to the videos, but not as good.

Table 4.7: Normalised scores for all statements, scale-categorised for off-line work instructions.

Iteration	(1)	(2)	(3)	(4)
Text 1	0	1.2	1.8	6.0
Picture 1	0.2	1.6	1.4	5.8
GIF 1	0.2	1.2	1.6	5.0
Video 1	0	0	0.4	8.6
Text 2	3.0	1.0	2.7	2.3
Picture 2	0.3	0.3	5.3	3.0
Video 2	0	0	1.3	7.7

The videos should include seven characteristics to be able to support the operator; shorter sequences, standardised work methods, subtitles similar to movies, snapshots with detailed instructions, clarifying figures, ergonomic guidelines, and internal key symbols.

4.8.3 System Interface

The interface of the system contains four parts; a log-in page, a home-page, on-line work instructions, and off-line work instructions. The aim of the prototype was not to visualise the log-in function and therefore its format is not presented.

The home-page will be available for the operator after a log-in is completed and when the production is standing still, see figure 4.21 and 4.22.

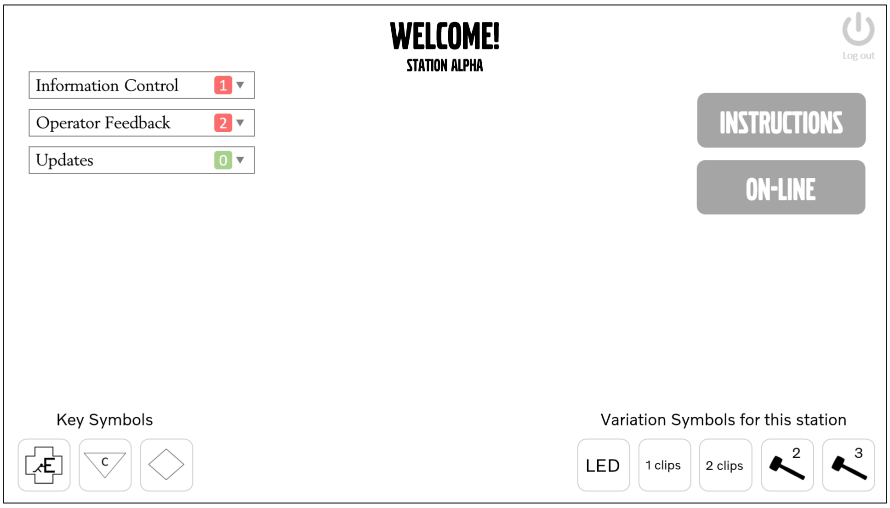


Figure 4.21: Snapshot of a Homepage interface for Station α.

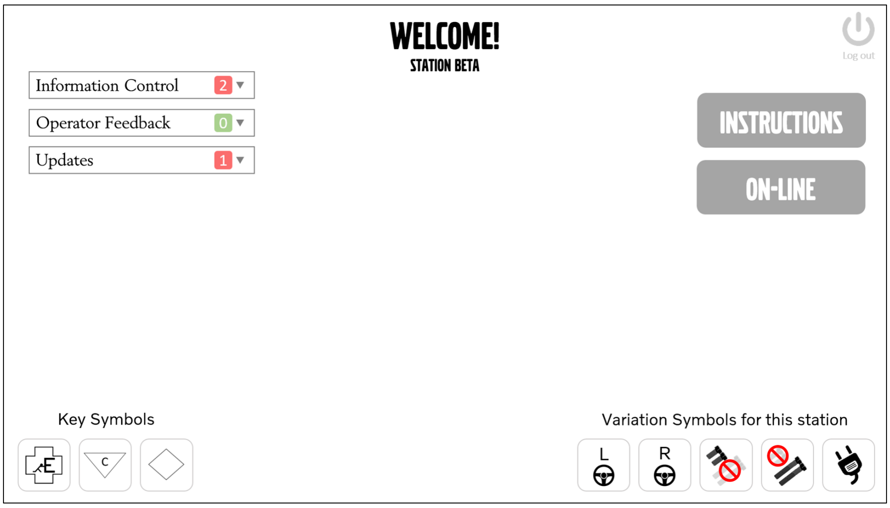


Figure 4.22: Snapshot of a Homepage interface for Station β.

The buttons for Information Control, Operator Feedback and Updates are used to present internal communication. Information control is the internal messages sent to the operators. Operator Feedback is the personal quality follow-up. Updates show updates of work instructions. All three parts are not station-specific messages and are shown to the operator regardless of where they are working at the line. Each of the buttons presents a drop-down list if pressed it shows both seen and unseen information. If the notification is red the operator has unread information and if it is green the operator is up to date.

Key Symbols describes the case company's internal key symbols. Variation Symbols presents the different station specific symbols which are used in the on-line work instructions. If a symbol is pressed a description of the symbol will be presented together with the models it applies for. The Instructions button will navigate to the off-line work instructions for the station and the On-line button to the on-line work instructions.

The on-line work instructions are presented to the operators during running production, see figure 4.23 and 4.24.

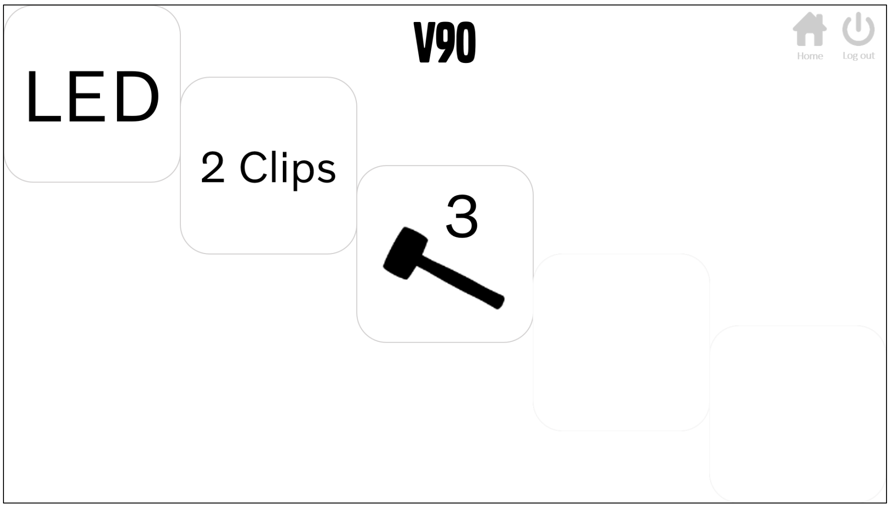


Figure 4.23: Snapshot of an On-line interface for Station α.

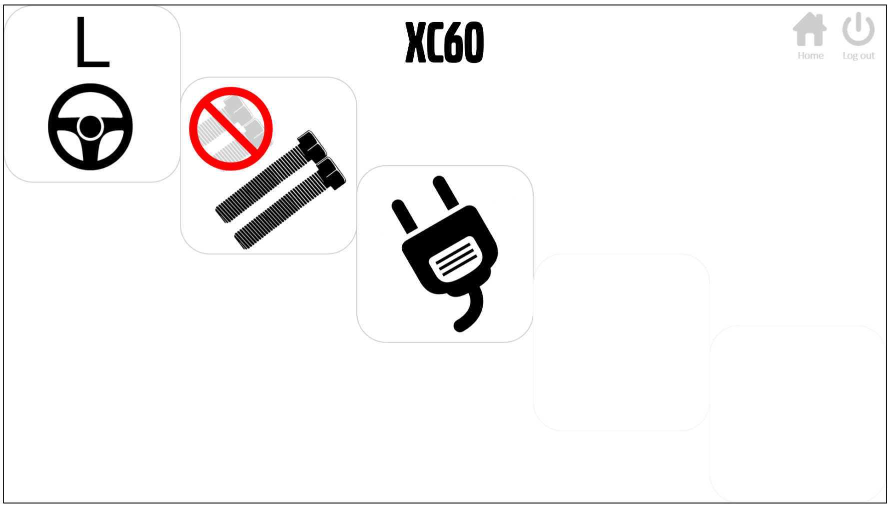


Figure 4.24: Snapshot of an On-line interface for Station β.

The different stations have station specific variation symbols depending on the assembly tasks performed. The page can show one to five variation symbols, dependant on the station design, and these will update as soon as a new car is arriving at the station. The variation symbols have a pre-determined box in which they may appear which will make it easier for the operators to scan the screen and find the information they are looking for. The variation symbols may also be colour coded based on the operator's knowledge matrix. This will make the system personalised with the support and work instructions the operator needs.

The off-line part of the system contains video instructions for all assembly sequences at a station, see 4.25 and 4.26.

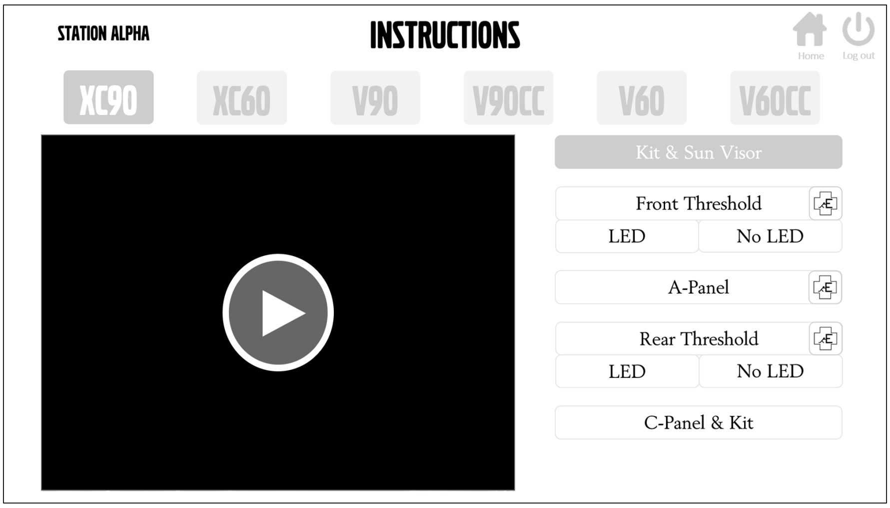


Figure 4.25: Snapshot of an Off-line interface for Station α.

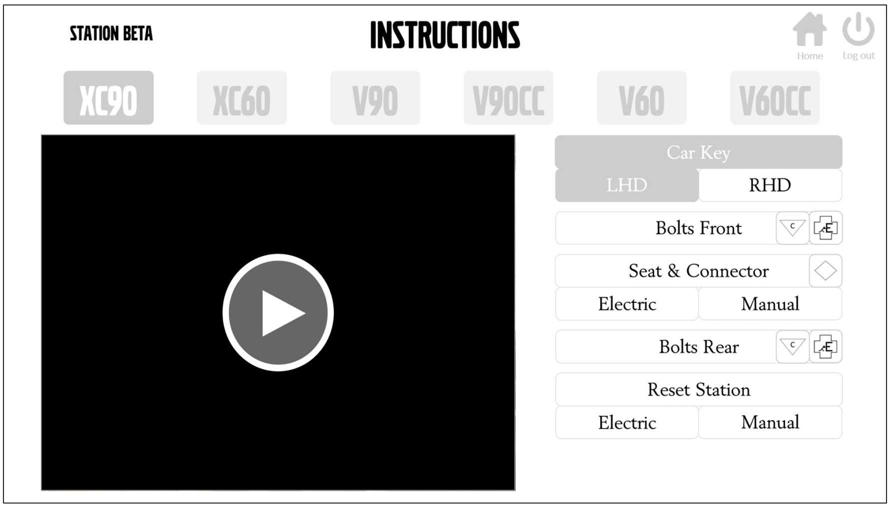


Figure 4.26: Snapshot of an Off-line interface for Station β.

The video instructions are sorted by car model and are reached by pressing one of the Car Model buttons. The instruction order is placed in the current working order, making it easy for the operators to understand how to work standardised. Some activities may vary between car models. These activities have tabs which the operator can choose between and videos corresponding to each variation. The video starts as soon as the operator presses the start button, and is looped until the operator stops the video. Some videos have their respective key symbols attached to them, giving further information about Safety Regulations, Critical Operations, or Quality.

5
Discussion

The chapter includes discussion about Quality of Research, Findings as well as the answers to the Research Questions, the Social Sustainability aspect, and areas for Future Research and Implications.

5.1 Quality of Research

The triangulation was used to get as defined picture as possible of the subject (Denscombe, 2014). The methods made it possible to gain a fundamental understanding of the subject, current problems, and areas of interest for the system. To collect knowledge and carry through the different methods have however been time-consuming. A lot of time was used to plan the execution of the different methods, but also on the execution and analyse itself. To use mixed methods have, on the other hand, given the necessary information to be able to develop a suitable system. If the triangulation was not applied to the thesis, the current state analyses would not have been as thoroughly and therefore less likely to deliver trustworthy results.

The triangulation further contributed with a deeper understanding of certain problems. For example, the observations detected problems which were later confirmed by the questionnaire. The interview then pinpointed the root cause of the problem.

The matrix study was favourable to use in a brain-storming context (Johannesson et al., 2013) and to stay objective when generating and evaluating concepts (Silverstein et al., 2012). The disadvantage with these methods was, however, that many concepts were generated, making the methods time-consuming when sorting and evaluating all concepts (Johannesson et al., 2013). Therefore, priorities were made when sorting which could be interpreted as subjectivity. The risk by having too many alternatives can be that good alternatives might be sorted away for the sake of sorting as the large numbers may feel overwhelming. On the other hand, the matrix study did not form the final decisions about the work instructions' formats, instead, the final validations were done with the operators giving an additional qualitative approach to the decision. Only the operators working in production can decide what type of work instructions they will use, increasing the bearing on reality and trustworthiness of the results.

During the validation of the work instructions, more test persons would have been preferred. Due to time limitations and changes in production, the number of available persons at the time was limited. Despite this, it was noticed that after a few sessions the same comments and feedback were given. Therefore it was chosen to move forward and start with the usability test of the system instead. To make sure the work instructions were designed in accordance with the operators' opinions, a final verification was done when performing the usability tests. Since Dumas & Fox (2008) states that as few as five participants in a usability test is enough to find severe problems in a system, the result is believed to be of satisfaction.

The aim of the methodology was to keep it as operator-centred as possible, both the disadvantages and advantages of following this approach should be mentioned. The results have the ability to become biased to the case-company since all the studies have been performed there, nor has any massive benchmarking studies been conducted at other companies with similar perquisites. However, the conclusions which have been drawn has the basis in both results from the studies, but are also supported by findings in the literature.

The results from one method worked as the input for the following one. This may indicate that if something was missed or interpreted wrong in the beginning it may have influenced the final results. Despite this, the results are seen as trustworthy and accurate as they have been verified with various stakeholders after each study.

5.2 Findings

The two research questions are answered separately even though some areas overlap between the questions. The key decisions made, choices which had a significant impact on the final result, are also discussed and commented upon.

5.2.1 Research Question 1

Which possibilities and limitations are currently existing for implementing digital work instructions?

By the help of the initial state analysis, the observations gave the understanding for the need of more support, since their results show that operators deviate from the standardised way of working every fourth to sixth car. The answers from the questionnaire also gave the understanding that the current work instructions are not used in a preferred way. By implementing relevant digital work instructions at each station, the instructions will with greater possibility be used, increasing the support and leading to increased quality (Bäckstrand et al., 2008; Olhager, 2017) and enhanced usage of standardised work (Berlin & Adams, 2017; Söderberg et al., 2014).

For the operators to find the work instructions useful they need to fulfil the six attributes stated by Kehoe et al. (1992). All the attributes have, at some point, been mentioned by the operators in the initial state analysis. The results from both the interviews and questionnaire gave indications that the existing work instructions, the WES:es, are too detailed and complicated to understand while the SSI:s are not supportive enough. This indicates the importance of the attributes relevancy and comprehensiveness of the work instructions (Kehoe et al., 1992). The thesis has shown that digital work instructions give the possibility to both develop comprehensive, clear and at the same time not too detailed work instructions.

The attribute timeliness and availability are not either fulfilled today since the work instructions are not available at the stations. By having the work instructions easily accessible, when the operator makes decisions, both the attributes timeliness and availability will be fulfilled (Kehoe et al., 1992). Having the work instruction in a digital form, the instructions can be available for the operator at the station at all times and show how assembly operations are performed (Berlin & Adams, 2017). The accuracy in the work instructions is, according to answers in the questionnaire and interviews, also limited. The WES:es and OIS:es which is in paper format are currently inadequately updated. Implementing digital work instructions would instead result in a possibility for flexibility and simplicity in updating the work instructions, thereby keeping them more accurate (Kehoe et al., 1992).

The format of the work instructions is affecting the majority of the other attributes. Currently, the work instructions are in paper format, leading to limited accuracy, timeliness and accessibility, due to earlier stated causes. Updating them to a digital format instead would also make it possible to show different kinds of graphics (Osvalder & Ulfvengren, 2009), which is not possible with an analogue format. The digital format has the ability to improve the work instructions due to increased flexibility in choosing presentation format as well as simplifying continues improvements.

A further possibility is to increase the level of cognitive automation when implementing digital work instructions. As for now, the work instructions are not used as support, leading to the cognitive automation being LoA 1, Totally Manual (Frohm et al., 2008). With the help of digital work instructions, fulfilling earlier stated improvement areas, the instructions will be used and the cognitive automation will thereby be increased to LoA 3, Teaching (Frohm et al., 2008).

Another limitation for implementing digital work instructions is that only to digitise the work instructions was by the case-company considered as a very large project. The effort of finding a solution suited for a great number of different station makes the process of finding a general solution more complicated. Another reason was the existing internal IT-structure, since a system for digital work instruction would need to be integrated into existing systems and processes. However, to implement digital work instruction is one step towards Industry 4.0 (Schuh et al., 2017). The company would then progress towards computerisation and thereby have the ability to become more competitive (Schuh et al., 2017). The implementation of a system with digital work instructions is seen as realisable due to all necessary data and variables for implementing digital work instructions are existing and available at the case-company today, but they are not connected into one system.

5.2.2 Research Question 2

How can a system including digital work instructions, coaching and quality follow-up be designed?

To develop a suitable system the thesis summarises six aspects to consider for the system to work and be used by the operators; Operator-Centred, Interpretation Time, Instructions Types, Interface Design, Hardware Design, and Personalisation.

The system needs to be developed with the operator as the centre of the system. The operators are the main users, and it is of greatest importance to satisfy their requirements, needs and wishes to be able to develop a system which will be used and supportive in their daily work. If the involvement of the operators is increased, it will lead to increased operator motivation (Mylan & Schmidt, 2001).

There are two situations the operator faces when the time to interpret the work instructions vary. Firstly, when production is running and the takt time is low it sets specific demands on the work instructions, due to the interpretation time need to be a few seconds at maximum. Secondly, when production is standing still the operators have more time to interpret the work instructions and comprehensive information can be presented. Therefore, it was seen that the system needs two instruction types; on-line and off-line. The on-line work instructions should be visualised by simplified symbols representing the variations between different models. To be able to keep the interpret time low the symbols need to be well known and easy to understand (Osvalder & Ulfvengren, 2009). The off-line work instructions should be presented by short videos of the main activities at the stations.

The system's interface needs to be simple and contain relevant information for the operators, further should information not be placed more than three clicks away. The simplicity of the system was something operators complimented during the usability tests of the prototype. Other aspects included in the interface are to sort the work instructions both by model and work order, thereby increasing the cognitive support and the usage of standardised work (Berlin & Adams, 2017; Söderberg et al., 2014).

The hardware for the system should be a stationary screen with a movable arm at each station. This will enable the operators to control and adjust it after their own ergonomic preferences, as the questionnaire result showed that the operators have varying heights. Important to take in consideration is the actual placement of the screen, as it needs to be clearly visible for the operators (Osvalder & Ulfvengren, 2009). The screen should further include a touch function, making it possible for the operators to interact with it in a simple way. Moving towards digital work instructions using stationary screens instead of papers goes hand-in-hand with trends seen in other productions facilities as (Berlin & Adams, 2017). For the system to be used over time, the technology needs to be understandable and manageable by the whole workforce. It was seen during the usability tests that everyone that tried the hardware managed the touch screens with simplicity regardless of their age.

The system should be able to coach each operator with the help of digitalised operator feedback, information controls and work instruction updates. If integrated efficiently, it could give the operators traceability and history of the information as well as it saving time from manually deliver and receiving the information in paper format.

With the belief that no operator wants to do mistakes (Liker & Meier, 2006) it can be seen that quality follow-up is of importance to be able to coach and educate the operators as it gives an indication of their performance. Therefore, digitalised operator feedback decreases the time it takes for the operators to receive their feedback and thereby increasing their performance (Thornock, 2016). Increased operator performance is required for companies to be able to succeed in a changing environment (Sheppard et al., 2014).

The system should also adjust itself based on the operator' individual knowledge matrices. When an earlier incorrectly assembled model is approaching, the incorrect assembly task will be clearly visualised with colours on the respective variation symbol. The feature was asked for by the operators themselves as they thought that it would increase their own performance and decrease the number of wrongly assembled cars. As the reminders will decrease the time it takes for the operators to react upon their operator feedback.

5.2.3 Key Decisions

At the beginning of the thesis, the scope only targeted experienced operators. The results from the questionnaire gave the understanding that the targeted line had a majority of experienced personnel and thereby the scope was validated to be realistic. If the scope would have targeted novices instead, the outcome of the thesis would most likely have been different since it would then focus more on teaching and learning rather than coaching.

The large number of concepts from the morphological matrix (Johannesson et al., 2013) was limited by only including the sub-functions which would directly affect the system. Sub-functions such as internet connectivity and power supply were not considered since all concepts have their own solutions to these sub-functions. To further limit the number of potential concepts, only the design options viewed as currently being realistic to implement and evaluate were listed. Therefore, VR-glasses, AR-glasses and social robots were neglected at this stage.

During the validation of the work instruction types, the share of top scores from the nine statements decreases from the first iteration to the second, for all instruction types. From the first iteration, the instructions were developed with regards to the received qualitative feedback, the expected results were that the share of top scores would have increased, instead, it decreased. It was however decided to continue developing the formats presented in the second iteration. The reason was that the persons validating the first and second iteration's work instructions had different work positions and thereby different experiences, perspectives and familiarity with the concept of digital work instructions. The qualitative data also gave the indication that the second iteration work instructions were more appreciated, even if they got lower quantitative scores. The instructions developed from the second iteration was moreover justified by the findings in the literature.

The targeted operators are experienced, thereby they have so-called skill-based behaviour in performing their tasks (Rasmussen, 1983). At this level, the tasks are stored in the long-term memory and the actions are no longer predominant by cognitive learning (Dar-El et al., 1995). The environment the operators are working in is perceived as complex and therefore support is needed for their cognitive processes (Fast-Berglund & Mattsson, 2017). To be able to support these processes, even when the takt time is about one minute, variation symbols are favourable as the format for the on-line work instructions. Symbols can be perceived quickly, be seen from far away, function in an international environment, and work with fewer interpretation errors (Osvalder & Ulfvengren, 2009). The system should limit the number of variation symbols to five since the interpretation needs to be quick. Presenting too much information at the same time makes the fast interpretation harder for the operator (Osvalder & Ulfvengren, 2009). Five is also the lower boundary for entities which can be stored in the short term memory (Berlin & Adams, 2017). By placing the same variation symbols at the same location in the on-line page view, the information will also be easier to interpret quickly (Osvalder & Ulfvengren, 2009). To indicate operator feedback colour coding should be used, but precautions need to be taken to use colours which cope with defected colour vision (Osvalder & Ulfvengren, 2009).

The operator will encounter situations where they are not familiar with the work tasks (Söderberg et al., 2014), such as re-balancing or introducing new variants. At these situations, the operators must learn new tasks or re-learn old ones. The operators can thereby be seen as novices again, using a knowledge-based behaviour (Rasmussen, 1983), but also using more cognitive learning to perform the right actions (Dar-El et al., 1995). The questionnaire results stated that the operators have a stressful work environment, making a visual presentation of information crucial (Osvalder & Ulfvengren, 2009). The validation stated that videos were the most suitable and preferred format, for the off-line work instructions, to receive more comprehensive work instructions. Visual information can also be watched several times and need to have a strong connection to reality (Osvalder & Ulfvengren, 2009). To make the videos more distinct they contain clarifying symbols, subtitles and pictures (Fast-Berglund & Mattsson, 2017).

5.3 Social Sustainability

The operators' opinions have been seen as the highest priority throughout the whole thesis. This approach made it possible to get the perspective of the operators and they have thereby influenced the system development. By involving the operators they feel increased ownership, leading to higher motivation (Mylan & Schmidt, 2001). Ethical aspects have further embraced the entire thesis, which can be viewed in the methodology. The operators' personal needs were taken into consideration when developing the system, which can be noticed in the specification of requirements. It was important to develop a system which is conceivable with the existing production system and also fulfilling the needs of the operators, increasing the likelihood that the operators trust the system and thereby also use it. In further development and research of this system, operators should be involved in every step of the way, including the implementation phase. By listening to the operators' opinions and acting upon them, the needs autonomy, relentless and competence can be reached (Fowler, 2014), making it more likely for a company to increase operators motivation.

With a digital system, the opportunity for noticing a possibility for competence development could increase. As all functions are gathered in one system, it creates traceability for the areas where operators may need more education and thereby creates a possibility to fulfil the need competence (Fowler, 2014). By having the system digital and with a log-in function, the operators also get increased privacy since the received information is not exposed to others in the same way as the analogue format.

5.4 Future Research and Implications

The thesis has discovered several areas applicable for future research as well as implications which could be interesting to further investigate for implementing a system with digital work instructions.

It was difficult to find research performed on how to use and display digital instructions to an operator during takt times of about one minute. The fast production is common in, among others, the automotive industry, where the final assembling work is characterised by high flexibility and mostly manual work (Fast-Berglund & Mattsson, 2017). Therefore, further research of digital instruction within this area would play an important role for the industry in question. Variations symbols are one alternative that the operators feel would support and be used during running production. Nevertheless, the concept of variation symbols has, in this thesis, only been tested in an office environment. To be able to further discover and determine the needs of the operators, the system needs to be validated and tested during running production as well.

Other types of technologies, such as AR, VR and social robots, can be used in various production areas (McTear et al., 2016). However, research performed on takt times of about one minute is limited, thereby the research on these technologies with the same prerequisites are also limited. The usage of these technologies could increase the LoA by increasing the cognitive support for the operators. In conclusion, these technologies have great possibilities but need future research to be applicable in production systems with takt times of about one minute.

During the interviews, operators stated that too many supportive systems exist in the current production system. Many different supportive systems make the amount of information presented to the operator too extensive to fully understand the information (Osvalder & Ulfvengren, 2009). Therefore, it would be favourable to investigate which surrounding systems could be integrated or removed when implementing a system containing both digital work instructions, coaching and quality follow-up functions. One key prerequisite to succeed with an implementation of a system is to include the operators in all phases (Osvalder et al., 2009). It is important to state that the system should digitalise existing functions, not only digitise them.

To further evaluate different features that could be added by the operators themselves, choosing what to display or not. This would increase the autonomy (Fowler, 2014) and create a sense of ownership (Mylan & Schmidt, 2001). The on-line screen could provide the operators with information about upcoming cars. The feature could present if the assembling is heavy or not, if the operator has done something wrong the previous X cars or if it is a model the operator never has assembled before. Methods to present this could be to use different colours and sizes of pictures to deliver the information (Osvalder & Ulfvengren, 2009). Other features for the on-line screen could be symbols indicating the time left until the next rotation or cycle. Nevertheless, it should never be too much information presented on the online screen and it is of great importance that the information presented adds value and support the operators (Osvalder & Ulfvengren, 2009). For the off-line work instructions, one recommendation has been to include bar charts, indicating how much time is spent on each operation at the assembly station. There are many different features possible to include in a digitalised system and the operators' opinions on which features are necessary should be the main decision driver. If the simplicity of the system is removed it will most likely lead to decreased use of the system and the supporting function of the system will be lost.

The system developed has the main focus to support and coach the operators at the line. By adding a Team Leader tool another dimension to the system could be integrated as well. The tool could include an overview feature for updates, operator feedback and information control for all operators in the team. This could be used to plan educations or competence development of operators. If an operator has been absent during a longer period of time, the tool could help the team leader by keeping the operators' competence up-to-date. Further, the tool could be used to educate new operators since the video material could replace the existing analogue education methods.

6
Conclusion

Implementing a system with digital work instructions would increase standardised work and quality, decrease cognitive load, and increase the ability to educate and coach the operators in their daily work. For digital work instruction to be used by the operators they need to fulfil the attributes availability, timeliness, format, accuracy, comprehensiveness and relevancy. The operators are the end-users of the system and therefore the system needs to be developed for and with the operators, to be able to take advantage of the possibilities and benefits it implies.

When having takt times of about one minute, difficulties for implementing digital work instruction are the comprehensiveness of such a system and the variation of support that the operators need depending on their work situation. On the contrary, digital work instructions have the ability to move the company towards computerisation and Industry 4.0, enabling increased competitiveness and the ability to faster react to changes in customer demand.

The thesis concluded that the digital work instructions need to be divided into an on-line and an off-line format. The on-line format should be used during running production, functioning as smaller reminders of what to assembled, conveyed using simplified Variation Symbols. The off-line format should be used when production is standing still providing time to watch Videos of how to assemble including both assembling order, ergonomic guidelines, an assortment of models and their variations. Connecting the system to existing quality follow-up system enables the possibility to coach the operators and enhance learning. Further, the system should interact with the operators through a stationary screen with a touch function, mounted on a movable arm at each station.

In conclusion, it all comes down to the operators and their needs. To be able to meet increasing demands on quality, cost, deliverability and customisation, companies will need to satisfy their operators. If the operators do not embrace the system with digital work instructions it is no purpose to implement it. Their opinions should, therefore, be of the highest priority.

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A

Observation Material

A.1 Work Order Template

Model	Observations Station ___

A.2 Support Areas Template

Cars Station ___	Dev. Assemble	Dev. Grabbing	Rework	Andon	Help	Stop	No Ergonomics

A.3 Observation Definitions

	Definition
Component	A part which is assembled to the car.
Fastener	A part which is used to fasten a component to the car.
Tool	**i)** An aid to assemble a component or fastener. **ii)** Manual or automated
Assembly	**i)** Assembling with their hands only. **ii)** Assembling with the help of a tool.
Grabbing	Collects or returns a component, fastener or tool.
Rework	Assembled one way but reassembles it during the same cycle.
Andon	Pulls the andon cord.
Help	Gets help from a colleague without asking for it.
Stop	The line stops due to the observed station.
No Ergonomics	The ergonomic guidelines are not followed.
Deviation	**i)** Stops to think before performing an action. **ii)** Takes longer time than normal to assemble. **iii)** Grabs the wrong component/fastener/tool.

B

Questionnaire Template

Background

Thank you for taking the time to answer our questionnaire! We are studying the final year of production engineering at Chalmers, and we are currently doing our master thesis here at Volvo. The thesis is about developing new types of instructions for operators, and present them in a digital format. The instructions should suit all kinds of people and be easy to perceive and understand.

In order for the solution to be used in TC, we need to gain insight and understanding of how it is to be an operator, team leader and production leader today. We are interested in what kind of solution you want to see and how the solution should be developed to be as useful as possible for you. We believe that the best way to gain access to your knowledge and experience is through questionnaires, interviews, and observations.

The questionnaire takes approximately 5 minutes to complete and is completely anonymous. If you do not want to answer a question, you can just skip it.

Please let us know if you have any questions or thoughts.
Best regards,
Emelie and Anna

Demographic Questions

These questions help us to understand who is currently working in TC, making it easier to develop a solution that fits as many as possible. If you do not want to answer any question, it is okay to skip it.

Question 1.
How old are you?

Question 2.
How tall are you in cm?

Question 3.
Which language(s) do you master in reading and writing?

Question 4.
How long time have you worked in TC?
a) 0-2 months
b) 2-6 months
c) 6 months - 1 year
d) 1 year +
e) Do not want to answer
f) Other:________________________________

Question 5.
How long time have you worked at this specific assembly line?
a) 0-2 months
b) 2-6 months
c) 6 months - 1 year
d) 1 year +
e) Do not want to answer
f) Other:________________________________

Question 6.
Which shift are you currently working?
a) Day
b) Evening
c) Night
d) Do not want to answer

Question 7.
Does any of the following apply to you?
a) Defective colour vision (colour blindness etc.)
b) Defected hearing
c) Nothing of the above
d) Other:________________________________

Grading Questions

These questions are about how you perceive the tools, education and guidelines that exist today. The first questions are about different working habits you have, in order to know if some solutions do not match with your way of working.

Question 8.
I always listen to music, podcast etc. when I am working.

	1	2	3	4	5	
I do not agree at all	○	○	○	○	○	I fully agree

Question 9.
I always wear glasses when I am working.
Both reading glasses and ordinary glasses.

	1	2	3	4	5	
I have never used glasses	○	○	○	○	○	I use glasses all the time

Question 10.
How often do you feel stressed in your daily work?

	1	2	3	4	5	
I never feel stressed at work	○	○	○	○	○	I feel stressed several times per day

Question 11.
It was easy to learn the work procedures at my assembly line.

	1	2	3	4	5	
I needed more support after the learning period	○	○	○	○	○	I manage the work without support after the learning period

Question 12.
I am always aware of when the WES:s at my assembly line are updated.

	1	2	3	4	5	
I never know when they are updated	○	○	○	○	○	I always know when they are updated

Question 13.
I understand all WES:s at my assembly line.

	1	2	3	4	5	
I do not understand them	○	○	○	○	○	I understand them fully

Question 14.
I use the WES:s available today as a support in my daily work.

	1	2	3	4	5	
I have never used them	○	○	○	○	○	I use them in my daily work

Question 15.
I am aware of and understand the ergonomic guidelines at my assembly line.

	1	2	3	4	5	
I did not know there were any	○	○	○	○	○	I know them fully

Question 16.
I always follow the ergonomic guidelines at my assembly line.

	1	2	3	4	5	
I do not follow them	○	○	○	○	○	I always follow them

Question 17.
When do you get feedback if you have assembled something wrong?

a) Right away
b) Same day
c) The next day
d) Within a week
e) I never get feedback
f) Other:____

Question 18.
Which kind of support tools, when it comes to instructions, would you like to include in your work today?
What do you think is important to think about within the area of digital instructions? How should the instructions be designed? How should they be displayed? Think big or small, all thoughts are welcomed.

____

Question 19.
Do you have any other recommendations or comments for us?
If you want us to gain some specific insight about something.

____

Thank you for your help!

Your answers are very helpful for us!

We will have further interviews during the work, if you want to continue to help and influence the future solution, please write your name on the note and we will further contact you. This means that we invite you to an interview where you are being asked questions about solutions you would like to see in the future. The interviews will be anonymous in the thesis.

Do not forget to take a cookie!

C

Interview Material

C.1 Interview Protocol

Introduction

We are two students who come from Chalmers, studying our final year within the area of production engineering and we are currently doing our Master Thesis at Volvo. The thesis has the aim to develop digital instructions for operators in TC. This means that we want to develop a solution that works for the vast majority of TC, shows relevant information for the operators, and works in reality.

This interview has the aim to gain in-depth information about what kind of solution operators, team leaders and production leaders wants. The interview takes approximately 45 minutes.

The interview and all answers will be treated anonymously and if you do not want to answer a question, we skip it. If you feel afterwards that there is some answer you do not want us to include, we delete them. The interview will go through five different main areas; background Information, questions about the initial state in production today, what kind of need the production has, how to make a change in the best way, and some summarising questions.

Do you have any questions before we start?

Background Information

We start with questions concerning formalities and your current work situation.

Question 1.
Is it okay if we record this interview?

- *The recorded material will only be used by the students and will be deleted after the work is finished, latest 14th of June 2019.*
- *The recording will be used as a support to remember what is said during the interview and to be able to analyse it further.*

Question 2.
All interviews will, by name, be anonymously in the study.
- Is it okay to use your work title in the study?
  - If yes: What is your current work title?
- Does your work tasks you have differ from other persons with the same working title as yours?
  - If yes: In what why?

Question 3.
How long have you worked in TC?

Question 4.
How long have you worked at this specific assembly line?

Question 5.
What is the best with your work?

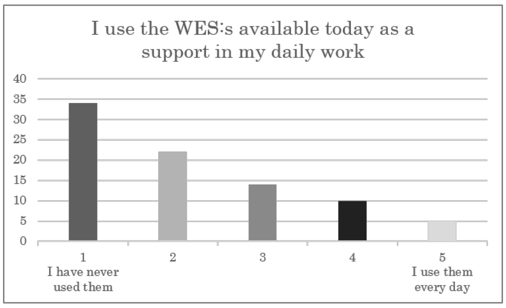
Question 6.
What is the most difficult part of your work?

Initial State Analyse

Now we change focus to the initial state in TC, which will include questions connected to the questionnaire that the operators answered, as well as questions about the various kinds of aids used in production today.

Question 7.
If we use the word working instructions.
- What does the word mean to you?
- What do you think it should mean?
- Which different types of work instructions are available in TC today?

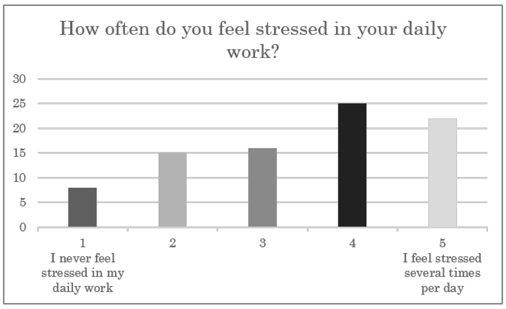
Question 8.
The figure presents data from the questionnaire.



Usage of the WES:s today in TC.

- Why do you think the results look like this?
- How could the work instructions be designed to be easier to use in your daily work?

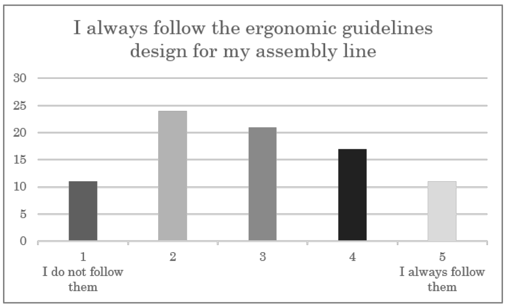
Question 9.
The figure presents data from the questionnaire.



Stress load among operators in TC.

- Why do you think the results look like this?

Question 10.
The figure presents data from the questionnaire.



Usage of the ergonomic guidelines in TC.

- Why do you think the results look like this?

Question 11.
We change subject to defect feedback.

- How do you receive defect feedback today?
- What is positive or negative with defect feedback?
- *OP:* How does the defect feedback make you feel?
- Would you like to have the defect feedback in any other way?

Needs

Now we change focus to the needs you think exists in production today. When we use the term aid it means the different solutions that are available in production to simplify the work for operators. This can be pick-by-light, andon, WES, OIS, poka yoke etc.

Question 12.
Are there any aids you find unnecessary in production today?

- If yes: Why are they unnecessary?

Question 13.
Do you have any ideas on how work instructions should be displayed?

Question 14.
How do we develop a solution that presents relevant work information for the majority of the workers?

Question 15.
SV/TL: Do you think any special features for supporting SV and TL are necessary?

Acceptance

Now we change focus to questions about how you think changes should be implemented in production for the developed solution to be accepted and work as it should.

Question 16.
What is the perception of change among the people working in production?

Question 17.

- What is the most important thing to think about when developing a solution like we are doing?
- Can you give an example of a change that has worked and one that has not?
  - What is the difference between these examples?
- What is the most important thing to consider when implementing a change for it to be accepted by people in production?

Summarising Questions

We are now reaching the end of the interview and will finish off with some summarising questions.

Question 18.
Is there anything you would like to talk more about?

Question 19.
Is there some subject you would like to talk about that we have not discussed?

Question 20.
Would you like to have follow-up/cooperate more in the proceedings of the project?

Question 21.
Now after the interview, is there some answer you would like that we leave out of the study?

Thank you for your help, you have contributed and helped us a lot!

C.2 Interview Protocol Matrix

Question 7	**IQ1**	**IQ2**	**IQ3**
What does the word mean to you?	X		
What do you think it should mean?		X	
Which different types of work instructions are available in TC today?	X		
Question 8			
Why do you think the results look like it this?	X		
How could the work instructions be designed to be easier to use in your daily work?		X	X
Question 9			
Why do you think the results look like this?	X		
Question 10			
Why do you think the results look like this?	X		
Question 11			
How do you receive defect feedback today?	X		
What is positive or negative with defect feedback?	X		
OP: How does feedback make you feel?	X		
Would you like to have the defect feedback in any other way?		X	X
Question 12			
Is there any aids you find unnecessary in production today?	X		
If yes: Why are they unnecessary?		X	X
Question 13			
Do you have any ideas how work instructions should be displayed?		X	
Question 14			
How do we develop a solution that presents relevant work information for the majority of the workers?		X	X
Question 15			
SV/TL: Do you think any special features for supporting SV and TL are necessary?		X	
Question 16			
What is the perception on change among the people working in production?	X		
Question 17			
What is most important to think about when developing a solution like we are doing?		X	X
Can you give an example of a change that has worked and one that has not?	X		
What is the difference between these examples?	X		
What is the most important to thing to consider when implementing a change for it to be accepted by people in production?			X

C.3 Feedback Checklist

Checklist	Yes	No	Feedback
Interview Structure			
The introduction questions are factual in nature.	X		
Key questions are majority of the questions and are placed between beginning and ending questions.	X		
Questions at the end of interview protocol are reflective and provide participant an opportunity to share closing comments.	X		
A brief script throughout the interview protocol provides smooth transitions between topic areas		X	Can be elaborated more.
Interviewer closes with expressed gratitude and any intents to stay connected or follow up.	X		
Overall, interview is organised to promote conversational flow.	X		
Writing of Interview Questions and Statements			
Questions/statements are free from spelling error(s).	X		
Only one question is asked one at a time.		X	Some questions include two questions in one.
Most questions ask participants to describe experiences and feelings.	X		
Questions are mostly open ended.	X		
Questions are written in a non-judgmentally manner.		X	Include questionnaire results instead of asking questions about already made conclusions.
Length of Interview Protocol			
All questions are needed.	X		
Questions/statements are concise.	X		
Comprehension			
Questions/statements are devoid of academic language.	X		
Questions/statements are easy to understand.	X		

D
Morphological Matrix Definitions

The following definitions have been used when deciding which design options to chose. The definitions do not necessarily cover all the commonly used aspects rather the ones used in the morphological matrix for the project-specific application.

A.1/B.3 Photo from Production is a photo taken during running production where an operator clearly present how to assemble something or how an activity is performed.

A.2/B.4 CAD-drawing is a rendering from a CAD software illustrating how components should be assembled or an activity that should be performed.

A.3 Key Symbols are simplified pictures or a few letters providing a reminder of an action.

A.4/B.6 Text is a text description or keywords used to indicate what activities should be performed.

B.1 Video from Production is similar to A.1 but the format is a video.

B.2 Computerised Animations is CAD-renderings put in motion.

B.5 GIF is a file format showing a handful of pictures in sequence making it look like a short video presenting what or how to assemble.

C.1 Stationary Display is a display placed on a stationary place, it is too big to wear or hold while working but it is not necessary too big to carry around in between.

C.2 Projector (+ Control Unit) is a projector placed in the ceiling beaming down information to the operator on the floor. The projector will need a control unit to provide what information to show.

C.3 AR-glasses are a pair of head-worn glasses containing AR-technology making it possible to display interacting instructions for an operator.

C.4 Smartwatch (+ Control Unit) is an arm-worn watch capable of digitally showing text and key symbols. It needs to be connected to a control unit.

C.5 Portable Display is a smaller display which is arm worn, though it is big enough to display both text, key symbols or other graphic instructions.

D.1 Movable Arm is a mount for a device which can be adjusted to a certain height or facing a certain direction. On end contains a stationary mount.

D.2 Attached to Body is when a device is attached to the operator's body during running production.

D.3 Stationary Fixture is when a device is stationarily mounted to the fixture and cannot be removed from it without using tools.

D.4 Removable Fixture is when a device is mounted to a fixture but can easily be removed with the use of tools.

D.5 Stand is holding a device through a fixture and placed on the ground, making it possible to move the device easily.

E.1 Touch Screen is when the operator can navigate the system by touching a screen, with or without gloves.

E.2 Computer Mouse is a physical hand-held device used to navigate, click and scroll in the system.

E.3 Keyboard is a physical device used to type information into the system.

E.4 Voice Control is using the operator's voice to navigate the system.

E

Usability Test Protocol

Scenario 1
You have just come to work station β and are about to start your shift. The line has not started moving yet.

1. Log-in to the system.
2. Check if you have gained any work instruction updates. If yes, how many unread messages have you and what are their headings?
3. Check if you have gained any information control. If yes, how many unread messages have you and what are their headings?

Scenario 2
You are at the homepage for station β. You do not understand some work instructions at these stations.

1. Find instructions for a V60 car.
2. Describe were you enter the screws to the front seat with the help of the information gained from the instruction videos.
3. Describe the control of the front seat connector with the help of the information gained from the instruction videos.
4. Describe the ergonomic guidelines for these activities.
5. Describe if there is any activity where it is important to consider the quality.
6. Find your way back to the homepage.

Scenario 3
[*Check three oon-line work instructions pages for station α.*]

Your shift starts in five minutes and you start at station α. You are currently on the homepage

1. Describe the meaning of the variation symbols at this station.
2. Describe which car model is connected to which symbol.
3. Log out from the system.

[*The test ends with five minutes of free navigation in the system where the on-line work instruction are being watched, and feedback is given on the overall system.*]

F
Pugh Matrices

Pugh 1 started with 242 alternatives. The baseline was set to alternative 1. After the assessments, the results were between 3 and -10, and it was chosen to move on with -3 and above, see figure F.1.

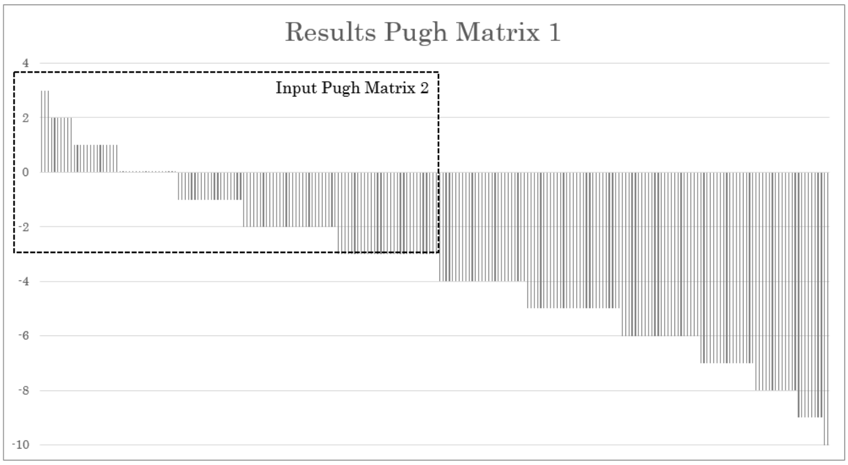


Figure F.1: Results from Pugh Matrix 1 and input for Pugh Matrix 2.

Pugh 2 started with 122 alternatives. The baseline was set to alternative 242. After the assessments, the results were between 3 and -3, and it was chosen to move on with 1 and above, see figure F.2.

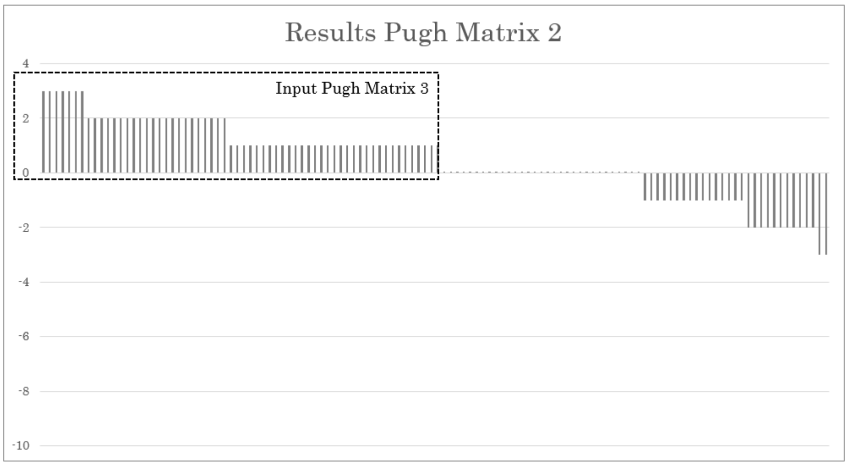


Figure F.2: Results from Pugh Matrix 2 and input for Pugh Matrix 3.

Pugh 3 started with 62 alternatives. The baseline was set to alternative 162. After the assessments, the results were between 2 and -6, and it was chosen to move on with -1 and above, see figure F.3.

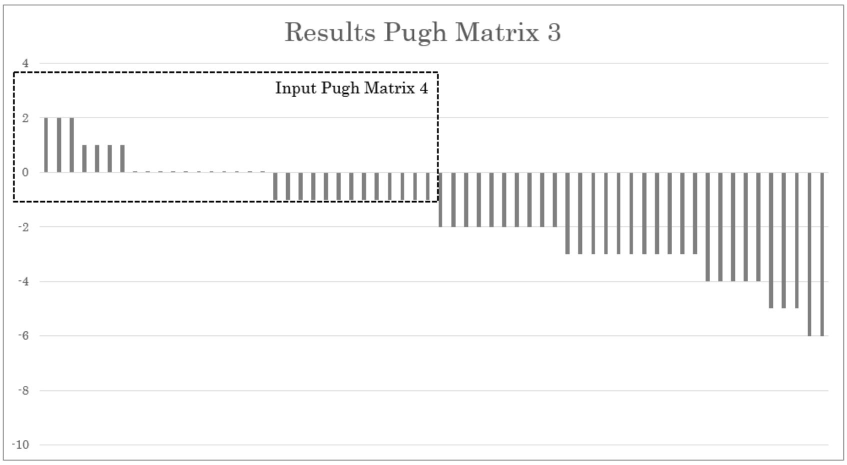


Figure F.3: Results from Pugh Matrix 3 and input for Pugh Matrix 4.

Pugh 4 started with 31 alternatives. The baselines were set to alternative 238. After the assessment, the results were between 4 and 0, and it was chosen to move on with 3 and above for the prototype development, see figure F.4.

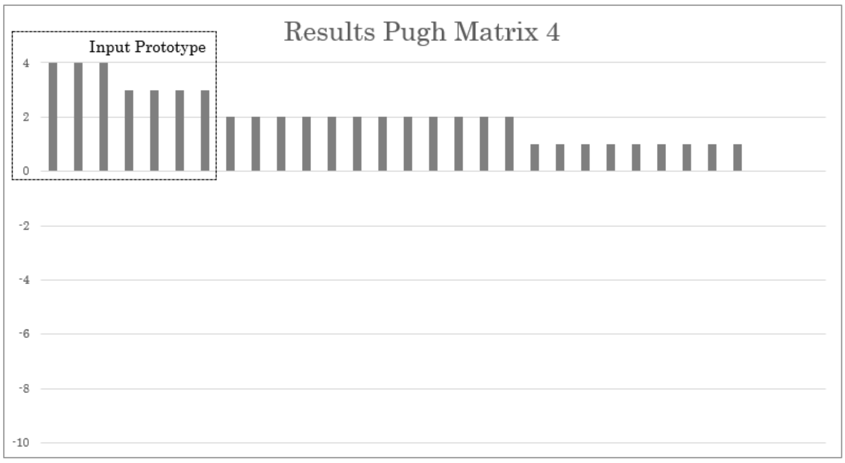


Figure F.4: Results from Pugh Matrix 4 and input for the Prototype development.